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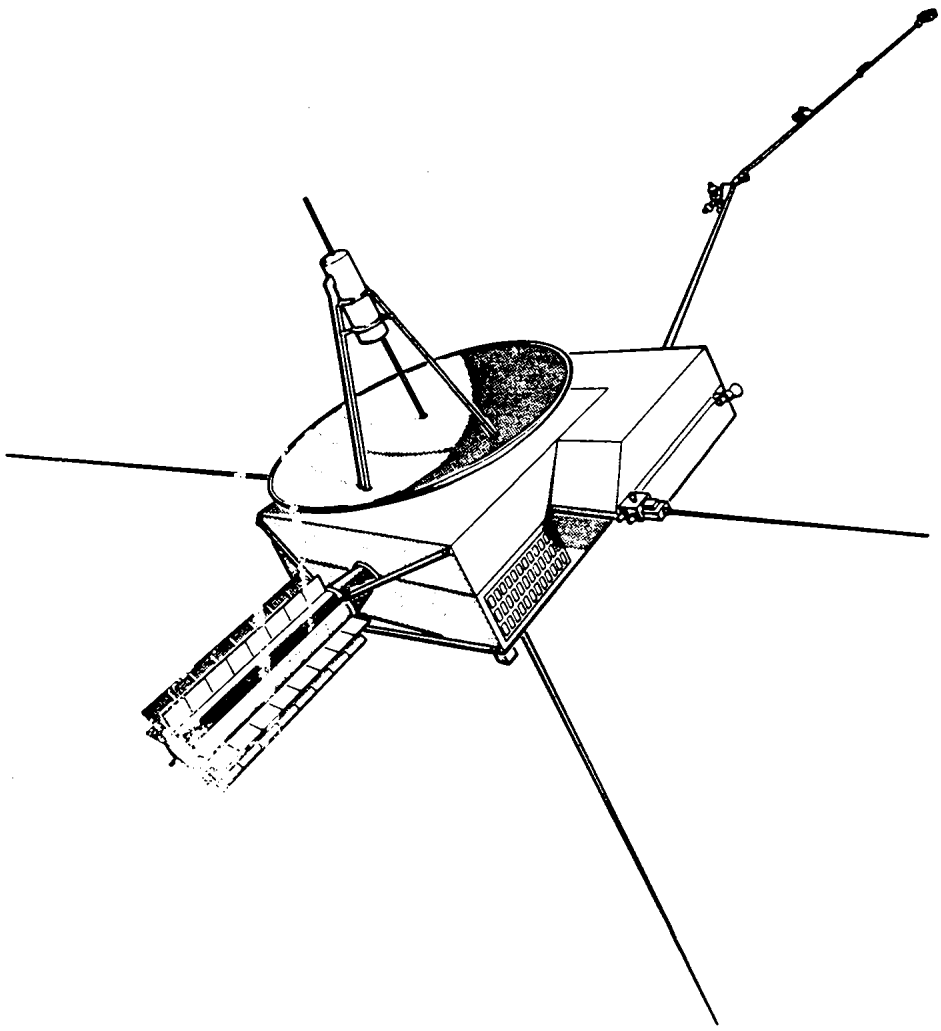
Space Administration

June 1990

# Final Environmental Impact Statement for the Ulysses Mission (Tier 2)



# ADDENDUM TO DRAFT ENVIRONMENTAL IMPACT STATEMENT FOR PROJECT GALILEO

(Environmental Impact Statement for Ulysses Project)

The impacts and alternatives associated with the Galileo and Ulysses payloads are essentially the same. Therefore, we are addressing both in the subject draft Environmental Impact Statement (EIS) by incorporating the following additional information into the body of the enclosed. These additions describe the different mission objectives and configuration associated with the Ulysses payload. Reviewers are requested to provide their comments on both payloads because the final EIS will address them under the same cover.

## Section 1.0 Purpose and Need for Action

Purpose of Ulysses Mission. The science objectives are the exploration of the heliosphere and view of the sun over a full range of heliographic latitudes. The chief study areas are:

a. The solar corona.

b. The solar wind.

c. Structure of the sun-wind interface.

d. Heliosphere magnetic field.

e. Solar and nonsolar cosmic rays.

f. Interstellar and interplanetary neutral gas and dust.

The European Space Agency spacecraft is to be launched from Kennedy Space Center (KSC) into an interplanetary orbit toward Jupiter. The orbital path permits, as secondary mission objectives, the performance of investigations of interplanetary physics and, during the Jupiter flyby phase, a study of the Jovian magnetosphere.

The experiments required to fulfill the mission objectives include:

a. Solar x-ray, cosmic ray, and Jovian x-ray.

b. Cosmic ray and solar particle.

c. Solar wind ion composition.

d. Plasma spectrometer.

e. Low energy heliospheric spectrum; composition and anisotropy.

f. Plasma waves.

g. Cosmic dust.

h. Magnetic field measurements.

## Section 2.0 Alternatives Including the Proposed Action

General. The Ulysses payload is to be launched by the Space Transportation System using a Centaur G Prime/Ulysses configuration and using the Centaur G Integrated Support System. The Centaur places the spacecraft on a cruise of approximately 1 year, 2 months to Jupiter. The trajectory is modified by Jupiter gravitation (at 6 Jupiter radii) to deflect the spacecraft into an out-of-the-ecliptic trajectory. The spacecraft proceeds with high heliographic inclination to pass over the sun's rotational pole at 1.6 to 2.0 AU from the sun. The orbital strategy is to maximize the trajectory time at heliographic latitudes greater than $70^{o}$, during the two polar passes with a minimum of 150 days total above $70^{o}$ on the two passes.

Nominal end of mission (EOM) is defined as the time when the spacecraft has reached a heliographic latitude less than $70^{o}$ after the second polar passage.

The launch injection dates for an assumed measure of the launch energy ($C_3$) of 133 $km^2/s^2$ and 380 kilogram payload results in an acceptable Ulysses launch period extending from May 15 to June 8, 1986. The launch strategy, at present, is to keep north pole and south pole trajectory options open. It should be noted that negotiations on a combined Ulysses-Galileo strategy must be accomplished since the launches are to occur (on separate Shuttle flights) within a short time of each other. (Galileo readiness to launch is May 1 with current baseline launch date May 20, 1986.)

For a south-going Ulysses mission with injection on May 15, 1986, the following mission characteristics result:

| | |
|---|---|
| Jupiter Arrival Date | July 29, 1987 |
| Perihelion Date | July 27, 1990 |
| EOM Date | March 27, 1991 |

| | | |
|---|---|---|
| Pass 1 | 114 | (Begins December 9, 1989) |
| Pass 2 | 121 | (Begins November 26, 1990) |
| Maximum Latitude | $8.3^{o}$ | |

Figure 1 represents the Ulysses spacecraft in operational configuration. The spacecraft structure is box-like with two overhanging balconies and a single aluminum honeycomb platform. On top of the spacecraft is a large (1.65 meter) high gain antenna (HGA). Protruding from one side is the radioisotope thermoelectric generator (RTG). There is a 5.6 meter radial boom to provide electromagnetic cleanliness for certain experiments and there is a 7.5 meter long axial boom. The spin axis of the launch configuration is the geometric centerline, the Z-axis of the spacecraft. The axis of the HGA will be aligned with the orbital spin axis. Two low gain antenna (LGA) are supplied for near earth communications.

The RTG is used to supply electrical power to the spacecraft. It is isolated from the main spacecraft subsystems by an outrigger structure.

The prime communications link during the mission will be via the HGA parallel to the spin axis. Precision maneuvers will be periodically performed to maintain earth pointing. This is accomplished through use of the Attitude and Orbit Control System (AOCS) using a reaction control equipment (RCE) tank containing monopropellant hydrazine under pressure to accomplish desired thrusting.

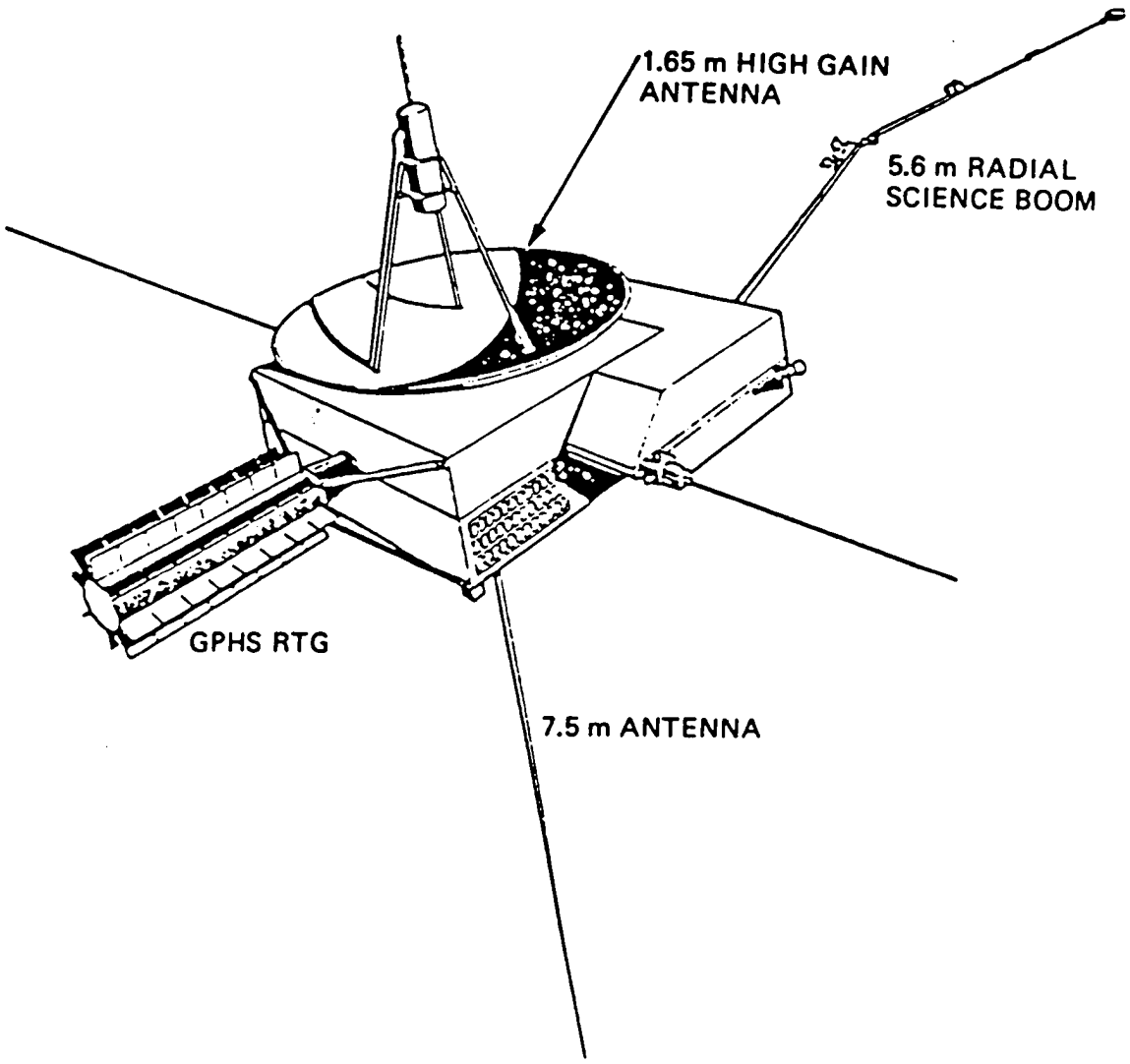



**Figure 1.** Representation of Ulysses-ESA Spacecraft in Operational Configuration

The Payload Subsystems that pose a potential impact to the environment are the power and the reaction control subsystems. The particular elements of these subsystems that are of concern is the RTG in the power subsystem, and the propellants in the reaction control subsystem. The remaining subsystems contain devices, materials, and electronics equivalent to the Galileo, Voyager, Pioneer, and Viking missions. As shown in their impact statements, the possible effects on the environment by these subsystems are negligible.

The reaction control equipment (RCE) provides the necessary impulse for:

a. Spin rate maintenance.

b. Attitude control.

c. Trajectory correction.

d. Targeting at Jupiter to obtain desired solar orbit.

The RCE consists of the following subassemblies:

a. Pressure vessel.

b. Eight 2-Newton thrusters.

c. Valves and filters.

d. The structure required to integrate the assemblies into a modular assembly.

e. The required propellant lines, electrical cables, and thermal blankets.

The RCE propellants, which are comprised of 33.5 kg (957 kg for Galileo retropropulsion module) of hydrazine and nitrogen tetroxide, have been commonly used in similar applications. The propellant tanks are filled after the spacecraft has been transported to the NASA Kennedy Space Center. All the propellant is contained within the tank until after ejection from the Shuttle.

**Section 3.0 Environmental Consequences.** No change.

**Section 4.0 Affected Environment.** No change.

**Section 5.0. List of Preparers.** Add, under paragraph 1., "This report was ... approved by J. R. Kolden, Ulysses Integration and Support Manager, and W. G. Meeks, Ulysses Manager."

**Section 6.0 Review Agencies.** No change.

# Final Environmental Impact Statement for the Ulysses Mission (Tier 2)

Office of Space Science and Applications
Solar System Exploration Division
Washington, DC 20546

June 1990

# ABSTRACT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This Final (Tier 2) Environmental Impact Statement (FEIS) addresses the environmental impacts which may be caused by the implementation of the Ulysses mission, a space flight mission to observe the polar regions of the Sun. The proposed action is completion of preparation and operation of the Ulysses spacecraft, including its planned launch at the earliest available launch opportunity on the Space Transportation System (STS) Shuttle in October 1990 or in the backup opportunity in November 1991. The alternative is canceling further work on the mission.

The Tier 1 EIS (NASA 1988a) included a delay alternative which considered the Titan IV launch vehicle as an alternative booster stage for launch in 1991 or later. This alternative was further evaluated and eliminated from consideration when, in November 1988, the U.S. Air Force, which procures the Titan IV, notified the National Aeronautics and Space Administration (NASA) that it could not provide a Titan IV vehicle for the 1991 launch opportunity because of high priority Department of Defense requirements. Subsequently, NASA was notified that a Titan IV could not be available until 1995. Consequently, NASA terminated all mission planning for the Titan IV as a backup launch vehicle for the Ulysses mission. Even if a Titan IV were available, a minimum of 3 years is required to implement mission-specific modifications to the basic Titan IV launch configuration after a decision is made to use the Titan IV. Therefore, insufficient time would be available to use a Titan IV vehicle in November 1991. Thus, the Titan IV launch vehicle is no longer a feasible alternative to the STS/Inertial Upper Stage (IUS)/Payload Assist Module-Special (PAM-S) for the November 1991 launch opportunity.

Because the only launch configuration available for a launch in 1990 or 1991 is the STS/IUS/PAM-S and the environmental impacts of an STS/IUS/PAM-S launch are the same whenever the launch occurs, a delay alternative would have the same environmental impacts as the planned launch in 1990. Hence, the

delay alternative would provide no new environmental information and is eliminated from further consideration. The 1991 backup launch date is a contingency opportunity due to the short launch period available in 1990.

The only expected environmental effects of the proposed action are associated with normal launch vehicle operation and are treated in published National Environmental Policy Act (NEPA) documents on the Shuttle (NASA 1978) and the Kennedy Space Center (NASA 1979), and in the KSC Environmental Resources Document (NASA 1986), the Galileo and Ulysses Mission Tier 1 EIS (NASA 1988a), and the Galileo Tier 2 EIS (NASA 1989a).

The environmental impacts of normal Shuttle launches have been addressed in existing NEPA documentation and are briefly summarized in Chapter 4. These impacts are limited largely to the near-field at the launch pad, except for temporary stratospheric ozone effects during launch and occasional sonic boom effects near the landing site. These effects have been judged insufficient to preclude Shuttle launches.

There could also be environmental impacts associated with the accidental release of radiological material during launch, deployment, or interplanetary trajectory injection of the Ulysses spacecraft. Intensive analysis indicates that the probability of release is small. The most probable release occurs during Mission Phase 4, interplanetary trajectory injection, with a total probability of release of 1 in 4,670 ($2.14 \times 10^{-4}$). Even in the rare event of a release, comprehensive analysis indicates that the chances of adverse health or environmental consequences are remote. No accident scenario in any phase of this mission, to a probability level of 1 in one million ($1 \times 10^{-6}$), would lead to a fatality.

There are no environmental impacts in the no-action alternative; however, the U.S. Government and the European Space Agency would suffer adverse fiscal and programmatic impacts if this alternative were adopted. The scientific benefits of the mission would be delayed and possibly lost. There could be significant impacts on the ability of the U.S. to negotiate international agreements for cooperative space activities.

# EXECUTIVE SUMMARY

## PURPOSE AND NEED FOR THE ACTION

The Ulysses mission is a joint effort conducted by the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA). ESA is responsible for developing and operating the spacecraft and for about half of the experiments installed on the spacecraft. NASA is responsible for providing the launch on the Space Transportation System (STS)/Inertial Upper Stage (IUS)/Payload Assist Module-Special (PAM-S) vehicles, the remaining experiments, and the mission support using the communications and spacecraft tracking facilities of NASA's Deep Space Network.

The Ulysses mission supports NASA's Solar System Exploration and Space Physics Programs. The scientific objectives for the Ulysses mission are to conduct studies of the Sun and the heliosphere (i.e., the regions of space for which the Sun provides the primary influence) over a wide and unexplored range of heliographic latitudes.

## ALTERNATIVES CONSIDERED

The proposed action addressed by this (Tier 2) Final Environmental Impact Statement (FEIS) is the completion of preparation and operation of the Ulysses mission, including its launch at the earliest available launch opportunity on the Space Shuttle in October 1990 or in the backup opportunity in November 1991. The launch configuration will use the STS/IUS/PAM-S combination. To achieve an orbit over the poles of the Sun, the spacecraft must travel to Jupiter and use that planet's huge gravitational pull to propel the spacecraft out of the Earth's orbital plane and into a polar orbit about the Sun.

The alternative to the proposed action is no-action; that is, canceling further work on the mission.

The Tier 1 EIS (NASA 1988a) included a delay alternative which considered the Titan IV launch vehicle as an alternative booster stage for launch in November 1991 or later. The Titan IV is not a commercially available launch vehicle; the U.S. Air Force procures that vehicle for NASA. The Titan IV alternative was further evaluated and eliminated from consideration when, in November 1988, the U.S. Air Force notified NASA that it could not provide a Titan IV vehicle for the 1991 backup launch opportunity because of high priority Department of Defense requirements. Subsequently, NASA was notified that a Titan IV could not be available until 1995. Consequently, NASA terminated all mission planning for the Titan IV as a backup launch vehicle. Even if the Titan IV were available, a minimum of 3 years is required from the decision to launch on a Titan IV in order to implement mission-specific modifications to the basic Titan IV launch configuration; therefore, insufficient time is available to use a Titan IV vehicle in November 1991, even if it were available. Thus, the Titan IV launch vehicle is no longer a feasible alternative to the STS/IUS for the November 1991 backup launch opportunity.

Because the only launch configuration available is the STS/IUS/PAM-S and the environmental impacts of an STS/IUS/PAM-S launch are the same whenever the launch occurs, a delay alternative involving the STS/IUS/PAM-S would have the same environmental impacts as the planned launch in 1990. The 1991 backup launch date is a contingency opportunity due to the short launch period available in 1990.

## ENVIRONMENTAL CONSEQUENCES

The only expected environmental effects of the proposed action are associated with normal launch vehicle operation. These effects have been considered in the previously published EISs on the Space Shuttle Program (NASA 1978) and the Kennedy Space Center (NASA 1979) and in the Final (Tier 1) EIS for the Galileo and Ulysses Missions (NASA 1988a), the Kennedy Space Center (KSC) Environmental Resource Document (NASA 1986), and the Final (Tier 2) EIS for the Galileo Mission (NASA 1989a). The environmental consequences of normal Shuttle launches are small and temporary, and have been judged insufficient to preclude Shuttle operations.

In the event of (1) an accident during launch, or (2) reentry of the spacecraft from Earth orbit, there are possible adverse health and environmental effects associated with the possible release of plutonium dioxide from the spacecraft's Radioisotope Thermoelectric Generator (RTG). The potential effects considered in preparing this EIS include risks of air and water quality impacts, local land area contamination by plutonium dioxide, adverse health and safety impacts, the disturbance of biotic resources, the occurrence of adverse impacts on wetland areas or in areas containing historical sites, and socioeconomic impacts.

An extensive analysis of the safety and environmental consequences of launch or mission accidents indicates very small risks to human health or the environment. The results of the detailed analyses are summarized for each mission phase.

The U.S. Department of Energy (DOE) has developed an extensive data base on the behavior of space nuclear power systems, and their components and materials, under a wide variety of environmental conditions over some 30 years of research, development, test, and evaluation. This data base was used to develop models and simulation techniques to conduct a detailed, in-depth safety analysis. Monte Carlo simulation was used to combine the range of release quantities with the range of atmospheric dispersion and deposition parameters to arrive at a distribution of possible accident consequences along with their probability of occurrence. This FEIS primarily discusses the mean consequences as a best estimate of the consequences and the 99th percentile as representative of the "maximum case."

In view of the detailed analyses of this STS/IUS launch vehicle configuration (DOE 1988a, DOE 1988b, DOE 1989a, DOE 1989b, DOE 1990a, DOE 1990b, DOE 1990c, DOE 1990d, DOE 1990e, DOE 1990f, DOE 1990g), enough information is available to indicate an envelope of the risks in the Ulysses mission. The most probable release occurs in Phase 4 (at interplanetary

trajectory injection) with a total probability of land impact of about 1 in 602 (i.e., $1.66 \times 10^{-3}$) and the conditional probability of one or more modules hitting rock and one or more clads having a release is 0.129. The total probability of release is $2.14 \times 10^{-4}$ (or 1 in 4,670). There are no health effects from the release in either the mean value or the 99th percentile analysis. The mean collective population dose over a 50-year period would be 0.19 person-rem. "Maximum" collective dose is predicted to be 3 person-rem with a probability of approximately 1 in 60,000. The ability of the modules to survive Earth orbital reentry heating without a loss of fuel has been demonstrated by test and operational experience. The release could occur only in the event of reentry and impact on rock or a similar unyielding surface. If the RTG modules reenter and lands in the ocean, statistically the most likely occurrence, there would be no release.

The maximum consequences accident scenario is a Solid Rocket Booster (SRB) case rupture near the end of first stage ascent (106-120 seconds). In the 99th percentile analysis, and without the de minimis assumption, that scenario would indicate up to 14.5 health effects worldwide at a probability level of 1 in 44,000,000 ($2.27 \times 10^{-8}$). This scenario involves high speed SRB fragment impact on the RTG and release of plutonium dioxide high in the stratosphere. The respirable size particles of interest have long residence times in the stratosphere which leads to wide dispersion and therefore low local dose levels. The maximum individual dose (99th percentile) is 0.0127 millirems over the fifty year dose commitment. At such a low dose level, zero health effects is equally as likely as 14.5.

In summary, the average individual risk of cancer fatality was calculated for this mission and was compared to risks tabulated by the Bureau of the Census. The risks associated with this mission are four to five orders of magnitude smaller than any of the risks tabulated as commonly occurring. Thus the health risks of this mission are very small.

No launch area accident would indicate environmental contamination of any area of significant size. An early first stage ascent (0-10 seconds) release in the 99th percentile analysis could lead to deposition above the EPA screening level of 0.2 $\mu Ci/m^2$ over an area of 111 square kilometers. This would indicate the need for monitoring to assess the need for remedial action.

There are no adverse impacts to the physical environment associated with the no-action alternative. However, the U.S. Government and the European Space Agency would suffer significant fiscal, programmatic and geopolitical impacts were the mission to be canceled.

TABLE OF CONTENTS


| Section | | | Page |
|---|---|---|---|
| Cover Sheet | | | |
| Abstract | | | i |
| Executive Summary | | | iii |
| List of Tables | | | xi |
| List of Figures | | | xii |
| 1. | PURPOSE AND NEED FOR ACTION | | 1-1 |
| | 1.1 | BACKGROUND | 1-1 |
| | 1.2 | PURPOSE OF THE PROPOSED ACTION | 1-1 |
| | | 1.2.1 Exploration Out of the Ecliptic | 1-2 |
| | | 1.2.2 Better Understanding the Sun to Better Understand the Earth | 1-4 |
| | | 1.2.3 Unraveling the Mysteries of the Stars | 1-5 |
| | 1.3 | NEED FOR THE ACTION | 1-5 |
| 2. | ALTERNATIVES, INCLUDING THE PROPOSED ACTION | | 2-1 |
| | 2.1 | ALTERNATIVES CONSIDERED | 2-1 |
| | 2.2 | DESCRIPTION OF THE PROPOSED ACTION TO PROCEED AS PLANNED WITH COMPLETION OF PREPARATIONS AND OPERATION OF THE ULYSSES MISSION, INCLUDING ITS PLANNED LAUNCH ON THE STS IN OCTOBER 1990 OR IN THE BACKUP OPPORTUNITY IN NOVEMBER 1991 | 2-1 |
| | | 2.2.1 Mission Design | 2-1 |
| | | 2.2.2 Mission Launch Operations | 2-1 |
| | | 2.2.3 Spacecraft Description | 2-3 |
| | | 2.2.4 Spacecraft Power System | 2-3 |
| | | 2.2.4.1 Power System Performance Criteria | 2-3 |
| | | 2.2.4.2 Alternative Spacecraft Power Systems | 2-5 |
| | | 2.2.4.3 Radioisotope Thermoelectric Generators | 2-8 |
| | | 2.2.4.4 RTG Performance History | 2-13 |
| | | 2.2.5 Spacecraft Propulsion Subsystem | 2-15 |
| | | 2.2.6 STS/IUS/PAM-S Launch Configuration | 2-15 |
| | | 2.2.7 Range Safety Considerations | 2-18 |
| | | 2.2.7.1 General | 2-18 |
| | | 2.2.7.2 Electromagnetic Hazard Conditions | 2-18 |
| | | 2.2.8 Mission Contingencies | 2-22 |
| | | 2.2.8.1 Intact Aborts | 2-22 |
| | | 2.2.8.2 Contingency Aborts | 2-23 |
| | | 2.2.8.3 On-Orbit Spacecraft Aborts | 2-23 |
| | 2.3 | ALTERNATIVES EVALUATED AND ELIMINATED FROM FURTHER CONSIDERATION | 2-23 |
| | 2.4 | DESCRIPTION OF THE NO-ACTION ALTERNATIVE | 2-24 |

TABLE OF CONTENTS (Continued)


| Section | | Page |
|---|---|---|
| 2.5 | COMPARISON OF ALTERNATIVES | 2-24 |
| 2.5.1 | Environmental Impacts of the Mission. | 2-24 |
| 2.5.1.1. | Environmental Impacts from Normal Mission. | 2-24 |
| 2.5.1.2. | Possible Environmental Impacts of Mission Accident | 2-29 |
| 2.5.2 | Scope and Timing of Mission Science Returns | 2-30 |
| 2.5.3 | Launch Preparation and Operation Costs (Mission Only). | 2-31 |
| 2.5.4 | Launch Schedules and Launch Vehicle Availability. | 2-31 |
| 2.5.5 | Facility and Personnel Availability | 2-31 |
| 2.5.6 | Summary | 2-31 |
| 3. | AFFECTED ENVIRONMENT. | 3-1 |
| 3.1 | REGIONAL OVERVIEW. | 3-1 |
| 3.1.1 | Land Use | 3-1 |
| 3.1.2 | Meteorology and Air Quality | 3-3 |
| 3.1.3 | Hydrology and Water Quality | 3-3 |
| 3.1.4 | Geology and Soils | 3-6 |
| 3.1.5 | Biological Resources and Endangered Species | 3-6 |
| 3.1.6 | Socioeconomic Environment | 3-9 |
| 3.1.6.1 | Population | 3-9 |
| 3.1.6.2 | Economics. | 3-10 |
| 3.1.6.3 | Transportation | 3-12 |
| 3.1.6.4 | Public and Emergency Services. | 3-12 |
| 3.1.6.5 | Historical/Cultural Resources. | 3-13 |
| 3.2 | LOCAL ENVIRONMENT. | 3-13 |
| 3.2.1 | Land Use | 3-13 |
| 3.2.2 | Meteorology and Air Quality | 3-17 |
| 3.2.3 | Hydrology and Water Quality | 3-19 |
| 3.2.3.1 | Surface Waters | 3-19 |
| 3.2.3.2 | Surface Water Quality. | 3-22 |
| 3.2.3.3 | Ground Waters. | 3-27 |
| 3.2.3.4 | Quality of Groundwater | 3-31 |
| 3.2.3.5 | Offshore Environment | 3-31 |
| 3.2.4 | Geology and Soils | 3-34 |
| 3.2.5 | Biological Resources | 3-34 |
| 3.2.5.1 | Terrestrial Biota. | 3-34 |
| 3.2.5.2 | Aquatic Biota. | 3-37 |
| 3.2.5.3 | Endangered and Threatened Species. | 3-38 |
| 3.2.6 | Socioeconomics. | 3-38 |
| 3.2.6.1 | Population | 3-38 |
| 3.2.6.2 | Economy. | 3-40 |
| 3.2.6.3 | Transportation | 3-40 |
| 3.2.6.4 | Public and Emergency Services. | 3-41 |
| 3.2.6.5 | Historic/Archaeologic Resources. | 3-42 |

TABLE OF CONTENTS (Continued)


| Section | | Page |
|---|---|---|
| 3.3 | GLOBAL COMMONS | 3-42 |
| 3.3.1 | Population Distribution and Density | 3-44 |
| 3.3.2 | Climatology | 3-44 |
| 3.3.3 | Surface Types | 3-44 |
| 3.3.4 | Worldwide Plutonium Levels | 3-44 |
| 4. | ENVIRONMENTAL CONSEQUENCES | 4-1 |
| 4.1 | ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION | 4-1 |
| 4.1.1 | Implications of Completion of Prelaunch Preparation of the Spacecraft | 4-1 |
| 4.1.2 | Environmental Consequences of Normal Launch of the Shuttle | 4-1 |
| 4.1.2.1 | Effects of the Exhaust Gases on Vegetation and Shallow Water | 4-1 |
| 4.1.2.2 | Effects of Exhaust Gasses on the Ozone Layer | 4-4 |
| 4.1.3 | Non-Radiological Consequences of Shuttle Launch Accidents | 4-5 |
| 4.1.4 | Procedure for Analysis of Radiological Accidents and Consequences | 4-7 |
| 4.1.4.1 | Accident Scenarios, Environments, and Probabilities | 4-7 |
| 4.1.4.2 | Accident Source Terms and Consequences | 4-9 |
| 4.1.4.3 | Risk Assessment | 4-10 |
| 4.2 | ENVIRONMENTAL ASSESSMENT METHODOLOGIES | 4-19 |
| 4.2.1 | Kennedy Space Center and Vicinity | 4-19 |
| 4.2.2 | Global Assessment | 4-21 |
| 4.2.3 | Economic Impact | 4-21 |
| 4.3 | ENVIRONMENTAL CONSEQUENCES OF ACCIDENTS RELEASING RTG FUEL | 4-25 |
| 4.3.1 | Plutonium Dioxide in the Environment | 4-25 |
| 4.3.2 | Assessment of Impacts to Kennedy Space Center and Vicinity | 4-30 |
| 4.3.2.1 | Surface Areas Contaminated by Representative Accidents | 4-30 |
| 4.3.2.2 | Exposure Effects | 4-30 |
| 4.3.2.3 | Long-Term and Mitigation Effects | 4-31 |
| 4.3.2.4 | Assessment of Global Impacts | 4-35 |
| 4.3.3 | Emergency Response Planning | 4-35 |
| 4.4 | INCOMPLETE OR UNAVAILABLE INFORMATION | 4-36 |
| 4.5 | NO-ACTION ALTERNATIVE | 4-37 |
| 4.6 | SUMMARY OF ENVIRONMENTAL CONSEQUENCES | 4-38 |
| 4.7 | ADVERSE ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED | 4-38 |

TABLE OF CONTENTS (Continued)


| Section | | Page |
|---|---|---|
| 4.8 | RELATIONSHIP BETWEEN SHORT-TERM USES OF THE HUMAN ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY. . . . . | 4-38 |
| 4.8.1 | Short-Term Uses . . . . . | 4-38 |
| 4.8.2 | Long-Term Productivity. . . . . | 4-38 |
| 4.9 | IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES. . . . . | 4-39 |
| 4.9.1 | Iridium . . . . . | 4-39 |
| 4.9.2 | Plutonium-238 . . . . . | 4-39 |
| 4.9.3 | Other Materials . . . . . | 4-39 |
| 5. | CONTRIBUTORS TO THE EIS . . . . . | 5-1 |
| 6. | AGENCIES AND INDIVIDUALS CONSULTED. . . . . | 6-1 |
| 7. | REFERENCES. . . . . | 7-1 |
| 8. | INDEX . . . . . | 8-1 |
| APPENDICES: | | |
| A - | GLOSSARY OF ABBREVIATIONS AND ACRONYMS . . . . . | A-1 |
| B - | DEVELOPMENT OF ACCIDENT SCENARIOS AND PROBABILITIES . . | B-1 |
| C - | SUMMARY OF DOE ULYSSES MISSION UPDATED ACCIDENT PROBABILITIES AND RISK ANALYSIS . . . . . | C-1 |
| D - | DEVELOPMENT OF PHASE 1 SOURCE TERMS FOR RISK ASSESSMENT . . . . . | D-1 |
| E - | RESPONSES TO PUBLIC COMMENTS . . . . . | E-1 |
| F - | STATE AND FEDERAL COORDINATION . . . . . | F-1 |
| G - | UPDATE OF ULYSSES FSAR RESULTS . . . . . | G-1 |

LIST OF TABLES


| Table | | Page |
|---|---|---|
| 1-1 | Relative Ranges, Over Time, of Other Spacecraft Important to the Ulysses Science Program | 1-3 |
| 2-1 | Summary Analysis of Power Source Alternatives for the Ulysses Mission. | 2-6 |
| 2-2 | Characteristics and Isotopic Composition of RTG Fuel | 2-11 |
| 2-3 | United States Spacecraft Launches Involving Nuclear Power Sources | 2-14 |
| 2-4 | Summary Comparison of Alternatives | 2-25 |
| 3-1 | Major Cover Types Within the Region by Percent Within County and By Acreage | 3-8 |
| 3-2 | Projected Population Growth, East Central Florida Region | 3-10 |
| 3-3 | KSC Air Quality Data from Permanent Air Monitoring System Station A, 1985 Annual Report | 3-20 |
| 3-4 | Surface Water Quality at KSC | 3-24 |
| 3-5 | Endangered and Threatened Species Residing or Seasonally Occurring on KSC/CCAFS and Adjoining Waters | 3-39 |
| 3-6 | Surface Type Distributions for Each Latitude Band | 3-48 |
| 3-7 | Major Sources and Approximate Amounts of Plutonium 238 Distributed Worldwide. | 3-50 |
| 4-1 | Summary of Environmental Consequences of Normal Launch of the STS and Balance of a Normal Ulysses Mission | 4-2 |
| 4-2 | Nonradiological Consequences of Unplanned Events | 4-6 |
| 4-3 | Summary of Average Source Terms | 4-11 |
| 4-4 | Summary of Radiological Consequences: Mean Values | 4-12 |
| 4-5 | Summary of Radiological Consequences: 99th Percentile Values | 4-13 |
| 4-6 | Average Annual Effective Dose Equivalent of Ionizing Radiations to a Member of the U.S. Population | 4-15 |
| 4-7 | Mission Risk Summary: Mean Values | 4-18 |
| 4-8 | Calculated Individual Risk of Fatality by Various Causes | 4-20 |
| 4-9 | Monitoring Program Cost Estimates | 4-23 |
| 4-10 | Range of Decontamination Methods for Various Land Cover Types for Potential RTG Accidents | 4-26 |
| 5-1 | Contributors to the EIS. | 5-2 |

LIST OF FIGURES


| Figure | | Page |
|---|---|---|
| 2-1 | Ulysses Spacecraft Trajectory and Missile Profile . | 2-2 |
| 2-2 | Diagram of Spacecraft Hardware and Science Instruments . . . . . | 2-4 |
| 2-3 | Diagram of RTG Assembly . . . . . | 2-9 |
| 2-4 | Diagram of General Purpose Heat Source. . . . . | 2-10 |
| 2-5 | Diagram Showing Configuration of Ulysses Spacecraft in Shuttle Bay for Launch . . . . . | 2-16 |
| 2-6 | Configuration of Ulysses Spacecraft Assembled with IUS/PAM-S. . . . . | 2-17 |
| 3-1 | Location of Regional Area of Interest . . . . . | 3-2 |
| 3-2 | Generalized Map of Potential Ground Water Recharge Areas in Eastern Central Florida . . . . | 3-5 |
| 3-3 | General Land Cover Types of the Region. . . . . | 3-7 |
| 3-4 | Location of KSC and CCAFS Relative to the Region. . | 3-14 |
| 3-5 | General Land Use at Kennedy Space Center. . . . . | 3-15 |
| 3-6 | Existing Land Use at CCAFS. . . . . | 3-16 |
| 3-7 | Wind Roses Indicating Seasonal Wind Directions -- Lower Atmospheric Conditions: Cape Canaveral/ Merritt Island Land Mass. . . . . | 3-18 |
| 3-8 | Major Surface Water Bodies Near KSC . . . . . | 3-21 |
| 3-9 | KSC Surface Water Classifications . . . . . | 3-23 |
| 3-10 | KSC Outstanding Florida Waters. . . . . | 3-25 |
| 3-11 | KSC Area Aquatic Preserves. . . . . | 3-26 |
| 3-12 | KSC Shellfish Harvesting Areas. . . . . | 3-28 |
| 3-13 | Potential Recharge for the Surficial Aquifer . . . | 3-29 |
| 3-14 | Qualitative Flow Net for the Surficial Aquifer Illustrating Groundwater Circulation. . . . . | 3-30 |
| 3-15 | Offshore Water Depth Near KSC/CCAFS . . . . . | 3-32 |
| 3-16 | Ocean Currents and Water Masses Offshore of KSC for January and July. . . . . | 3-33 |
| 3-17 | General Land Cover Types at KSC/CCAFS and Vicinity. | 3-35 |
| 3-18 | General Locations of Historic/Archaeological Resources in the Vicinity of KSC/CCAFS. . . . . | 3-43 |
| 3-19 | Total and Urban World Population by Equal Area Latitude Bands . . . . . | 3-45 |
| 3-20 | World Population (Band Land Area) Density by Latitude Bands . . . . . | 3-46 |
| 3-21 | Climates of the Earth . . . . . | 3-47 |
| 4-1 | Final Safety Analysis Report Development Process. . | 4-8 |

# 1. PURPOSE AND NEED FOR ACTION

## 1.1 BACKGROUND

The Ulysses mission is an international cooperative effort of the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). The mission will, for the first time, explore the Sun and its influence on interplanetary space over the full range of heliographic latitudes (i.e., over the solar poles). ESA will provide the spacecraft, the spacecraft operations team and control software, integrate all the science instruments, and provide a complement of scientific investigations; NASA will provide launch services, including integration of the ESA-assembled spacecraft into the launch vehicle, mission control facilities and support, spacecraft tracking and data recovery, the RTG power system and an additional complement of scientific investigations.

This Final (TIER 2) Environmental Impact Statement (FEIS) provides updated information associated with the launch and operation of the Ulysses mission. The proposed action is the completion of preparation for launch and operation of the Ulysses mission, including its planned launch at the earliest launch opportunity in October 1990 or in the November 1991 backup opportunity (i.e., the earliest opportunities), using the Space Transportation System (STS) Shuttle, the Inertial Upper Stage (IUS) and the Payload Assist Module-Special (PAM-S) launch configuration. Alternative approaches for achieving the mission are described in Section 2. This document succeeds a Final EIS (TIER 1) for the Galileo and Ulysses missions (NASA 1988a).

The Ulysses mission supports both NASA's Solar System Exploration Program (SSEP) and NASA's Space Physics Program (SPP). The Ulysses mission will contribute to the SSEP goal of characterizing the solar system's interplanetary medium; the mission will contribute to the SPP goals of describing the high latitude characteristic of the solar wind and how it helps control the geospace environment and possible effects of solar processes on the Earth.

## 1.2 PURPOSE OF THE PROPOSED ACTION

The Ulysses mission will be the first solar exploration mission to observe the polar regions of the Sun and explore the heliosphere at high heliographic latitudes. The mission will provide scientists with a unique opportunity to broaden human understanding of the Sun. Since the Sun is the star nearest Earth, knowledge gained from the Ulysses mission will also enhance the understanding of other stars and the space that separates them. The major scientific objectives of the Ulysses mission are to:

- Characterize the inner heliosphere as a function of heliographic latitude

- Characterize particles and fields from the ecliptic to the Sun's poles
  - Particles: solar wind, cosmic rays, solar-heliospheric energetic particles
  - Fields: plasma waves, solar emissions, solar-heliospheric magnetic particles.

Specifically, Ulysses carries individual instruments to conduct investigations of the properties of the solar wind (plasma and ion composition), the Sun/wind interface, the Sun's magnetic field, solar radio bursts and plasma waves, solar x-rays, solar and galactic cosmic rays, and interplanetary and interstellar neutral gas and dust.

In pursuing these ends, the Ulysses mission, as a joint endeavor between NASA and ESA, will serve to strengthen the spirit of international cooperation in space exploration.

The findings of the Ulysses mission are expected to be very important for the following reasons. First, because of its proximity, the Sun is the only star whose internal processes can be studied with high temporal and spatial resolutions. Since our Sun is of a common stellar size and nature that is generally found in the universe, our increased understanding of its behavior will contribute greatly to our knowledge of stellar processes. Second, solar processes have great influences on Earth. Not only does the Sun heat and illuminate the Earth, but the Sun also influences terrestrial phenomena in more subtle ways. For instance, solar flares and solar magnetic disturbances can disrupt radio communications on Earth. Solar emissions, both the solar particle flux and the photon flux, play important roles in the Earth's upper atmospheric chemistry. Solar variability may also contribute to the variability in climate on Earth.

### 1.2.1 Exploration Out of the Ecliptic

The plane in which the Earth orbits our Sun is called the ecliptic. Because the Sun's spin axis is tilted seven degrees toward this plane, direct earth-based measurement of the Sun's particle emissions and magnetic field tend to be limited to within 7 degrees of the equator. Until recently, the same limitation has plagued direct space-based measurements. In order to study the complete range of heliographic latitudes (the third dimension), a spacecraft must leave the ecliptic and traverse the solar poles. No launch vehicles have been available with sufficient energy to send the spacecraft out of the ecliptic. However, Ulysses will overcome these limitations by using Jupiter's immense gravitational field to swing out of the ecliptic and back toward the Sun and into an orbit that will allow observation from a polar perspective. To gain sufficient energy to leave the ecliptic, the Ulysses spacecraft will execute a gravity-assisted fly-by of Jupiter and head back toward the Sun. The trajectory will carry the spacecraft first over the Sun's south pole and then upward over the north pole. In so doing, the spacecraft will monitor the heliosphere out to 5 astronomical units (AU) (i.e., Sun-to-Earth distances), which is Jupiter's orbital distance, and then back to approximately 1.3 AU at perihelion, its point of closest approach to the Sun.

The mission is planned to arrive in the Sun's polar regions near the solar minimum when the Sun's activity is less volatile; this provides an opportunity to view phenomena such as the solar winds and the Sun's magnetic fields in their least perturbed state. The nominal end of the mission is September 30, 1995, but the mission could be operated until the spacecraft power level is reduced to a point where the spacecraft systems and instruments no longer function properly. The spacecraft will continue to travel around the Sun in a 5 AU to 1.3 AU elliptical orbit.

The heliosphere is the region encompassing the Sun where the solar wind (a wind of charged particles emitted from the Sun) dominates the interstellar medium and tends to sweep away much of the interstellar gas. The heliosphere is thought to exist as far out as 100 AU, well beyond the outermost planet. While the journey to high solar latitudes by Ulysses is an entirely worthwhile mission on its own, its value will clearly be enhanced by simultaneous measurements in the ecliptic near the Earth and by the two Pioneer and two Voyager spacecraft which are approaching the heliospheric boundary. The heliosphere extends to the point where the pressure of the solar winds equal those of the interstellar gas. Ulysses will provide a unique opportunity to compare heliospheric measurements from high solar latitudes with those obtained from six other spacecraft at great distances from the Sun. These spacecraft are located both near the ecliptic (Pioneers 10 and 11), and at moderate distances from the ecliptic (Voyagers 1 and 2). The IMP-8 spacecraft will provide a good comparison with in-ecliptic data obtained near the Sun (1 to 3 AU), Table 1-1 shows the configuration of the Pioneer and Voyager spacecraft. As a result of these combined measurements, scientists will be able to measure the solar winds and magnetic fields from their origins to near the edge of the heliosphere.

TABLE 1-1. RELATIVE RANGES, OVER TIME, OF OTHER SPACECRAFT IMPORTANT TO THE ULYSSES SCIENCE PROGRAM

| Spacecraft | Solar Inclination | Range in AU | | |
|---|---|---|---|---|
| | | 1990 | 1995[a] | 1998 |
| Voyager 1 | 35 deg N. | 44 | 60 | 71 |
| Voyager 2 | 45 deg S. | 30 | 46 | 57 |
| Pioneer 10 | 3 deg N. | 48 | 61 | 69 |
| Pioneer 11 | 17 deg N. | 30 | 42 | 50 |

[a] Ulysses in high solar polar region

To have a comprehensive understanding of the Sun, both of how it behaves as a star and how it influences Earth, it is important to understand how the Sun influences the heliosphere in three dimensions. There is good reason to believe that the solar wind phenomena change as one moves away from the solar equatorial region (i.e., the region of ecliptic in which the Earth orbits the Sun). For instance, as the Sun rotates, the solar magnetic field lines, which are carried outward by the escaping solar wind, spiral outward in the Sun's equatorial plane, the ecliptic. However, as one moves away from the ecliptic to high solar latitudes, the influences of the Sun's rotation dramatically diminish, hence the solar magnetic field lines are expected to be more nearly radial.

From high solar latitudes, scientists expect to observe solar phenomena significantly different from that previously observed in the Sun's equatorial region. In particular, scientists anticipate differences in the behavior of the solar wind. This "wind" is comprised of charged particles that flow continuously from the Sun pushing against interstellar gas molecules situated beyond 50 AU. Because the particles in these flows carry with them the Sun's magnetic field, any disturbance on the Sun will be reflected both in the wind and the magnetic field. Ulysses will be investigating regions of the Sun where such disturbances, known as sunspots, occur. It will also investigate areas known as coronal holes. Within these regions, the topology of the Sun's magnetic field differs. Together, these areas are part of the reason why scientists expect to see solar wind behavior that is different from what has been previously observed in the Sun's equatorial regions.

The Pioneer spacecraft were launched in 1972 and 1973 and the Voyagers were launched in 1977. As these spacecraft recede from Earth and their power systems diminish in strength, it will become increasingly difficult to receive their data. Tracking and data acquisition experts estimate that data from the Pioneer spacecraft will no longer be available after 1997 or 1998, while data from the Voyager spacecraft will be available beyond 2010. With its planned launch in October 1990, Ulysses will transmit data from its Jupiter flyby to the first solar polar pass in 1994 as the solar wind becomes less turbulent following the solar maximum of 1990. The Ulysses pole-to-pole passage in 1994-to-1995 will occur just before solar minimum conditions when the spacecraft should encounter a relatively well-ordered structure in which latitude dependencies are most clear.

### 1.2.2 Better Understanding the Sun to Better Understand the Earth

Conditions on Earth are in many ways linked to conditions on the Sun. For instance, variations in the Sun's magnetic field and solar wind interfere with radio communication and electric power distribution on Earth. These solar variations also cause dramatic changes in the constituents of the Earth's upper atmosphere, perhaps affecting its climate. The Earth's magnetic field also varies in accordance with these solar variations, sometimes allowing energetic charged particles to reach the Earth's surface.

To the extent that such changes on the Sun can have a measurable effect upon the Earth, a better understanding of the Sun will facilitate understanding and predicting conditions on Earth. Ulysses will undertake a

variety of observations designed to improve this understanding. In particular, Ulysses will observe, from a polar perspective, the solar corona (the Sun's outer atmosphere), the solar wind, and the Sun's magnetic field. These observations are expected to yield new insights into the behavior of sunspots, solar flares, solar x-rays, solar radio noise, and the behavior of the solar atmosphere across different heliographic latitudes, phenomena which may have a bearing on what happens on Earth.

### 1.2.3 Unraveling the Mysteries of the Stars

Since the Sun is our nearest star, better understanding of its nature and physical behavior may also help us to unravel the mysteries associated with other stars and the space that separates them. Ulysses will endeavor to improve this understanding by investigating the role that solar wind and coronal holes play in dissipation of the solar atmosphere. By carrying special cosmic ray instrumentation out of the ecliptic to high latitudes where such rays can more easily penetrate the Sun's magnetic field, scientists hope to detect virgin, mid-energy, interstellar cosmic rays. This will lead to a better understanding of the nature and origins of cosmic rays. Scientists will also directly measure the heliosphere's neutral helium content. These helium measurements will help provide information on the state of the interstellar gas in the vicinity of the solar system, and the measurement of the heliosphere's dust particle content will help scientists to better understand where this dust comes from and how it evolves.

## 1.3 NEED FOR THE ACTION

It is vital at this stage of solar system exploration and space physics to fully characterize the three dimensional structure of the heliosphere. The Ulysses mission will be the first source of those data that will contribute to a number of national and international goals. The Ulysses mission is expected to make major scientific contributions to the International Heliospheric Study, whose aim is investigation of the structure of the heliosphere. The measurements to be gained from the Ulysses mission cannot be obtained from Earth or from Earth orbit. They can only be made in-situ by a spacecraft that is well out of the ecliptic.

Furthermore, the President of the United States has announced the intention to establish a permanent human presence on the Moon and to undertake human exploration of Mars. In a general sense, the more we understand the physics of the Sun, the better we will understand solar flares and other energetic solar disturbances that could influence the environment in which humans may operate in space.

Ulysses will be the first mission to explore interplanetary space above the Sun's polar regions. As such, it will return new discoveries no matter when it is executed. However, two compelling reasons suggest that the planned 1990 launch is particularly timely to ensure a maximum scientific return from this mission.

The first reason has to do with the 11-year cycle of solar activity. A 1990 launch allows Ulysses to undergo its sequential polar passages in mid-

1994 and mid-1995 (south and then north poles, respectively). Since the current solar activity cycle will peak in 1990, Ulysses will therefore traverse the high solar latitude heliosphere when the Sun is rapidly approaching its minimum of activity. This means that the interplanetary medium, which is what Ulysses measures, will be least complicated by sporadic, energetic solar events, and therefore, easiest to interpret as far as a new environment is concerned. Conversely, when the last few solar events do occur during these polar overflights, they will be far more isolated so that their effect on the interplanetary medium will be most obvious. The original 1983 launch would have had solar passage near solar minimum.

The second reason is that space science in the early to mid 1990's will enjoy a particularly rich complement of other solar and interplanetary missions sponsored by NASA, ESA, Japan, and the USSR (a subset of which is called the International Solar Terrestrial Program). These 13 to 15 different missions range from NASA's Pioneers and Voyagers at the outer edge of the solar system, to missions like Polar in near Earth orbit, each of which simultaneously samples a different part of the heliosphere or near-Earth space environment. Taken as an entire mission set, the total scientific return will be immensely greater than the sum of its parts. Even though fully justified in its own right, for Ulysses to conduct its primary mission during this same period, thereby measuring the otherwise unsampled solar polar region, is a particularly fortuitous circumstance that will not be repeated in even the most optimistic of mission planning scenarios. This constellation of simultaneously operating spacecraft is a definitely perishable circumstance. The life of these spacecraft will deteriorate, and the very distant ones (e.g., Pioneers) will no longer be within range for receipt of data.

The Ulysses mission can be launched only during specific periods, spaced about 13 months apart, depending on the position of Jupiter and the capability of the available launch vehicles. Presently, the earliest available launch opportunity is in October 1990. The proposed action is needed to implement the mission at the earliest available launch opportunity.

# 2. ALTERNATIVES, INCLUDING THE PROPOSED ACTION

## 2.1 ALTERNATIVES CONSIDERED

This Final (Tier 2) Environmental Impact Statement (FEIS) for the Ulysses mission considers the following alternatives:

- Proposed Action: Completion of preparation and operation of the mission, including its planned launch on the Space Transportation System/Inertial Upper Stage (STS/IUS) vehicle, supplemented by the Payload Assist Module-Special (PAM-S) third stage, in October 1990 or in the backup opportunity in November 1991.

- No-Action Alternative: Cancellation of any further commitment of resources to the mission.

Delay alternatives, to allow access to alternative power sources or alternative launch systems were further evaluated and eliminated from consideration for reasons discussed in subsections 2.2.4.2 and 2.3, respectively.

## 2.2 DESCRIPTION OF THE PROPOSED ACTION TO PROCEED AS PLANNED WITH COMPLETION OF PREPARATIONS AND OPERATION OF THE ULYSSES MISSION, INCLUDING ITS PLANNED LAUNCH ON THE STS IN OCTOBER 1990 OR IN THE BACKUP OPPORTUNITY IN NOVEMBER 1991

### 2.2.1 Mission Design

The launch of the Ulysses spacecraft is planned for October 1990. Its trajectory, as shown in Figure 2-1, provides for it to travel in the ecliptic and pass over the north pole of Jupiter in February 1992. The flyby will thrust it out of the ecliptic and return it toward the Sun. The spacecraft will reach 70 degrees south polar latitude in June 1994, will reach maximum latitude in August 1994, and will again cross 70 degrees south latitude in September 1994. The spacecraft will achieve its closest approach to the Sun of 1.3 astronomical units (AU) (i.e., Sun-to-Earth-distances) at the solar equatorial crossing in February 1995. The second polar pass will begin when the spacecraft exceeds 70 degrees north latitude between June and September 1995. This will end the primary Ulysses mission, although the spacecraft will remain in a 1.3 by 5 AU orbit and will have the potential to remain operational and provide limited data acquisition for one additional solar orbit.

### 2.2.2 Mission Launch Operations

The Ulysses mission can be launched only during specific periods depending on the positions of the planets and the capabilities of the launch vehicles. The principal opportunity for launch occurs in October 1990. Planetary missions have a relatively short launch period during each launch opportunity where the Earth is properly positioned. In 1990 this period is 19 days for the Ulysses launch (10/5/90 to 10/23/90). Since technical problems with the launch vehicle or the spacecraft, or adverse weather conditions,

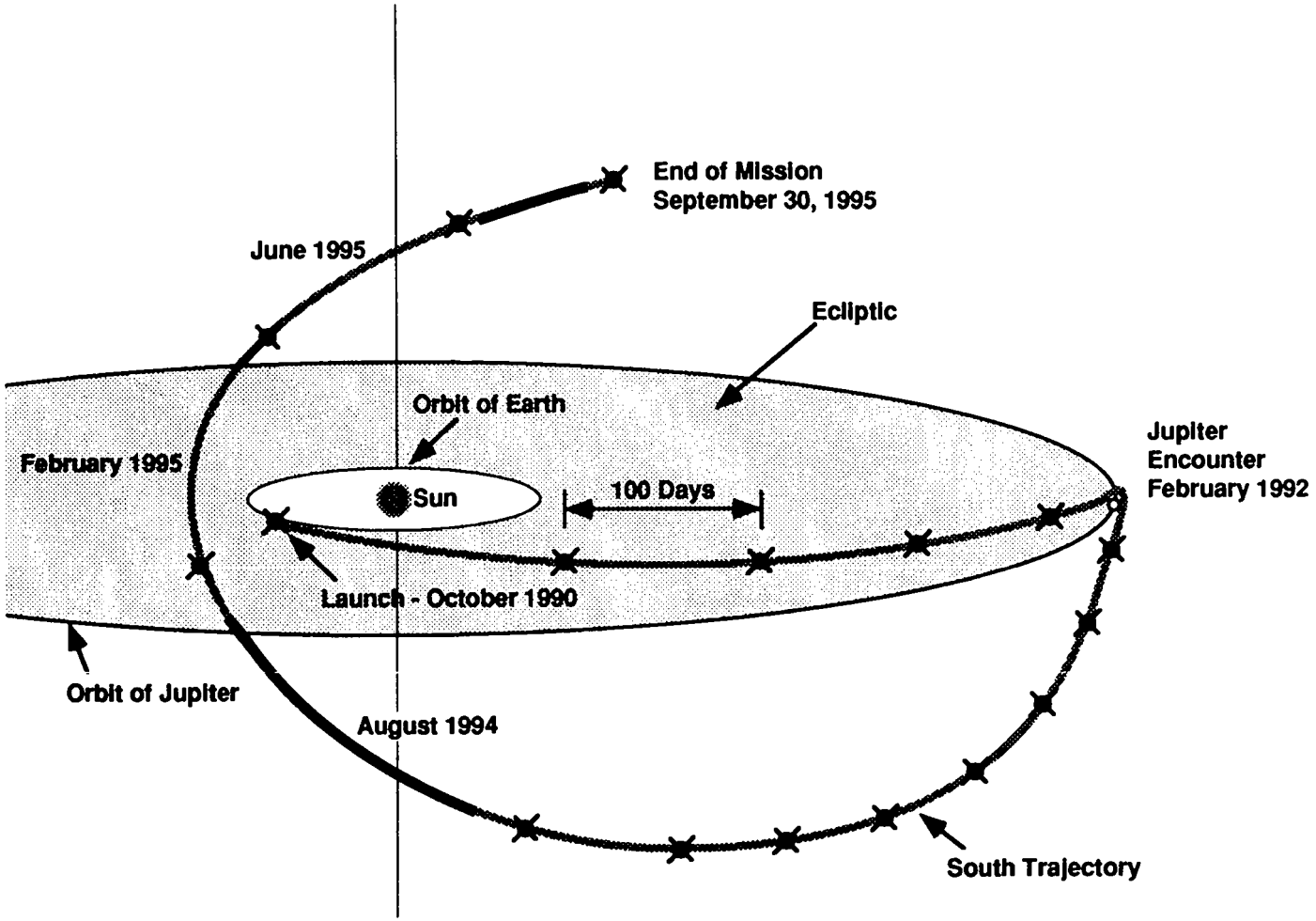


FIGURE 2-1. ULYSSES SPACECRAFT TRAJECTORY AND MISSION PROFILE

could occur which would cause the launch opportunity to be lost in this period, NASA has identified a contingency launch period. The contingency launch period for Ulysses occurs in November 1991.

When a mission delay causes a launch opportunity to be missed, spacecraft trajectories and mission operations must be redesigned and generally mission budgets must be augmented. The redesign of the mission operations requires modified plans for communications, spacecraft tracking, and mission operation facilities support. These new plans affect not only the delayed missions but also other missions that depend on the resources of these facilities. Because of the specialized nature of space exploration missions such as Ulysses, trained personnel and the use of supporting facilities must be retained when missions are delayed between launch opportunities. These factors all result in large additional costs and program disruption associated with delaying a mission.

### 2.2.3 Spacecraft Description

The Ulysses spacecraft weighs 809 pounds and is illustrated in Figure 2-2. The spacecraft is spin-stabilized with an antenna on top, one Radioisotope Thermoelectric Generator (RTG), a boom used for selected scientific experiments, and a main body that contains the remainder of the science experiments and the spacecraft subsystems.

The portions of the spacecraft that are relevant to assessing potential environmental impacts are the power and propulsion subsystems. The particular elements of these subsystems that are of interest are the RTG use in the power subsystem and the propellants in the attitude control and propulsion subsystem.

### 2.2.4 Spacecraft Power System

Alternate power sources include fuel cells, batteries, photovoltaic systems, RTGs, alkali metal thermoelectric converters, and turbine energy conversion. These potential power systems and the specific power system performance criteria for the Ulysses mission are discussed below.

#### 2.2.4.1 Power System Performance Criteria

The Ulysses spacecraft 5-year mission through the solar system imposes stringent performance criteria on spacecraft systems and components. The following performance criteria apply to the power system:

(1) Safe passage through the asteroid belt
(2) Operation during and after passage through the intense radiation field of Jupiter
(3) Sufficient power to operate at Jupiter's distance from the Sun
(4) Low weight-to-power ratio
(5) Maximum reliability.

NASA and other agencies of the Federal government support a wide range of research and technology development programs in spacecraft power systems. An

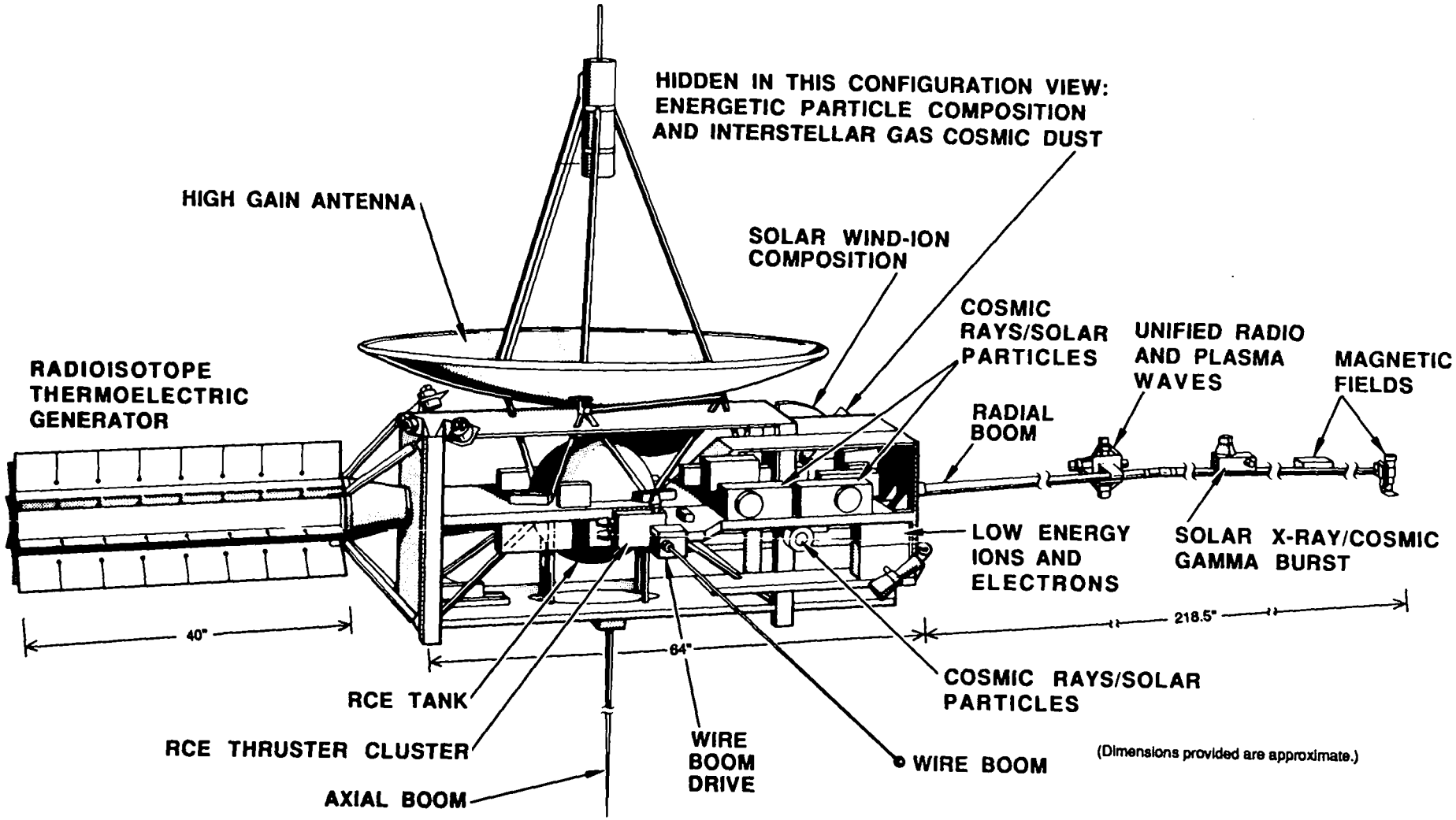


FIGURE 2-2. DIAGRAM OF SPACECRAFT HARDWARE AND SCIENCE INSTRUMENTS

analysis of alternate power sources was summarized in the Tier 1 EIS (NASA 1988a, Section 2). In response to scoping comments, an updated and expanded analysis of alternative power systems is presented below.

2.2.4.2 Alternative Spacecraft Power Systems

Spacecraft power sources include fuel cells, batteries, photovoltaic power systems, advanced solar dynamic (ASD) power sources, a new type of radioisotope thermoelectric converter known as an alkali metal thermoelectric converter (AMTEC), and radioisotope driven turbine converters (TECs). Table 2-1 summarizes the analysis of these alternatives with respect to their ability to satisfy the power requirements for the Ulysses mission. While fuel cells and batteries have a proven record of reliability and safety, their large weight (over 15,000 kg in each case) to achieve the required power precludes their use as sole power sources for any long duration planetary mission.

Because of the necessity to turn the spacecraft away from the Sun to perform a trajectory correction maneuver, the use of photovoltaic power would have to be augmented by the additional use of batteries and associated control equipment. Solar power technologies have not yet progressed to a stage of development consistent with the requirements of the Ulysses mission and use of available launch vehicles. Since the Ulysses spacecraft must fly by Jupiter where solar intensity is only 4 percent that at Earth, the large solar array for a Ulysses mission would require a complete spacecraft system redesign. A conceptual design study using state-of-the-art array technology indicates that this system would require an increase in the total spacecraft mass by about 1,200 pounds. This would require at least a Titan/Centaur/3-axis stabilized kick stage launch vehicle which would require the development of the 3-axis stabilized kick stage. No such launch vehicle configuration currently exists.

Even with the Advanced Photovoltaic Solar Array (APSA), now in the ground demonstration phase, with a specific power of 130 W/kg which is about 4 times the specific power of the current state-of-the-art planar rigid array, a complete spacecraft redesign would be needed. Moreover, the state of development of light-weight photovoltaic technology is such that technology readiness cannot be expected before 1993, after which flight testing and spacecraft adaptation will have to be made. Such a process normally will take another 5 years before an actual array is ready to be integrated with and used on a spacecraft. However, because of the newness of the design and the lack of flight experience, use of such a system would greatly increase the risk of spacecraft failure during the mission. Although APSA would be lighter than the rigid array design, a launch vehicle capability greater than the STS/IUS/PAM-S would be required.

Improved isotope powered systems are also in an early state of technological readiness with the earliest ground demonstration expected in the late-1990s. Initial laboratory models of the AMTEC systems have been constructed which indicate that AMTEC may be capable of a power density of about 20 W/kg. However, AMTEC development will not progress to the point of flight testing until the mid to late 1990s. The radioisotope-driven TECs are

TABLE 2-1. SUMMARY ANALYSIS OF POWER SOURCE ALTERNATIVES FOR THE ULYSSES MISSION

| POWER SOURCE | TECHNOLOGY READINESS+/ SUBSYSTEM APPLICATION | MASS (kg)* | SPACECRAFT ADAPTATION | OTHER COMMENTS |
|---|---|---|---|---|
| I. NONISOTOPIC | | | | |
| 1. Fuel Cell | Now | 73,000 | Integration | Non-rechargeable. Too heavy for any available vehicle. |
| 2. Batteries | Now | 18,250 | Integration | Too heavy for any available launch vehicle. |
| 3. Photovoltaic (Solar) | | | | |
| a. Rigid Array | Now | (Array only) 250 | Configuration, attitude control, and dynamics | Difficult with attitude, difficult to stow and deploy. No array of the size needed for the outer solar system has been flown. Requires at least Titan/Centaur/kick stage. Flown on Magellan (inner solar system). |
| b. SAFE | Now | (Array only) 90 | Configuration, attitude control, and dynamics | Flown on Shuttle experiment; requires at least Titan/Centaur. |
| c. APSA | 1995/ 2000 | (Array only) 50 | Configuration attitude control, and dynamics | High performance, lightweight; ground demonstration in 1991, flight experiment in 1993; Spacecraft development by 1998; requires at least Titan/Centaur. |
| d. CSA | 2010 | 15 | Configuration attitude control, and dynamics | Conceptual designs. Bulky, plastic. |
| 4. Advanced Solar Dynamics (ASD) | 2000 | 15 | Integration and attitude control issue | Ground demonstration in mid to late 1990s. |

KEY: SAFE - Solar Array Flight Experiment
APSA - Advanced Photovoltaic Solar Array
CSA - Concentrated Solar Array
TOPEX - Ocean Topographic Experiment

+Does not account for time required for power system construction and spacecraft adaptation

*Assumptions - 250W at Jupiter, 5AU from Sun
- 5 year mission, continuous 250 W requirement
- Excludes additional mass for propulsion or structural requirements, for example, for the rigid array, the additional mass would be 500 kg.

Source: JPL 1989

NOTE: Technology readiness does not imply space mission suitability.

TABLE 2-1. SUMMARY ANALYSIS OF POWER SOURCE ALTERNATIVES FOR THE ULYSSES MISSION (Continued)

| POWER SOURCE | TECHNOLOGY READINESS+/ SUBSYSTEM APPLICATION | MASS (kg)* | SPACECRAFT ADAPTATION | OTHER COMMENTS |
|---|---|---|---|---|
| II. ISOTOPIC | | | | |
| 1. RTG | | | | |
| a. Current | Now | 47 | None | Power level decays; proven technology, mission tested, very lightweight. |
| b. Advanced (MOD-RTG) | 1996/ 2000 | 32 | Minimum Modifications | Power level decays; modular design; reduced amount of Plutonium dioxide. |
| c. Advanced Material RTG | 1998/ 2003 | 16 | Minimum Modifications | Will compete with APSA. |
| 2. AMTEC | 2000/ 2005 | 13 | Modifications necessary to operate in zero gravity environment | Laboratory scale. Flight experiment in late 1990s. |
| 3. TEC | 1997/ 2002 | 13 | Attitude control | Scaling would be an issues. Laboratory scale based on Closed Brayton and Rankine Cycles; component life tests in 1998. The program has recently been terminated by DOE. |

KEY: AMTEC - Alkali Metal Thermoelectric Converter
TEC - Turbine Energy Conversion

+Does not account for time required for power system construction and spacecraft adaptation

*Assumptions - 250W at Jupiter, 5AU from Sun
- 5 year mission, continuous 250 W requirement
- Excludes additional mass for propulsion or structural requirements, for example, for the rigid array, the additional mass would be 500 kg.

Source: JPL 1989

only in the preliminary design phases. Therefore, these systems cannot be considered for use to power a spacecraft on missions such as Ulysses for any launch prior to 2000.

2.2.4.3 Radioisotope Thermoelectric Generator (RTG)

The RTG provided by the U.S. Department of Energy (DOE) to NASA for use on the Ulysses spacecraft uses the general purpose heat source (GPHS) as its source of energy. The GPHS is the culmination of almost 25 years of design evolution of heat source technology. The RTG (see Figure 2-3) is designed to provide a minimum of about 284 Watts at the beginning of the Ulysses mission. RTGs have been used on 22 previous U.S. space missions. These applications have included some of the Nation's most impressive successes, including Voyager, Pioneer, Viking, and all but the first of the manned Apollo landings on the Moon.

The RTG consists of a heat source and a thermoelectric converter that converts heat into electricity. The RTG heat source consists of a stacked column of 18 individual modules containing a total of 10.75 kg (23.7 lbs) of plutonium dioxide* fuel (DOE 1990a). The plutonium dioxide is basically a ceramic material with a density of 11.5 grams/cm$^3$ and a molecular weight of 270. Each GPHS module contains one graphite block, called an aeroshell, that encases two graphite cylinders called graphite impact shells (see Figure 2-4). Each cylinder contains two pellets of plutonium dioxide encased in iridium/tungsten alloy metal; i.e., two fueled clads. Each clad contains 0.15 kg (0.33 lbs) of plutonium dioxide fuel. The graphite blocks provide protection against atmospheric heating and subsequent release of the plutonium dioxide in the event that the modules are released in an accident and fall back to Earth. The graphite cylinders provide protection from ground or debris impacts in the event of an accident. The iridium/ tungsten metal contains the fuel and provides an additional layer of protection. The plutonium dioxide generates heat by the natural radioactive decay largely of the Pu-238 isotope. Table 2-2 provides a breakdown and isotopic composition of the 10.75 kg (23.7 lbs) of plutonium dioxide used to manufacture an RTG.

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* Plutonium is radioactive element 94. It can exist in a number of isotopic forms, from Pu-232 to Pu-246. Isotopes of an element have different atomic weights (e.g., 238, 239, etc.) but have the same or very similar chemical characteristics. The isotope, Pu-238, forms the basis for the fuel in an RTG, while Pu-239 is the weapons-grade isotope. Plutonium-239 comes from neutron capture by naturally occurring uranium-238, while plutonium-238 comes from the neutron bombardment of neptunium-237. Plutonium-238 decays with an 87.7 year half-life to form naturally occurring Uranium-234. The curie content, radioactive half-lives, specific activity of each of the plutonium radioisotopes, and the weight percent of plutonium in the Ulysses RTG is shown in Table 2-2.

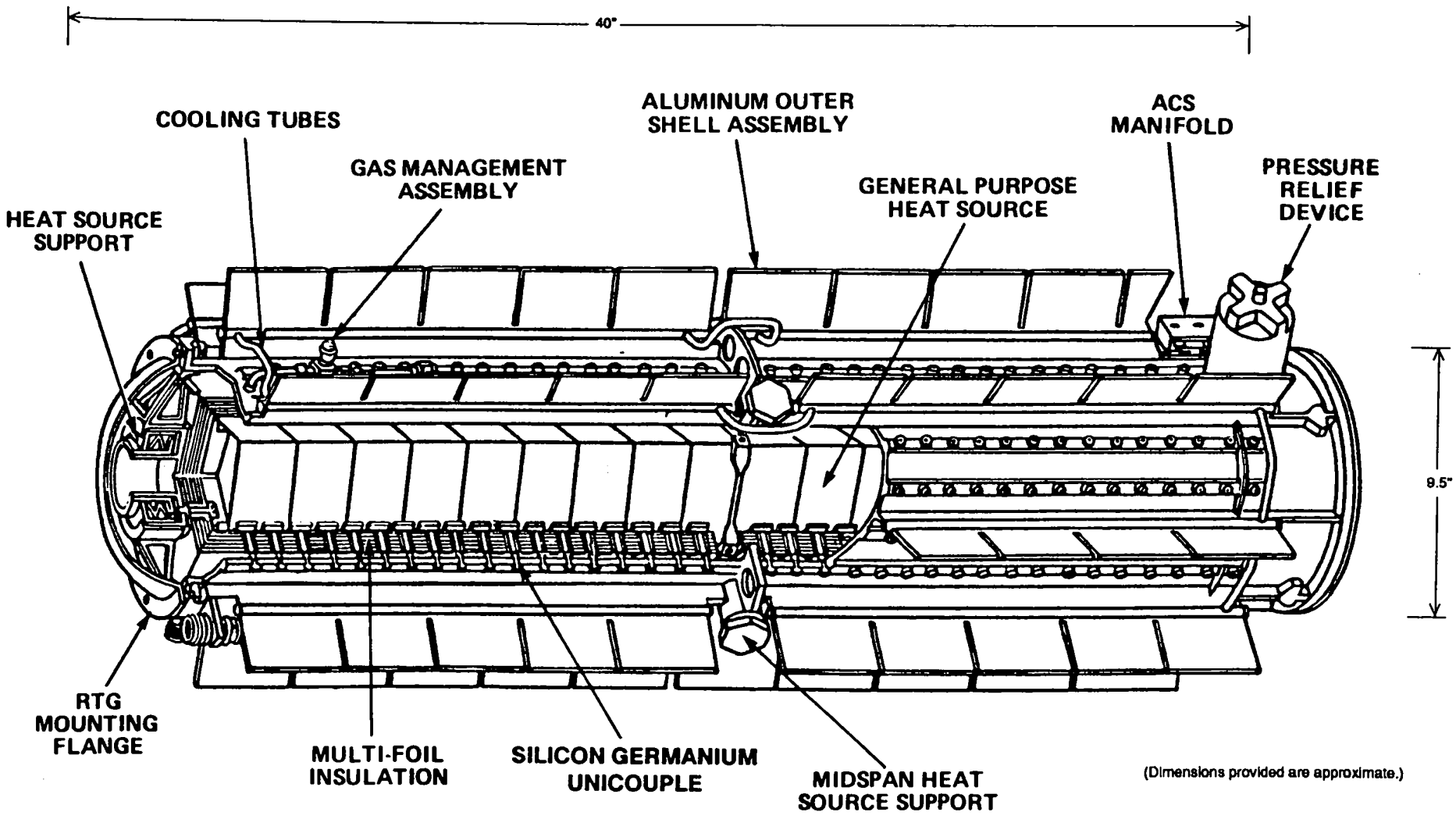



FIGURE 2-3. DIAGRAM OF RTG ASSEMBLY

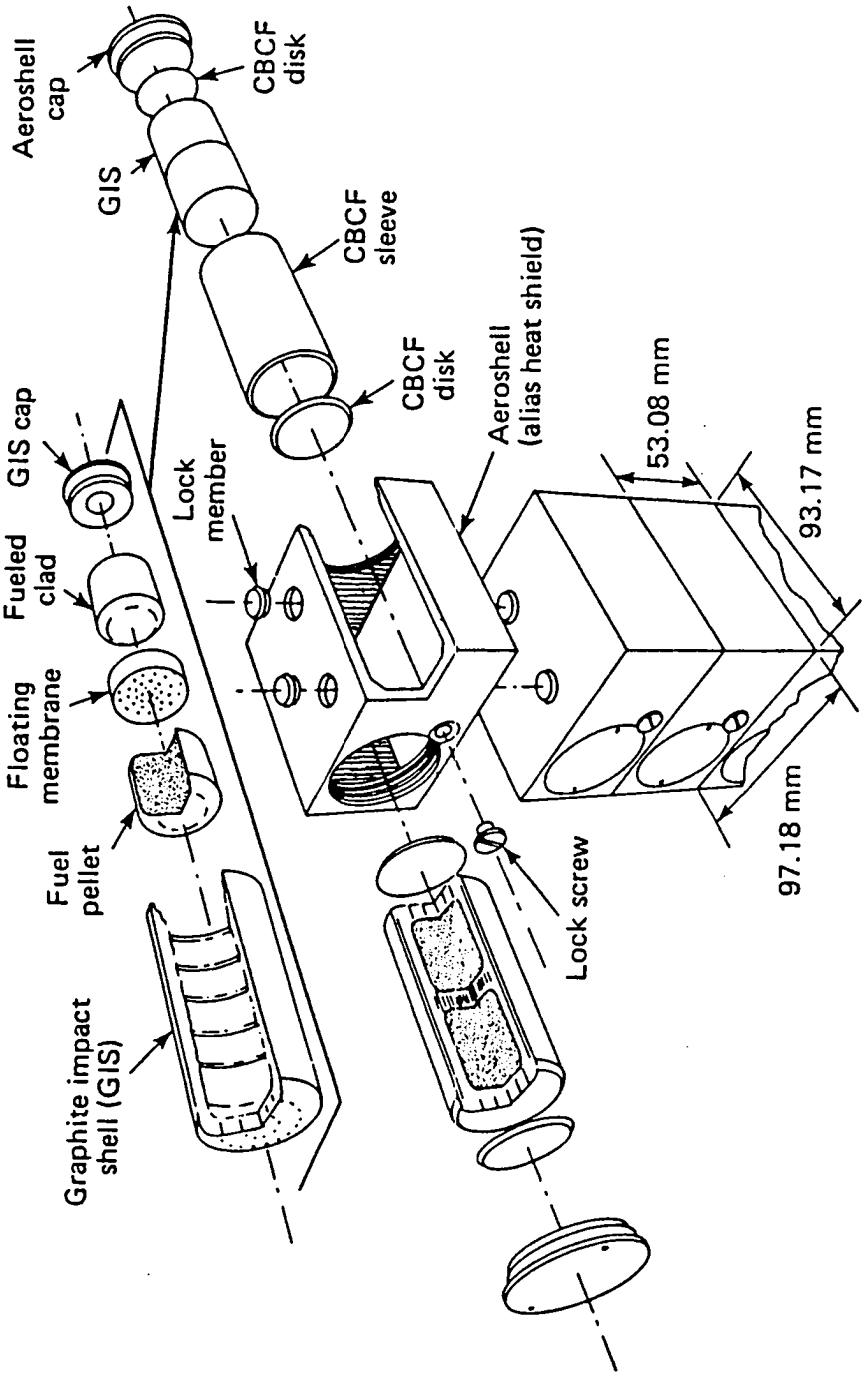



FIGURE 2-4. DIAGRAM OF GENERAL PURPOSE HEAT SOURCE

TABLE 2-2. CHARACTERISTICS AND ISOTOPIC COMPOSITION OF RTG FUEL

| Plutonium Isotope | Weight Percent at Manufacture | Half-Life (Years) | Specific radioactivity (Curies/gram of plutonium) | Total Curies (10/90)* |
|---|---|---|---|---|
| 236 | $5.27 \times 10^{-5}$ | 2.85 | 532 | 0.4 |
| 238 | *85.03 | 87.7 | 17.1 | 130,000 |
| 239 | 12.85 | 24,100 | 0.0621 | 75.5 |
| 240 | 1.70 | 6,560 | 0.227 | 36.4 |
| 241 | 0.35 | 14.4 | 103.2 | 2,360 |
| 242 | 0.08 | 376,000 | 0.00393 | <0.1 |
| Other radioisotopes | 0.11 | -- | -- | 3.6 |
| TOTALS | 100% | | | 132,500 |

* Based on computation of isotopic composition by Mound Laboratory for the launch date in October 1990. The radioisotopic fuel for the Ulysses RTG is a mixture of plutonium dioxide ($PuO_2$) containing 85 percent (plus or minus 1 percent) Pu-238 and totalling 10,754 grams (Campbell 1989).

The DOE safety philosophy for the design of the RTG requires containment or immobilization of the plutonium fuel to the maximum extent possible during all mission phases, including ground handling, launch, and unplanned events such as reentry, impact, and post-impact situations. Safety is a principal engineering design goal of the heat source. The safety-related design goals are to: 1) contain or immobilize the fuel to the maximum extent possible under normal and accident environments, and 2) ensure compatibility with the power generation system. The following is a brief summary of relevant safety environments and the GPHS response to testing (also see additional data available in DOE 1989b):

- Explosions: Fueled clads contained in GPHS modules and intact RTGs were shown to survive overpressure of 2,210 psi without any release; bare fueled clads withstood pressures of 1,070 psi without breaching.

- Solid Propellant Fires: Bare fueled clads and clads contained in the Graphite Impact Shell (GIS) were shown to survive in solid propellant fires (i.e., temperature calculated at 2,360°C or 4,280°F, DOE 1990f), without fuel release. [Liquid propellant fires, which reach a lower temperature than solid propellants, would not damage fueled clads contained in a GIS (DOE 1990b).]

- High Velocity Fragments: Tests with bare fueled clad exposed to small high velocity projectiles indicate that, given the protection afforded by the RTG case and the GPHS module, projectiles of this type will not result in damage to the clads. Further tests, representative of Solid Rocket Booster (SRB) fragment impacts (1/2 inch thick steel), indicate that the RTG will survive face-on fragment impacts at a velocity up to 212 m/s (695 f/s) with no release of fuel; edge-on fragment impacts at 95 m/s (312 f/s) breached only the leading clads of the GPHS module impacted.

- Reentry: GPHS modules survive Earth-escape-velocity-reentry ablation and thermal stress with wide margins.

- Earth Impact: GPHS modules were designed to survive impact on hard surfaces (granite/steel/concrete) at terminal velocity (maximum speed reached by falling object) of 53 m/s (172 f/s). Test results show no failures of clads against sand up to 250 m/s (820 f/s), no clad failures against concrete at terminal velocity, and small releases against steel or granite at terminal velocity.

The design features for the GPHS incorporate many safety-related considerations. The fuel used in the GPHS design is plutonium-238 dioxide, high-fired and hot-pressed into 62.5 Watt capacity ceramic fuel pellets. In this form, plutonium dioxide is virtually insoluble in ground or sea water should such exposure occur. In fact, GPHS modules survive water impact and will resist significant fuel release for virtually unlimited periods when submerged.

The primary protective material used to encapsulate and immobilize the fuel is an alloy of iridium. Iridium is a unique noble metal found in deposits of gold and platinum. It is compatible with the fuel material to over 1,500°C (2,700°F), resists oxidation in air to 1,000°C (1,800°F), and melts at 2,447°C (4,437°F). Each clad also contains a vent designed to release the helium generated by the fuel alpha particle decay and to prevent the release of the plutonium dioxide.

The graphitic materials in the GPHS perform several functions. The primary function is to provide reentry protection for the fueled clads through the use of the aeroshell. A second major function is impact protection. This is accomplished by both the aeroshell and the impact shell. The impact shell also serves as a redundant reentry aeroshell. The third function is to provide a mounting structure for the clads to survive normal ground handling and launch dynamic loads. The material used for the aeroshell and impact shell is called fine weave, pierced fabric (FWPF). FWPF is a carbon-carbon composite material woven with high-strength graphite fibers in three perpendicular directions. Upon impregnation and graphitization, the material has an extremely high thermal stress resistance as required for reentry protection. FWPF has a very fine structure that results in uniform ablation characteristics leading to high confidence in ablation margins. This material, used primarily by the Air Force for missile nose cones, is one of the best available for reentry applications.

The GPHS deliberately was designed to be composed of small, modular units so that reentry heating and terminal velocity would be lower than they were for previous heat sources. A modular heat source tends to minimize the amount of fuel that can be postulated to be released in a given accident. For example, for a high-velocity fragment impact resulting from a severe explosion that penetrates the GPHS, only a few of the fueled clads would be expected to release fuel. This is an improvement over earlier heat source designs.

Overall, the DOE has spent 9 years in engineering, fabricating, and safety and environmental testing of the GPHS, building on the experience gained from previous heat source development programs and a data base that has accumulated since the 1950s. Test results have demonstrated the present design exceeds the already stringent safety standards achieved by earlier heat source models.

The RTG systems also have a proven record of reliability and are the only power source available that satisfies all of the performance criteria associated with the Ulysses mission.

#### 2.2.4.4 RTG Performance History

RTGs have been used in the U.S. space program since 1961 and have powered some of this Nation's most successful missions including the Apollo Lunar Surface Experiment Packages (ALSEPs), the Viking Lander on Mars, Pioneers 10 and 11 and Voyagers 1 and 2. In all, there have been 40 RTGs involved in 22 previous U.S. space missions (see Table 2-3).

## TABLE 2-3. UNITED STATES SPACECRAFT LAUNCHES INVOLVING NUCLEAR POWER SOURCES

| Power Source (and Number of Sources) | Spacecraft | Mission Type | Launch Date | Status | Power System Inventory of Pu at Launch (Curies) |
|---|---|---|---|---|---|
| SNAP-3B7 (1) | TRANSIT 4A | Navigational | 29 Jun 61 | Currently in orbit. | 1,500 - 1,600 |
| SNAP-3B8 (1) | TRANSIT 4B | Navigational | 15 Nov 61 | Currently in orbit. | 1,500 - 1,600 |
| SNAP-9A (1) | TRANSIT 5BN-1 | Navigational | 28 Sep 63 | Currently in orbit. | 17,000 |
| SNAP-9A (1) | TRANSIT 5BN-2 | Navigational | 05 Dec 63 | Currently in orbit. | 17,000 |
| SNAP-9A (1) | TRANSIT 5BN-3 | Navigational | 21 Apr 64 | Mission aborted; burned up on reentry as designed. | 17,000 |
| SNAP-10A (Reactor) | SNAPSHOT | Experimental | 03 Apr 65 | Successfully achieved orbit; after 43 days in orbit, was shut down. | N/A |
| SNAP-19B2 (2) | NIMBUS-B-1 | Meteorological | 18 May 68 | Mission aborted; heat source retrieved. | 34,400 |
| SNAP-19B3 (2) | NIMBUS III | Meteorological | 14 Apr 69 | Currently in orbit. | 37,000 |
| SNAP-27 (1) | APOLLO 12 | Lunar | 14 Nov 69 | Station shut down. | 44,500 |
| SNAP-27 (1) | APOLLO 13 | Lunar | 11 Apr 70 | Mission aborted on way to moon. Heat source fell in Pacific Ocean. | 44,500 |
| SNAP-27 (1) | APOLLO 14 | Lunar | 31 Jan 71 | Station shut down. | 44,500 |
| SNAP-27 (1) | APOLLO 15 | Lunar | 26 Jul 71 | Station shut down. | 44,500 |
| SNAP-19 (4) | PIONEER 10 | Planetary | 02 Mar 72 | Successfully operated to Jupiter and beyond. | 80,000 |
| SNAP-27 (1) | APOLLO 16 | Lunar | 16 Apr 72 | Station shut down. | 44,500 |
| TRANSIT-RTG (1) | "TRANSIT" (TRIAD-01-1X) | Navigational | 02 Sep 72 | Currently in orbit. | 24,000 |
| SNAP-27 (1) | APOLLO 17 | Lunar | 07 Dec 72 | Successfully placed on lunar surface. | 44,500 |
| SNAP-19 (4) | PIONEER 11 | Planetary | 05 Apr 73 | Successfully operated to Jupiter and Saturn and beyond. | 80,000 |
| SNAP-19 (2) | VIKING 1 | Mars | 02 Aug 75 | Programmed to operate until 1994. | ~40,980 |
| SNAP-19 (2) | VIKING 2 | Mars | 09 Sep 75 | Lander shut down. | ~40,980 |
| MHW-RTG (4) | LES 8/9 | Communications | 14 Mar 76 | Currently in orbit. | 318,800 |
| MHW-RTG (3) | VOYAGER 2 | Planetary | 20 Aug 77 | Successfully operated to Jupiter and beyond. | 240,000 |
| MHW-RTG (3) | VOYAGER 1 | Planetary | 05 Sep 77 | Successfully operated to Jupiter and beyond. | 240,000 |
| GPHS-RTG (2) | GALILEO | Planetary | 17 Oct 89 | Successfully operating on flight to Jupiter. | 264,400 |

Source: DOE 1980, NASA 1989a

Three U.S. spacecraft powered by RTGs have failed to achieve their intended mission and two have involved accidental reentries. In each case the malfunction was neither caused by nor related to the RTG, and in fact, the RTGs on these spacecraft performed entirely as intended. The RTGs on each of these spacecraft responded to the reentry environment as designed.

Early RTG models carried only a few pounds of radioactive material and were built to burn up at high altitude during accidental reentry. When the Navy's Transit-5BN-3 navigational satellite malfunctioned in 1964 and failed to achieve orbit, the RTG on board met the design criteria by burning up in the upper atmosphere upon reentry. A total of 17,000 curies were dispersed high in the stratosphere. Local dose levels were small compared to background radiation (see DOE 1980).

Since 1964, RTGs have been designed to contain or immobilize their plutonium fuel to the maximum extent possible during all mission phases regardless of the accident environment. This design philosophy has performed flawlessly in two subsequent mission failures where RTGs were present. In May 1968, two SNAP 19B2 RTGs landed intact in the Pacific Ocean after a Nimbus B weather satellite failed to reach orbit, and the fuel was recovered. Even though the recovery operation took 5 months, there was no release of plutonium. In April 1970, the Apollo 13 lunar module reentered the atmosphere and its SNAP 27 RTG heat source, which was jettisoned, fell intact into the 20,000 feet deep Tonga Trench in the Pacific Ocean. The corrosion resistant materials of the RTG are expected to prevent release of the fuel for a period of time equal to 10 half-lives of the Pu-238 fuel or about 870 years (DOE 1980).

### 2.2.5 Spacecraft Propulsion Subsystem

The Ulysses spacecraft propulsion subsystem uses hydrazine monopropellant, which spontaneously ignites by catalytic decomposition within the propulsion subsystem thrust chambers. This propellant is the most efficient, space-storable (i.e., can be stored without any special temperature control equipment) propellant available for the mission, and the use of any other space-storable propellants would result in unacceptable weight increases for the spacecraft. The propellant tank of the spacecraft is loaded at the KSC. The Ulysses spacecraft carries 34 kgs (74 lbs) of hydrazine. NASA has prescribed specifications concerning the storage and handling of this propellant.

### 2.2.6 STS/IUS/PAM-S Launch Configuration

The STS/IUS/PAM-S launch configuration consists of the STS Shuttle launch vehicle to achieve Earth orbit, and a two-stage IUS supplemented with a PAM-S third stage for use to propel the spacecraft on its interplanetary trajectory. The IUS/PAM-S and attached spacecraft are carried into Earth orbit in the Shuttle cargo bay. Figure 2-5 illustrates the configuration of the IUS/PAM-S and spacecraft in the Shuttle cargo bay for launch. Figure 2-6 shows the configuration of the spacecraft assembled with the IUS/PAM-S. The selection of the STS/IUS/PAM-S launch vehicles was addressed in the Tier I FEIS (NASA 1988a).

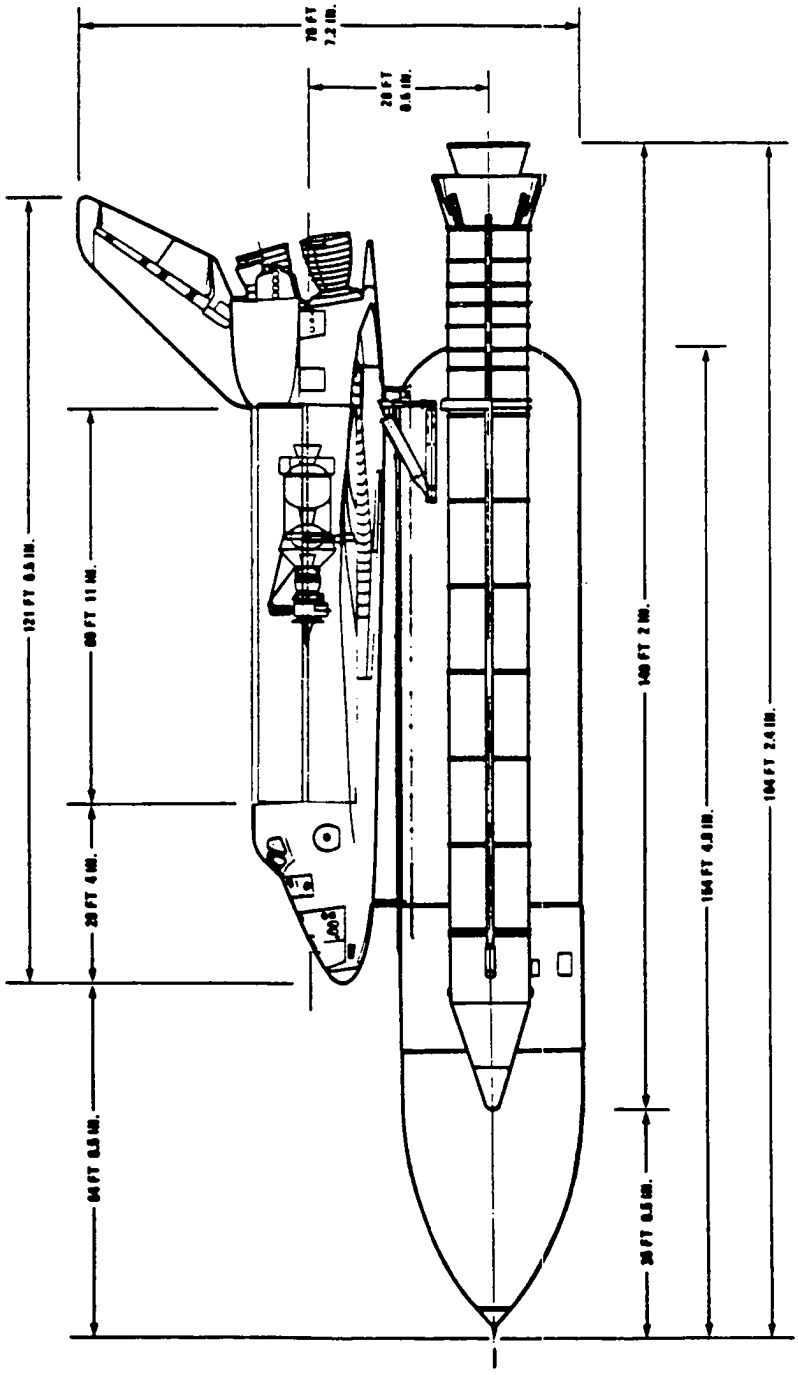


FIGURE 2-5. DIAGRAM SHOWING CONFIGURATION OF ULYSSES SPACECRAFT IN SHUTTLE BAY FOR LAUNCH

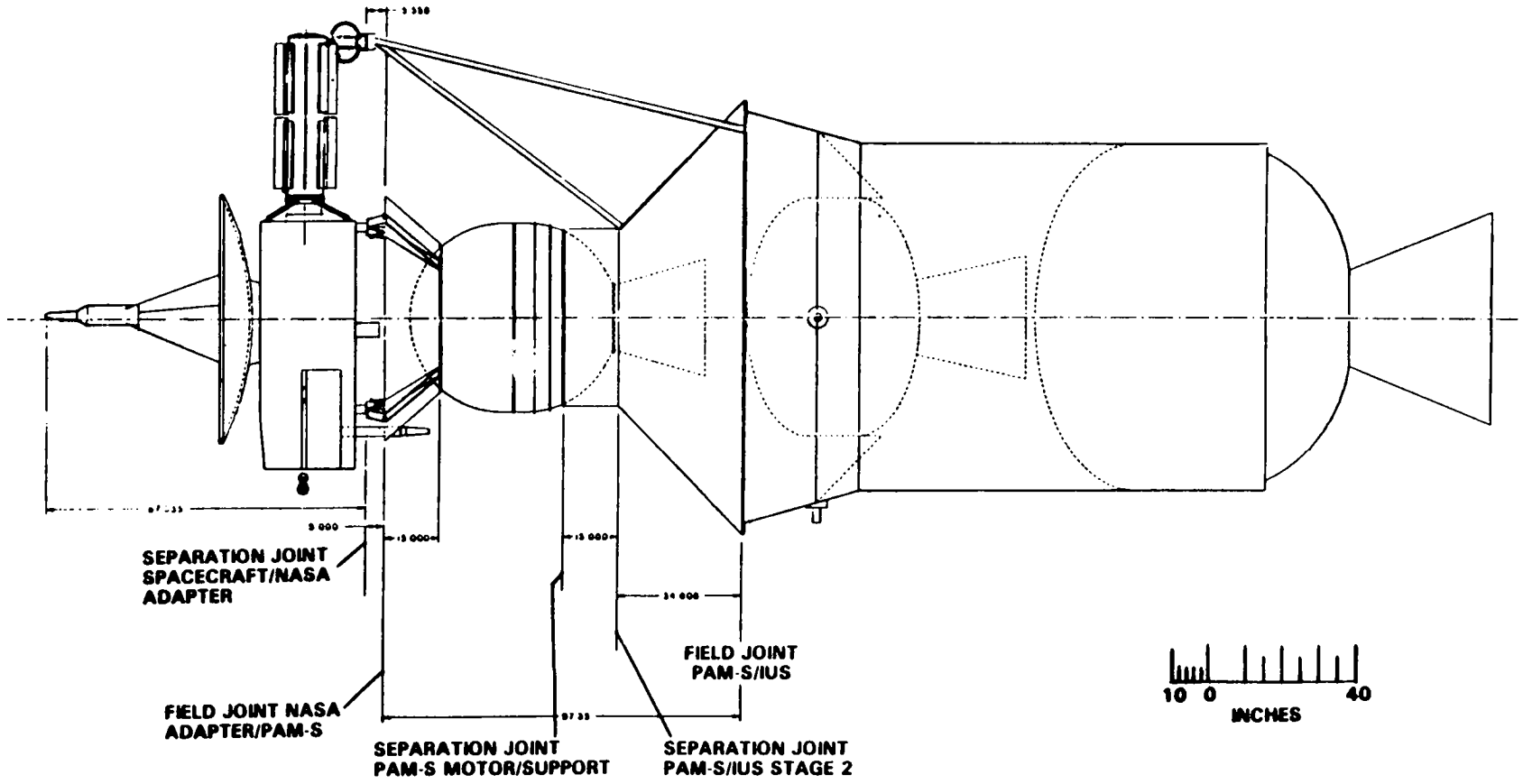



FIGURE 2-6. CONFIGURATION OF ULYSSES SPACECRAFT ASSEMBLED WITH THE IUS/PAM-S

The STS consists of a piloted reusable vehicle (the Shuttle) mounted on a non-reusable External Tank (ET) containing liquid hydrogen and oxygen propellants and two Solid Rocket Boosters (SRBs). The Shuttle has three main rocket engines and a cargo bay 60 feet long by 15 feet in diameter (NASA 1978).

At launch, both SRBs and the Shuttle's rocket engines burn simultaneously. After approximately 128 seconds into the flight, the spent SRB casings are jettisoned and subsequently recovered from the ocean. The ET is jettisoned before the Space Shuttle goes into Earth orbit. The Shuttle's Orbital Maneuvering System (OMS) is then used to propel the Shuttle into the desired Earth orbit. Once the IUS with its payload is deployed, the OMS is used to take the Shuttle out of orbit. The Shuttle is piloted back to Earth for an unpowered landing. A more detailed description of the Shuttle can be found in Appendix B of the Galileo Tier 2 EIS (NASA 1989a) and the Shuttle EIS (NASA 1978).

Once deployed from the Shuttle, an "upper stage" propels the spacecraft into higher Earth orbits or to Earth-escape velocities needed for planetary missions. The upper stage for use on the Ulysses mission is a two-stage solid fuel rocket IUS supplemented with the solid fuel PAM-S booster.

### 2.2.7 Range Safety Considerations

#### 2.2.7.1 General

The Eastern Space and Missile Center (ESMC) at Patrick Air Force Base is responsible for range safety for any NASA/KSC space launch. The goal of Range Safety is to control and contain the flight of all vehicles, precluding the impact of intact vehicles or pieces thereof in a location that could endanger human life or damage property. Although the risk can never be completely eliminated, Range Safety attempts to minimize the risks while not unduly restricting the probability of mission success.

Each STS flight vehicle carries a Range Safety Flight Termination System (FTS). When activated by an electronic signal sent by the Range Safety Officer, the FTS activates explosive charges designed to destroy the vehicle. The STS FTS enables the Range Safety Officer to destroy the SRBs and ET if the flight trajectory deviates unacceptably from the planned course.

#### 2.2.7.2 Electromagnetic Hazard Conditions

Various potential electromagnetic hazard conditions exist for aerospace launch vehicles and payloads. These include:

- Lightning
- Powerful electromagnetic transmitters (radars, radio transmitters, etc.) also referred to as the electromagnetic environment (EME)

- Charging effects (triboelectric charging effects and resultant electrostatic discharges)

- Electromagnetic emissions of the vehicle, itself.

These conditions are a design concern for NASA, both with respect to the total vehicle as well as ordnance (explosives and explosive detonators/fuses), fuels, exposed skins of the vehicle, and critical electronic systems which must have highly reliable operations. These special concerns are well-known and have been given specific names by the specialists who address these issues. These include:

- Electromagnetic radiation on ordnance

- Electromagnetic radiation on fuels

- Electrostatic Discharges (ESD)

- Electromagnetic Interference (EMI).

A large body of technical literature exists on these subjects and has been used by NASA in designing safeguards. To better understand these hazards, a brief description of these conditions and hazards is presented in the following paragraphs.

Lightning

Lightning is the well-known electrical discharge typically occurring in thunderstorms. Large electrical current which can approach several hundred thousand amperes can flow from cloud to cloud or from cloud to ground in a fraction of a second. If a vehicle is in the vicinity of a thunderstorm, there is a chance that all, or some, of the electrical current can flow into or through the vehicle. This is mitigated both by avoiding flight through thunderstorms, and through special vehicle designs to prevent the serious effects of lightning strikes.

The conditions whereby lightning is likely to occur can be monitored by measuring the local electric fields around the vehicle. Large electric fields indicate the presence of large amounts of electrical charge present in the overhead clouds. Since lightning results from an electrical discharge built up in these clouds, these fields are an indicator of the likelihood of lightning activity in the area. NASA conducts monitoring of electrical fields at and around KSC during launch times.

NASA employs rigorous design specifications and testing of systems (e.g., Military Standard MIL-B-05087B, "Bonding, Electrical, and Lightning Protection for Aerospace Systems," 30 July 1954 as amended 31 August 1970) and subsystems to mitigate the potential effects of lightning strikes, and has strict meteorological criteria for launch of the Shuttle to avoid subjecting the vehicle and its payload to unacceptable environments. The meteorological launch criteria are summarized in NASA (1988b). In addition to visibility, ambient temperature and surface wind restrictions, there are severe-weather

restrictions. These restrictions are strictly enforced, and address the maximum weather-induced ground-level (launch and landing site) and flight path electrical fields acceptable for launch (1 kilovolt/meter). There are no plans by NASA to relax any Launch Commit Criteria (LCC).

Electromagnetic Environment

The electromagnetic radiation found in our environment has, in recent years, become stronger and more prevalent. This is due primarily to the increased number of radar systems and other radio transmitters around the world.

Response of the Shuttle and payload systems to the electromagnetic environment is controlled through two means: control of the radiated power of transmitters in the immediate vicinity of the vehicle; and use of proven, effective electrical system design techniques. These techniques include shielding, controlling any naturally occurring electromagnetic leaks in the shields, proper electrical bonding and grounding, filtering out and/or suppressing undesired effects in the electrical system, and using special signal computer "software" which recognizes interference and works around it. Techniques used by NASA to qualify systems to this environment are prescribed in MIL-STD-B-5087B and NASA custom-tailored versions of military standards 461 and 462. In addition, the effective radiated power levels of ground emitters at the Eastern Test Range and at the Shuttle landing sites (e.g., Edwards Air Force Base), and their associated electromagnetic environments are rigidly controlled to yield an electromagnetic field within NASA Program Requirements Documents, during both launch and landing of the Shuttle.

Charging Effects

Electrical charging effects can be associated with picking up an electrical charge which can be suddenly discharged when the person touches a metallic object. Such discharges are known as electrostatic discharges or ESD. These effects are also known as triboelectric effects from the Greek word "tribo" which means "to rub." The effect results from rubbing or touching and parting two dissimilar materials together.

Charging can be produced by space vehicles flying through dust, and clouds which are composed of water droplets. Such discharges can lead to electrical interference (EMI).

Techniques to mitigate the effects of ESD are well-known and generally depend upon proper bonding and grounding of the external and internal vehicle assemblies and parts. This prevents large differential charges from building up between surfaces and arc discharging. Most vehicle charge resides on external and payload bay surfaces. NASA uses Class S bonding as prescribed by MIL-STD-B-5087B to preclude electrostatic discharging effects.

## Electromagnetic Compatibility

Electromagnetic compatability (EMC) is defined as the condition which prevails when telecommunication (communication/electronic) equipment are collectively performing their individual designed functions in a common electromagnetic environment without causing or suffering unacceptable degradation due to electromagnetic interference to or from other equipment and systems in the same environment.

All payload manufacturers are required by NASA to conduct EMC testing of their unintentional radiated and conducted emissions. Test data are reviewed by NASA against strict specifications. When a piece of equipment, system or subsystem is found to have an inadequate Electromagnetic Interference Safety Margin (EISM), appropriate action is taken, (e.g., redesign, substitution, or additional protection). The concerns for payload to payload, payload to Shuttle, and Shuttle to payload radiated emissions are thus thoroughly addressed and resolved before flight readiness is attained.

Many well-known techniques are available to achieve electromagnetic compatibility. The procedures used by NASA to achieve this operational compatibility are prescribed in Military Standard, Mil-E-6051D, "Electromagnetic Compatibility Requirements System," dated 5 July 1968, and supporting procedures. All Shuttle avionics equipment have been EMC qualified per NASA, USAF, and contractor specifications. All EMC reports are presented and reviewed at a series of cargo integration reviews involving all contractor and government elements. Problems are resolved during these reviews. In addition, all payload and Shuttle EMC requirements are in constant review and are updated whenever new information becomes available.

## Ordnance and Fuels

Ordnance and Fuels represent special concerns. Electrostatic and electrodynamic energy can potentially trigger fuel ignition or special ordnance known as electroexplosive devices or EEDs. This can lead to undesired ordnance ignition and possibly equipment separations. Due to the fuel containment design, it takes rather substantial amounts of energy from the RF environment or electrostatic discharge to trigger the liquid and solid fuels.

Techniques used to protect such ordnance and fuels from lightning, the electromagnetic environment, and discharges are well-known and used in many aircraft and missile systems. These techniques, used by NASA, are prescribed in Military Standard 1576 ("United States Air Force Electroexplosives Subsystems Safety Requirements and Test Methods for Space Systems"), and Mil-E-6051D which includes "provisions to protect ordnance subsystems from inadvertent ignition or dudding caused by any form of electromagnetic or electrostatic energy." Special designs of fuel tanks and fuel delivery subsystems are used to prevent ordnance ignition.

On the Ulysses spacecraft, for example, there are three types of such devices: NASA Standard Initiators, Dimple Motors and Cable Cutters. These are low-yield devices that present no threat to the Ulysses RTG. All three

are designed to specifications which require an inability to "fire" when 1 watt or 1 ampere is applied to the device. These devices are controlled by 10 redundant firing circuits which are inhibited during launch by a separation switch. The switch is armed after separation of the spacecraft from the IUS/PAM-S.

Electromagnetic interference is also a design consideration with respect to the pyrotechnic devices on the IUS and the PAM-S. These devices and the firing circuits are designed to perform to Military Standard 1512 - "Electro-explosive Systems, Electrically Initiated, Design Requirements, and Test Methods for Space Transportation Systems (STS) Payloads." The firing circuits of the devices on the IUS are not armed until just prior to ignition of the solid rocket motor which occurs at least 45 minutes after deployment from the Shuttle. The firing circuits on the PAM-S are, in turn, armed by commands from the IUS. All spacecraft and upper stages that fly on the Shuttle are required to undergo an intensive review of their susceptibility to electromagnetic radiation in accordance with strict NASA specifications. Hazard reports must be prepared and closed out for devices that do not meet the specifications. There have been no such reports to date for the Ulysses spacecraft.

The pyrotechnic devices on the Shuttle reflect the design and operational experience gained from the entire U.S. launch vehicle/spacecraft history to date. Shuttle design requires that three separate, distinct electrical signals in the proper sequence, be received to initiate firing outputs from the pyrotechnic initiator controllers. Circuit designs have been developed to ensure that shorts to either ground or power will not cause premature firing of these devices. In addition, the explosive materials in these devices have been chosen after extensive material test programs and development testing under flight conditions to ensure that they will not auto-ignite in the flight environment which includes electromagnetic radiation.

### 2.2.8 Mission Contingencies

#### 2.2.8.1 Intact Aborts

The STS vehicle has an intact abort capability in the event specific failures (e.g., engine loss, electrical/auxiliary power failure, etc.) occur during the early phases of launch. Intact abort is defined as safely returning the Shuttle crew and cargo to a suitable landing site. Five basic abort modes exist providing continuous intact abort capability during ascent to orbit: Return To Launch Site, Transoceanic Abort Landing, Abort-Once-Around, Abort-To-Orbit, and Abort-From-Orbit. These intact, safe abort capabilities enable protection of the crew and the payload after anomalies and may avoid loss of missions. Manned systems offer an abort capability that does not exist on expendable launch vehicles that is unique to this type of launch vehicle. The planned U.S. and tentative foreign intact abort landing sites for the Ulysses mission are as follows.

| Type of Abort | Site |
|---|---|
| Return To Launch Site | Kennedy Space Center |

| | |
|---|---|
| Transoceanic Abort Landing | Ben Guerir, Morroco<br>Alternate -<br>Moron, Spain<br>Banjeel, Gambia<br>Zaragoso, Spain<br>Dakar, Senegal |
| Abort-Once-Around | Edwards Air Force Base, CA<br>Alternates -<br>White Sands Space Harbour, NM<br>Kennedy Space Center |
| Abort-From-Orbit | Edwards Air Force Base, CA<br>Alternates -<br>White Sands Space Harbour, NM<br>Kennedy Space Center |

2.2.8.2 Contingency Aborts

Contingency abort conditions are defined when two of the three Shuttle main engines fail prior to single engine Transoceanic Abort Landing capability or when all three engines fail prior to achieving an Abort-Once-Around capability. These conditions result in a crew bailout and subsequent ocean impact of the Shuttle.

There is a possibility of performing a Return To Launch Site abort if two or three main engines fail within 20 seconds after launch or a Transoceanic Abort Landing if three engines fail during the last 30 seconds of powered flight. During the remainder of the ascent phase; however, two or three main engine failures result in a contingency abort scenario.

2.2.8.3 On-Orbit Spacecraft Aborts

It is also possible to abort the Ulysses mission if problems occur after deployment of the Ulysses/IUS/PAM-S from the STS Shuttle up to the point of IUS ignition. In the event any upper stage motor fails to ignite, the IUS/PAM-S will continue to sequence through subsequent burns and spacecraft separation, assuming the IUS sequencing continues to function. If the IUS attitude control is operating, then the nominal IUS stage 1 and stage 2 burns will leave the PAM-S/spacecraft on an escape trajectory without the PAM-S burns. If either or both IUS stages were not to burn, then the PAM-S burn alone would place the spacecraft on an escape trajectory.

The percent of anomalous burns occurring in one of the three stages in the IUS/PAM-S assembly that still achieve an escape trajectory are 34, 58, and 99.6 percent for the IUS Stage 1, IUS Stage 2, and PAM-S, respectively. Overall 66 percent of the trajectories for which a single motor anomalous burn has occurred result in an escape trajectory (NASA 1988b).

## 2.3 ALTERNATIVES EVALUATED AND ELIMINATED FROM FURTHER CONSIDERATION

The only launch configuration other than the STS/IUS/PAM-S potentially capable of achieving the launch requirements of the Ulysses mission is the Titan IV/IUS/PAM-S. The Titan IV is a military launch vehicle which is

procured by the U.S. Air Force. The Air Force has informed NASA that a Titan IV launch vehicle will not be available to NASA before 1995 (Mahon 1990). Therefore, the STS/IUS/PAM-S launch configuration is the only feasible launch configuration available to NASA for the Ulysses mission.

Since the only launch configuration available is the STS/IUS/PAM-S, and since environmental impacts of an STS/IUS/PAM-S launch are the same whenever the launch occurs, the delay alternatives will have the same environmental impacts as the proposed action. Furthermore, the discussion of alternative power systems (Section 2.2.4) also indicated that the proposed power system is the only feasible alternative for achieving the Ulysses mission with currently available launch systems. Therefore, as neither alternative power systems nor alternative launch configurations will be available before the late 1990s to achieve this mission, and delays involving the same systems as proposed would not yield different impacts even if undertaken at a later date, this EIS does not consider a delay of the launch as a separate alternative.

The Ulysses mission has the objective of collecting data on the three-dimensional nature of the heliosphere. A key element of that objective is to relate the behavior of the solar wind and solar magnetic field lines close to the Sun (as observed by Ulysses) with their behavior in the outer solar system. With a launch of the Ulysses spacecraft in the 1990 or 1991 opportunity, the timing is such that the tracking and data collection systems of the Deep Space Network (DSN) will be capable of acquiring outer solar system data from the Pioneer 10 and 11 and Voyager 1 and 2 spacecraft in 1994, 1995, or 1996. It is estimated that the DSN could receive data from both of the Pioneer spacecraft until possibly as late as 1997 or 1998. However, with later launches of Ulysses, the continuing deterioration of the Pioneer spacecraft makes it unlikely that these spacecraft will be able to provide outer planet measurements. No alternative power system or launch vehicle will be available prior to 1995. So, for example, if the launch of Ulysses were delayed until 1995, then its solar passes would not occur until 1999 and 2000; therefore, outer solar system data from the Pioneers would be lost (see Section 1.3).

## 2.4 DESCRIPTION OF THE NO-ACTION ALTERNATIVE

The no-action alternative would result in the termination of this mission.

## 2.5 COMPARISON OF ALTERNATIVES

The criteria pertinent to a comparison of the proposed action with the no-action alternative are summarized in Table 2-4 and have been separated into those related to normal missions and those related to accidents.

### 2.5.1 Environmental Impacts of the Mission

#### 2.5.1.1 Environmental Impacts from Normal Mission

None of the alternatives, including the proposed action, are expected to result in any significant environmental impacts to the physical environment.

## TABLE 2-4. SUMMARY COMPARISON OF ALTERNATIVES

| PROGRAMMATIC CONSIDERATIONS | PROPOSED ACTION<br>STS/IUS/PAM-S<br>IN 1990<br>(AND 1991 BACKUP) | NO ACTION |
|---|---|---|
| **LAUNCH OPPORTUNITY** | | |
| Vehicle Availability | Firm Commitment | N/A |
| | Launch Pad 39-B on Discovery | N/A |
| Launch Period | | |
| - First Possible Launch Date | October 5, 1990 | N/A |
| - Length | 19 Days | N/A |
| Daily Launch Window | up to 120 Minutes | N/A |
| Mission Margins: | | |
| - Power | Adequate | N/A |
| - Propellant | Adequate | N/A |
| **SCIENCE RETURN** | | |
| Jupiter Arrival Date | February 1992 | None |
| High Solar Latitude Arrival Date | June 1994 | None |
| **SCIENCE PROGRAM** | Full Return Probable | No Substitute Mission Planned |
| **TOTAL ESTIMATED MISSION COST *** | $210 Million | Sunk Cost of $150 Million |
| **OTHER CONSIDERATIONS** | | |
| Supporting Facility Availability | Firm Commitment | Not Required |
| Personnel Availability | Project Team in Place | None |
| **SAFETY & ENVIRONMENTAL IMPACT** | | |
| Expected (Normal Launch) | | |
| • Land Use | No significant adverse impacts on non-launch related land uses. | No Effect |
| • Air Quality | Short-term degradation of air quality within launch cloud and near-field (about 1,600 feet from launch pad). No significant adverse impacts outside the near-field environment. Short term localized decrease in ozone, with rapid recovery. | No Effect |

* United States costs.

TABLE 2-4. SUMMARY COMPARISON OF ALTERNATIVES (Continued)

| SAFETY & ENVIRONMENTAL IMPACT | PROPOSED ACTION<br>STS/IUS/PAM-S<br>IN 1990<br>(AND 1991 BACKUP) | NO ACTION |
|---|---|---|
| • Sonic Boom | No sustained adverse impacts. | No Effect |
| • Hydrology and Water Quality | No significant adverse long-term impacts. Short-term increase in the acidity of nearby water impoundments. | No Effect |
| • Biological Systems | Short-term vegetation damage contributes to long-term decrease in species richness in near-field over time with Shuttle operations. Fish kills in near-by waterways possible with each Shuttle launch. No significant adverse effects outside the near-field | No Effect |
| • Endangered and Threatened Species | No impact. | No Effect |
| • Socioeconomic Factors | No significant adverse effects. Short-term economic benefits from tourism. | No Effect |
| Expected (Balance of Mission) | No significant adverse effects. | No Effect |
| Potential Accidents:* | | |
| Quantity of Plutonium Dioxide Released to the Biosphere in the Event of an Accident during Mission. | | |
| Launch Vicinity Accident Causing Release: | | |
| - Mean Values: 0 - 10 sec. | 65.6 Ci @ $3.36 \times 10^{-6}$ Probability | None |
| 11 - 20 sec. | 12 Ci @ $8.47 \times 10^{-7}$ Probability | |
| 21 - 70 sec. | 3.7 Ci @ $4.37 \times 10^{-7}$ Probability | |

* Based on information contained in the Final Safety Analysis (DOE 1990g) and Appendix C Report for the Ulysses mission.

TABLE 2-4 SUMMARY COMPARISON OF ALTERNATIVES (Continued)

| SAFETY & ENVIRONMENTAL IMPACT | PROPOSED ACTION<br>STS/IUS/PAM-S<br>IN 1990<br>(AND 1991 BACKUP) | NO ACTION |
|---|---|---|
| Lifetime Incremental Collective (Population) Dose in the Event of a Mission Accident-Total. | | |
| Launch Vicinity Accident Causing Release: | | |
| - Total Dose - Mean Values | | None |
| 0 - 10 sec. | 77.8 person rem | |
| 11 - 20 sec. | 12.4 person rem | |
| 21 - 70 sec. | 2.15 person rem | |
| - Total Dose-99 Percentile Value | | |
| 0 - 10 sec. | 457 person rem @ $3.36 \times 10^{-8}$ Probability | |
| 11 - 20 sec. | 157 person rem @ $8.47 \times 10^{-9}$ Probability | |
| 21 - 70 sec. | 29 person rem @ $4.37 \times 10^{-9}$ Probability | |
| Incremental Cancer Fatalities among Exposed Population in the Event of a Mission Accident. | | |
| Launch Vicinity Accident Causing Release: | | |
| - Cancer Fatalities-Mean Value | | None |
| Phase 1: 0 - 10 sec. | 0.04 | |
| 11 - 21 sec. | 0.01 | |
| 21 - 70 sec. | 0.00114 @ $1.1 \times 10^{-8}$ Probability | |
| - Cancer Fatalities-99 Percentile Value | | |
| Phase 1: 0 - 10 sec. | 0.12 | |
| 11 - 20 sec. | 0.06 | |
| 21 - 70 sec. | 0.00852 @ $4.37 \times 10^{-9}$ Probability | |
| Maximum Dose to the Individual: | | |
| - Mean Values | | |
| Phase 1: 0 - 10 sec. | 3.84 mrem | |
| 11 - 20 sec. | 1.64 mrem | |
| 21 - 70 sec. | 0.19 mrem | |
| Phase 2: | 4.67 mrem | |
| Phase 3: | 13.1 mrem | |
| Phase 4: | 13.1 mrem | |

TABLE 2-4. SUMMARY COMPARISON OF ALTERNATIVES (Continued)

| SAFETY & ENVIRONMENTAL IMPACT | PROPOSED ACTION<br>STS/IUS/PAM-S<br>IN 1990<br>(AND 1991 BACKUP) | NO ACTION |
|---|---|---|
| - 99 Percentile Value | | |
| Phase 1: 0 - 10 sec. | 22.6 mrem | |
| 11 - 20 sec. | 20.8 mrem | |
| 21 - 70 sec. | 2.6 mrem | |
| 71 - 105 sec. | 0.0009 mrem | |
| 106 - 170 sec. | 0.0013 mrem | |
| Phase 2: | 73.2 mrem | |
| Phase 3: | 197 mrem | |
| Phase 4: | 197 mrem | |
| Inland Area Potentially Affected by Deposition exceeding 0.2 $\mu Ci/m^2$ in Event of an Accident. Launch Vicinity Accident Causing Release: | | |
| - Mean Value: 0 - 10 sec. | 4.65 $Km^2$ | None |
| 11 - 20 sec. | 0.52 $Km^2$ | |
| 21 - 70 sec. | 0.85 $Km^2$ | |
| >71 sec. | <0.0001 $Km^2$ | |
| - 99 Percentile Value: | | |
| 0 - 10 sec. | 111 $Km^2$ @ 3.36 x $10^{-8}$ Probability | |
| 11 - 20 sec. | 9 $Km^2$ @ 8.47 x $10^{-9}$ Probability | |
| 21 - 70 sec. | 22.8 $Km^2$ @ 4.37 x $10^{-9}$ Probability | |
| >71sec. | <0.0001 $Km^2$ | |
| Inland Area Potentially Requiring Cleanup and Mitigation at Second Year Following Accident (i.e., Annual Dose Rate Exceeding 10 mrem/yr). Launch Vicinity Accident Causing Release: | | |
| - Mean Value: 0 - 10 sec. | 0.024 $Km^2$ | None |
| 11 - 20 sec. | 0.015 $Km^2$ | |
| 21 - 70 sec. | 0.024 $Km^2$ | |
| - 99 Percentile Value: | | |
| 0 - 10 sec. | 0.063 $Km^2$ | |
| 11 - 20 sec. | 0.204 $Km^2$ | |
| 21 - 70 sec. | 0.517 $Km^2$ | |

The proposed action will result in limited short-term air, water quality, and biological impacts in the immediate vicinity of the launch site. These impacts have been previously addressed in other National Environmental Policy Act (NEPA) documents (NASA 1978, NASA 1986, NASA 1988a, NASA 1989a, USAF 1986, USAF 1988) and are associated with the routine launch operations of the STS and Titan IV launch vehicles. The impacts were determined to be localized to designated areas and, therefore, insufficient to preclude Shuttle operations. This EIS is intended to support decision-making with respect to the Ulysses mission, a Shuttle payload, rather than the operation of the Shuttle system, per se. The following paragraphs briefly summarize the impacts described in Section 4.

Proposed Action

Short-term air quality degradation at the launch site and downwind of the launch will occur from the hydrochloric acid and aluminum oxide emissions from the solid rocket booster engines. The greatest effect will be in the "near field" (i.e., within about 900 feet of the launch pad). Additional deposition will occur outside this area in lower concentrations, with most deposition expected to occur over the ocean.

Short-term impacts on natural vegetation and biota could be acute near the launch pad. Damage would be confined to vegetation and biota near the launch pad. Acidification of mosquito impoundments near the launch pad also may occur. These impacts are similar to those observed during the past 10 years and are on KSC land. At the time of launch, birds are expected to be startled by the noise, but no long-term consequences are expected. No adverse impacts on endangered species are expected (based on experience with Shuttle launches to date).

Beneficial impacts on the local economy will result from the influx of tourists who come to view the launch. Additional benefits will result from the science returns, as discussed previously.

No-Action Alternative

The no-action alternative, while not creating any direct environmental impacts, could limit the scientific base for future technological advances. On the other hand, successful completion of the mission under the proposed action would result in new scientific knowledge that could lead to technological advances that could have significant long-term positive benefits as discussed in Section 1.

If NASA did not proceed with the Ulysses mission, the potential scientific returns of this mission would not be obtained. In addition, cancellation of the mission would leave the European Space Agency (ESA) without the means for launching or powering their Ulysses spacecraft; such an action by NASA would likely have severe repercussions on the future prospects for U.S./International cooperation in space exploration.

### 2.5.1.2 Possible Environmental Impacts of Mission Accidents

Proposed Action

For the proposed action, detailed analysis indicates that the chance is remote of any accident occurring that could release plutonium dioxide (NASA 1988a, NASA 1989a, and Section 4 of this EIS); and even in the remote instance of such an accident, the consequences of release are quite limited.

The DOE conducts a detailed program of safety verification testing and analysis to determine the chances and consequences of releasing plutonium dioxide from the spacecraft's RTG in the event of an accident. The goal of the DOE program is to ensure the integrity of RTGs, predict their response to a broad range of accident conditions, and estimate the environmental impact, if any, of an accident. The results of analyses available to date are presented in Section 4 and are briefly summarized in Table 2-3.

For the mission as a whole, the accident with the highest probability of release is an IUS failure during Phase 4 (at interplanetary injection) which leads to reentry, RTG breakup, and impact of the modules. The probability of the initiating accident and impact on land is $1.66 \times 10^{-3}$. The mean (i.e., expectation) value release has a subsequent conditional probability of 0.129 for a total probability of release of $2.14 \times 10^{-4}$ (or 1 in 4,670). The expectation release is 0.084 Ci. This is conservatively assumed to be available for transport even though test data indicate that the release may well be contained within the graphite impact shell. The mean collective population dose over a 50-year period would be 0.19 person-rem. The "maximum" collective dose is predicted to be 3 person-rem with a probability of approximately 1 in 60,000. The ability of the modules to survive Earth orbital reentry heating without a loss of fuel has been demonstrated by test and operational experience. The release could occur only in the event of reentry and impact on rock or a similar unyielding surface. If the RTG reenters and lands in the ocean, statistically the most likely occurrence, there would be no release.

No-Action Alternative

There are no adverse health or environmental impacts from the no-action alternative.

### 2.5.2 Scope and Timing of Mission Science Returns

Evaluation of the alternatives indicates that there are no significant health or environmental impacts outside the immediate vicinity of the launch pad associated with a normal mission. There are, however, major adverse fiscal and programmatic impacts attendant with the no-action alternative.

The proposed action would accomplish NASA's scientific objectives for the Ulysses mission's study of the Sun. The proposed action would result in the earliest collection of this scientific data at a most optimum time because of the position of other spacecraft.

The no-action alternative, by eliminating the previously cited small risk of consequences from its operation, would result in not obtaining any science data and therefore would effectively prevent the United States and the ESA from achieving their solar system exploration objectives. Most significantly, the scientific investigations of scores of scientists who have worked many years to conduct experiments as part of the Ulysses mission would be terminated.

### 2.5.3 Launch Preparation and Operation Costs (Mission Only)

The proposed Ulysses mission, with an estimated cost to completion (United States cost only) of approximately $210 million (excluding launch vehicle costs), represents the minimum cost alternative to NASA for meeting the objectives of the Ulysses mission. The November 1991 backup contingency launch date, if necessary, would add an additional $14 million in U.S. costs, excluding launch vehicle costs.

The no-action alternative would represent the least cost alternative for NASA but would render useless the $150 million current investment.

### 2.5.4 Launch Schedules and Launch Vehicle Availability

Consistent with the planning for the proposed action, the Ulysses mission has been manifested for flight on board the STS in October 1990. There are no plans within the existing launch manifest to launch Ulysses on board the STS in 1991; however, if NASA were unable to launch Ulysses in 1990, a contingency plan would be to rearrange the manifest and attempt a launch in 1991.

### 2.5.5 Facility and Personnel Availability

To maintain the proposed action, the necessary NASA and ESA scientific and engineering personnel are in place to implement the Ulysses mission in 1990. NASA's Deep Space Network is prepared to meet the project's tracking and data relay requirements.

Selection of the no-action alternative would immediately result in loss of the significant investment in facilities and personnel to date, and loss of a Shuttle mission opportunity. The currently existing engineering and scientific work force would be dispersed and may be irretrievably lost.

### 2.5.6 Summary

The launch of the Ulysses mission in 1990 or 1991 will allow collection of data during the solar minimum. These data will be less complicated to analyze and should yield a better understanding of the solar processes. An additional benefit will be the collection of data simultaneously with the Pioneer 10 and 11 and Voyager 1 and 2 spacecraft in the outer heliosphere and will enable a three-dimensional study of the heliosphere. In the event that the mission were delayed well beyond 1991, some of the data acquisition in the Ulysses science program would be lost. As discussed in this section, the only combination of spacecraft, power source, and launch vehicle configuration that can meet the objectives is the currently designed Ulysses spacecraft, the use of an RTG as the power source, and the STS/IUS/PAM-S as the launch vehicle.

The STS/IUS/PAM-S launch vehicle option is the only technically feasible choice for launches prior to January 1994 because approximately three years is required from the time a decision is made to use a particular launch vehicle, such as the Titan IV expendable launch vehicle, to the time that the requisite modifications can be completed to the spacecraft and launch vehicle. The U.S. Air Force, which procures the Titan IV launch vehicle, notified NASA in November of 1988 that it could not provide a Titan IV vehicle for the 1991 launch opportunity due to high priority Department of Defense requirements. Consequently, NASA terminated all mission planning and preparation for the Titan IV planetary back-up (i.e., back-up launch capability for the Magellan, Galileo, and Ulysses missions). Furthermore, the U.S. Air Force has indicated that the first availability of a Titan IV vehicle will be in 1995. Therefore, only the STS/IUS/PAM-S is both capable of performing the mission and available to NASA for missions in the early 1990s.

The issue of alternative power systems was addressed in the Tier 1 EIS (NASA 1988a), and no new information has been brought to light which would alter the earlier decision to use an RTG power system. Information on a number of potential power source alternatives for the spacecraft were presented in Section 2.2.4. The only power source currently available which can perform reliably during all phases of the mission is the RTG. Developmental work currently underway is expected to provide additional potential power sources in the mid to late 1990s. To await those systems would, however, entail an indefinite delay.

In summary, no alternative to the proposed launch vehicle is available before 1995, and no alternative to the RTG as a power source is available before the late 1990s. Therefore, alternative launch vehicles and power sources have been evaluated and eliminated from further consideration.

The proposed action of completion of preparation and operation of the Ulysses mission, including its planned launch in October 1990, with November 1991 as a back-up opportunity, is the only reasonable alternative for accomplishing the Ulysses mission in a timely manner and without major disruption to the NASA and ESA scientific programs. The no-action alternative involves cancellation of the mission, loss of the sunk costs, loss of the potential for collecting significant scientific data (see Section 1.3). The Ulysses mission has been a key scientific objective of the United States and the European science communities. It has received continuing support from the U.S. and the European governments for over a decade. The scientific results of the mission have potential practical benefits for people here on Earth, as well as for potential activities in space. Adoption of the no-action alternative would have severe adverse implications for the U.S. space program.

# 3. AFFECTED ENVIRONMENT

This section addresses those elements of the human environment that could potentially be affected by the proposed and alternative actions addressed within this document. The section is divided into three major parts addressing: (1) the region in which the Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) launch areas are located, (2) the local area encompassing the STS and Titan IV launch sites, and (3) the "global commons" or the global environment. A brief discussion of plutonium levels in the environment is included in the third subsection to provide the reader with a perspective regarding the types, sources, and levels of environmental plutonium on a broad scale.

The affected environment has been discussed in detail in a previous (Tier 2) Environmental Impact Statement (EIS) for the Galileo mission (NASA 1989a). Refer to that document for additional maps of environmental resources.

## 3.1 REGIONAL OVERVIEW

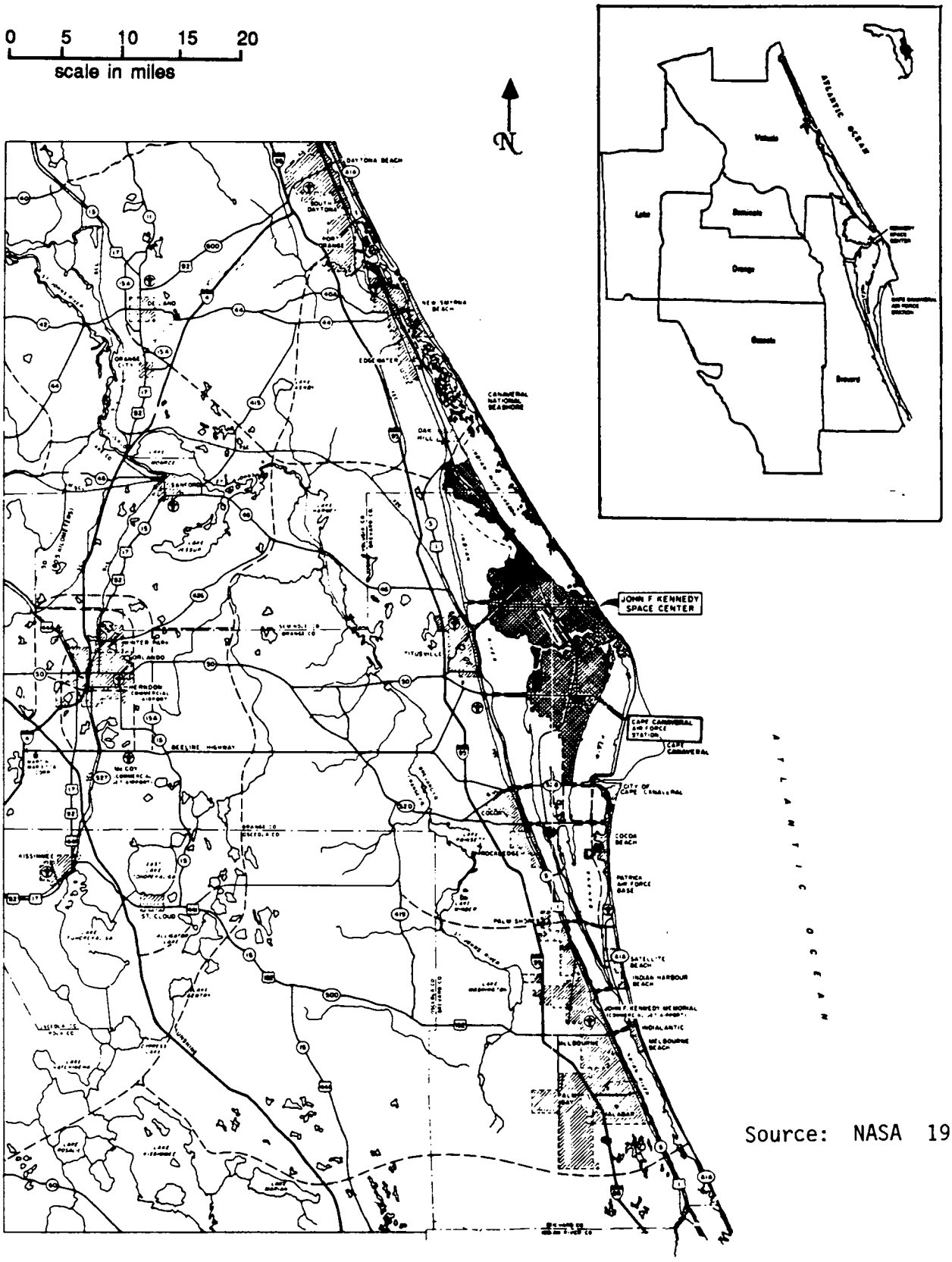
For the purpose of this document, the region is defined as the six county area (Brevard, Volusia, Seminole, Lake, Orange, Osceola counties) which encompasses KSC and CCAFS, as shown in Figure 3-1.

### 3.1.1 Land Use

About 8 percent (328,000 acres) of the total region (4.1 million acres) is urbanized (ECFRPC 1987), with the largest concentrations of people occurring in three metropolitan areas: (1) Orlando in Orange County, with expansions into the Lake Mary and Sanford areas of Seminole County to the north; and into the Kissimmee and St. Cloud areas of Osceola County to the south; (2) the coastal area of Volusia County, including Daytona Beach, Port Orange, Ormond Beach, and New Smyrna Beach; and (3) along the Indian Lagoon and coastal area of Brevard County, specifically the cities of Titusville, Melbourne, and Palm Bay. Approximately 85 percent of the region's population lives in developed urban areas.

The majority of the region is considered rural, which includes agricultural lands and associated trade and services areas, conservation and recreation lands, as well as undeveloped areas. Agricultural activities include citrus groves, winter vegetable farms, pastureland and livestock, foliage nurseries, sod farms, and dairy land. Citrus farming has been harmed in recent years by canker outbreaks and freezes, and the majority of groves in Lake, Seminole, Volusia, and Orange counties remain vacant and unused (ECFRPC 1987). With over 5,000 farms, nurseries, and ranches in the region, about 35 percent (1.4 million acres) of the regional area is devoted to agriculture.

Conservation and recreation lands account for almost 25 percent of the total acreage in the region, or slightly over 1 million acres (ECFRPC Undated). About 866,600 acres are land resources, and about 156,000 acres are water areas. The region also contains about 5,400 acres of saltwater beaches and about 48 acres of archaeological and historic sites.




Source: NASA 1979

FIGURE 3-1. LOCATION OF REGIONAL AREA OF INTEREST

A number of areas within the region have special status land use designations. These include a portion of the Ocala National Forest, the Canaveral National Seashore adjacent to KSC, one State preserve, seven State wildlife management areas, and two national wildlife refuges including the Merritt Island National Wildlife Refuge at KSC.

### 3.1.2 Meteorology and Air Quality

The climate of the region is subtropical with two definite seasons: long, warm, humid summers and short, mild, dry winters. Rainfall amounts vary both seasonally and from one year to the next. Average rainfall is 51 inches; the monthly high occurs in July and the low usually in April. These fluctuations result in frequent, though usually not severe, episodes of flooding and drought. Temperature is more constant than precipitation with prolonged cold spells and heat waves being rare. Tropical storms, tropical depressions, and hurricanes, all of which can produce large amounts of rainfall and high winds, occasionally strike the region. The last hurricanes to affect the area were David in September 1979 which paralleled the coast (ECFRPC 1987), and Hugo in September 1989 which went ashore in South Carolina.

There are 14 air monitoring sites in the region: 7 are for total suspended particulates, 2 each for sulfur dioxide, carbon monoxide and ozone, and 1 for nitrogen dioxide. Lead is not monitored anywhere in the region. Most of the monitoring sites are located in the Orlando urban area; there are no air quality monitoring sites in Lake or Osceola Counties.

Air quality is generally good. Orange County is the only county in the region that had been designated a non-attainment area (in this case, for ozone). Data from the period 1984-1986 indicate that ozone standards were being met (State of Florida 1987). Orange County was redesignated by EPA (5/13/87) as an ozone "attainment" area (52 FR 17953).

### 3.1.3 Hydrology and Water Quality

The region not only borders the Atlantic Ocean, but contains approximately 2,300 lakes, 2 major estuaries, and about 700 miles of streams and rivers.

Almost all (89 percent) of the fresh water used in the region is drawn from groundwater supplies, principally the artesian Floridan Aquifer. Some small users withdraw water from the nonartesian surficial aquifers that overlie the Floridan Aquifer. The Floridan Aquifer covers 82,000 square miles and is 2,000 feet thick in some areas. In portions of the region, such as the coastal zone and an area bordering the St. Johns River, the Floridan Aquifer is too saline for potable water use (ECFRPC 1987). Wells tapping the surficial, unconfined aquifer are largely used for non-potable or individual domestic uses, although this source is also used for some municipal public supply systems (e.g., the cities of Mims and Titusville, about 15 miles northwest of the KSC/CCAFS launch sites; and Palm Bay, about 40 miles south of the KSC/CCAFS launch sites, in Brevard County). Lake Washington, in Brevard County, about 32 miles south of the KSC/CCAFS launch sites, is the only surface water used as a potable water supply in the region, supplying the City of Melbourne (ECFRPC 1987).

Groundwater reserves are recharged by the percolation of rainwater. The region contains some effective recharge areas for the Floridan Aquifer (Figure 3-2). These areas are located primarily in the upland portions of Lake, Orange, Seminole, Osceola, and Volusia Counties and are composed of very porous, sandy soils. Rainfall quickly percolates through the soils into the aquifers below. In the most effective recharge areas, approximately 15 inches of rainfall enter the Floridan Aquifer each year -- almost 30 percent of the total rainfall.

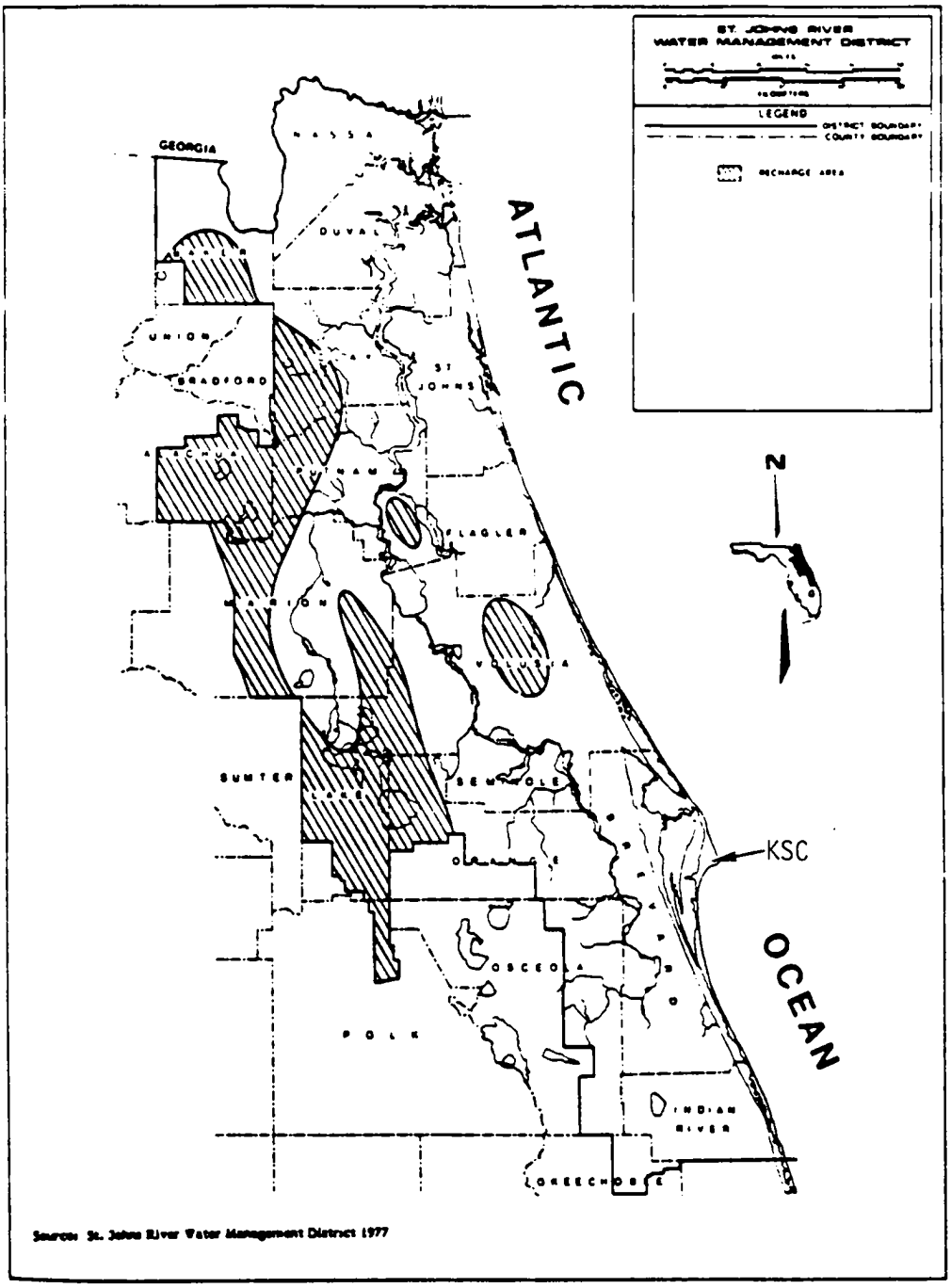
The major surface water resources in the region are the upper St. Johns River basin, the Indian River Lagoon system, the Banana River and a portion of the Kissimmee River along the western border of Osceola County. The St. Johns River, from its headwaters in the marshes at the southern end of Brevard County to the northernmost part of Lake Washington, is classified by the State as Class I water (potable water supply), and as noted earlier, serves as the source of potable water for the City of Melbourne and much of the surrounding population in that area. The remainder of the St. Johns within the region is Class III water (recreation and fish and wildlife propagation).

The Kissimmee River (and its system of lakes) is a major contributor of flow into Lake Okeechobee to the south of the region, and is the major drainage for Osceola County and a portion of eastern Orange County. The river system is characterized by a series of control structures and channeled connections between the lakes for the purposes of flood water level control and navigation (FSU 1984).

Waters with special status within the region include the:

- Weikiva River; a federally designated Wild and Scenic River, which forms the border between northwestern Seminole County and eastern Lake County
- Mosquito Lagoon portion of the Indian River Lagoon which is a State of Florida Aquatic Preserve
- Southern portion of the Banana River from the southern end of CCAFS south and the Indian River Lagoon between Malabar and Sebastian Inlet, also designated as Aquatic Preserves
- Portions of the Banana River and Mosquito Lagoon, as well as the northern portion of the Indian River within the confines of KSC designated by the State as Outstanding Florida Waters, along with the Weikiva River, the Butler chain of lakes, and the Clermont chain of lakes.

In total, the region contains 4 aquatic preserves, 24 bodies of surface water designated as Outstanding Florida Waters, and 1 Area of Critical State Concern - the Green Swamp.




Source: FSU 1984

FIGURE 3-2. GENERALIZED MAP OF POTENTIAL GROUND WATER RECHARGE AREAS IN EASTERN CENTRAL FLORIDA

### 3.1.4 Geology and Soils

The region is underlain by a series of limestone formations with a total thickness of several thousand feet. The lower formations (the Avon Park and Ocala group) constitute the Floridan Aquifer. Overlying these formations are beds of sandy clay, shells, and clays of the Hawthorn formation which form the principal confining beds for the Floridan Aquifer. Overlying the Hawthorn formation are Upper Miocene, Pleiocene, and recent deposits which form secondary semi-confined aquifers and the surficial aquifer.

### 3.1.5 Biological Resources and Endangered Species

As noted in Sections 3.1.1 and 3.1.3, the region has a large number of terrestrial and aquatic conservation and special designation areas (e.g., wildlife management areas and aquatic preserves), which serve as wildlife habitat, and comprise about 25 percent (about 1 million acres) of the total land and water acreage within the region (about 4.1 million acres).

Figure 3-3 provides an overview of land cover types found throughout the six county region, with a county-by-county breakdown provided in Table 3-1. Freshwater and coastal wetlands comprise about 23 percent of the total area of the six county region, followed by xeric grassland (21 percent), scrub and bush (17 percent), water (12 percent), and hardwood/pine forest (11 percent) being the dominant cover types in the region.

A total of 141 species of freshwater, estuarine, and marine fish have been documented within the northern portions of the Indian River Lagoon near KSC (ECFRPC 1988). Of these, 65 species are considered commercial fish and 85 are sport fish and/or are fished commercially. One species known to inhabit the river, the rainwater killifish (Lucania parva), while not on the Federal or State threatened and endangered lists, has been listed by the Florida Committee on Rare and Endangered Plants and Animals as "imperiled statewide" (S2), and by the Florida Natural Areas Inventory as a "species of special concern."

The St. Johns River supports both fresh and saltwater fishing (DOE 1989a). Sport fish include largemouth bass, bluegill, black crappie, bowfin, gar, bullhead, bream, and catfish. The St. Johns River basin is heavily fished, as indicated by an estimated 50,000 man-hours of fishing effort in 1983 in Lake Washington and Lake Harney alone.

As noted in Section 3.1.6.2, commercial fishing is an important economic asset to the region. Brevard County and Volusia County ranked fifth and sixth respectively, among the 12 east coast Florida counties in terms of 1987 finfish landings. Brevard ranked first in invertebrate landings (crab, clams, oysters, etc.) and first in shrimp landings, with Volusia fifth in both categories.

Important terrestrial species in the region include migratory and native waterfowl (ringneck, pintail, and bald pate ducks, for example), as well as turkey, squirrel, white-tailed deer and wild hogs. Black bear also are known in the region. The St. Johns River basin is an important waterfowl hunting area. The seven State wildlife management areas in the region are hunted for small game, turkey, hogs, or deer.

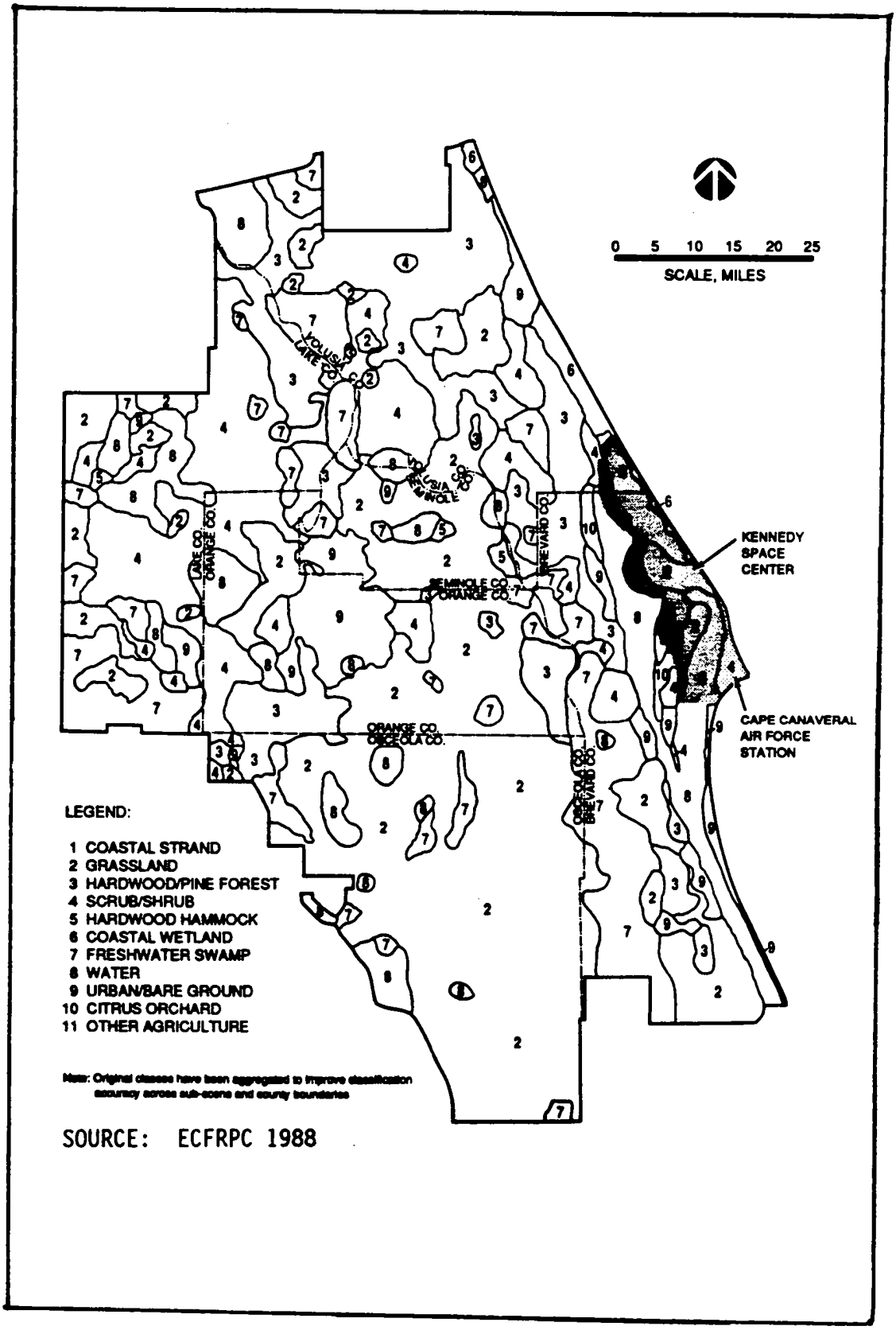



FIGURE 3-3. GENERAL LAND COVER TYPES OF THE REGION

TABLE 3-1. MAJOR COVER TYPES WITHIN THE REGION BY PERCENT WITHIN COUNTY AND BY ACREAGE*

| CLASS # | CLASS NAME | BREVARD COUNTY | | LAKE COUNTY | | ORANGE COUNTY | | OSCEOLA COUNTY | | SEMINOLE COUNTY | | VOLUSIA COUNTY | | REGION TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ACREAGE | % | ACREAGE | % | ACREAGE | % | ACREAGE | % | ACREAGE | % | ACREAGE | % | ACREAGE | % |
| 1 | COASTAL STRAND | 1050 | 0.13 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 657 | 0.08 | 1707 | 0.04 |
| 2 | XERIC GRASSLAND | 108457 | 13.51 | 89604 | 12.08 | 139117 | 21.66 | 434402 | 46.01 | 45937 | 21.55 | 76856 | 9.48 | 894486 | 21.53 |
| 3 | HARDWOOD/PINE FOREST | 73492 | 9.16 | 59617 | 8.04 | 87415 | 13.61 | 60308 | 6.39 | 17204 | 8.07 | 182406 | 22.50 | 480488 | 11.57 |
| 4 | SCRUB/SHRUB | 102363 | 12.75 | 218044 | 29.40 | 119224 | 18.56 | 79970 | 8.47 | 33053 | 15.50 | 155060 | 19.13 | 707799 | 17.04 |
| 5 | HARDWOOD HAMMOCK | 23312 | 2.90 | 45587 | 6.15 | 34588 | 5.38 | 13706 | 1.45 | 23191 | 10.88 | 60621 | 7.48 | 201031 | 4.84 |
| 6 | COASTAL WETLAND | 22129 | 2.76 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 17846 | 2.20 | 39978 | 0.96 |
| 7 | FRESHWATER SWAMP | 185636 | 23.13 | 176512 | 23.80 | 104830 | 16.32 | 238997 | 25.31 | 38949 | 18.27 | 162584 | 20.06 | 907614 | 21.85 |
| 8 | WATER | 175268 | 21.83 | 83751 | 11.29 | 57851 | 9.01 | 77598 | 8.22 | 21186 | 9.94 | 93134 | 11.49 | 508849 | 12.25 |
| 9 | URBAN/BARE GROUND | 90203 | 11.24 | 68563 | 9.24 | 99359 | 15.47 | 39236 | 4.16 | 33692 | 15.80 | 60401 | 7.45 | 391509 | 9.43 |
| 10 | CITRUS ORCHARD | 19305 | 2.40 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1040 | 0.13 | 20347 | 0.49 |
| 11 | OTHER AGRICULTURE | 1520 | 0.19 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| | | 802733 | | 741677 | | 642384 | | 944215 | | 213212 | | 810605 | | 4153807 | |

SOURCE: ECFRPC 1988

* The data provided herein were compiled directly from the computer database referenced. The level of precision implied by the numbers is an artifact of the computer compilation process, thus data should be viewed only as approximate acreages and approximate percentages.

The Federal government's Endangered or Threatened Species List, prepared by the U.S. Fish and Wildlife Service (USFWS), currently recognizes 19 endangered or threatened species in this region. Another 55 species are "under review" for possible listing, of which 35 are plants. The State of Florida list includes 47 species considered endangered or threatened. The Florida Committee on Rare and Endangered Plants and Animals, a group consisting largely of research biologists, gives endangered or threatened status to 55 species. The Florida Natural Areas Inventory, run by the Nature Conservancy under contract to the Florida Department of Natural Resources, includes 62 species in its top two most endangered categories. Roughly half of all the endangered and threatened species identified by these lists occur in wetlands, principally estuarine environments; the other half depend on upland habitats (ECFRPC 1987).

### 3.1.6 Socioeconomic Environment

The socioeconomic environment of the six counties that could be affected by the launch includes fast growing communities and urban areas that have adopted long-range plans reflecting the rapid influx of development in the regional area.

#### 3.1.6.1 Population

The existence of three separate metropolitan areas is reflected in the designation of three Metropolitan Statistical Areas (MSAs) within the region by the U.S. Bureau of the Census (ECFRPC 1987). These MSAs are the Orlando MSA (Orange, Osceola, and Seminole Counties), the Daytona Beach MSA (Volusia County), and the Melbourne-Titusville-Palm Bay MSA (Brevard County). The population in Lake County, though growing faster than the State average, is split between many small-to-medium-sized municipalities and rural areas.

Growth Rate

The regional population is growing at a rate faster than the State--during 1960 the region contained 12.8 percent of the state population; in 1970 and in 1980 the growth rate flattened out and the region contained 13.6 percent and 13.7 percent of the State population, respectively. In June of 1980 the disproportional growth of the region resumed. The 1980 regional population was 1,336,646, a 45 percent increase from the 1970 census. The estimated growth from 1980 to 1986 was a 33.6 percent increase (an addition 448,898 persons). Current estimates (1987) are that the growth rate is higher in recent years than at the beginning of the decade, and that between 1986 and 1987 the population increased 4.6 percent (77,711 people), placing 14.6 percent of Florida's population in the region. This trend is projected to continue through 1991. The 1987-1991 growth is expected to be almost 20 percent, or approximately 337,000 people (ECFRPC Undated).

All counties are expected to show increases in population. In the early 1990s, it is anticipated that 2,000,000 people will be living in the region. By the year 2000, official estimates show the region will have about 2,300,000 residents, 40 percent more than in 1985 (ECFRPC 1987).

Orange County is expected to remain the most populated county, growing to 673,200 in 1991, followed by Brevard (428,200), Volusia (373,400), Seminole (302,100), Lake (153,000), and Osceola (115,200). Osceola is projected to have the fastest population growth rate over the 1987 to 1991 time frame with an increase of 39.5 percent. Seminole is projected to have a 25.2 percent increase, followed by Brevard (19.9 percent), Lake (17.6 percent), Volusia (17.1 percent) and Orange is expected to show the slowest growth rate (16.5 percent). This projected population growth is summarized in Table 3-2 (ECFRPC Undated).

TABLE 3-2. PROJECTED POPULATION GROWTH, EAST CENTRAL FLORIDA REGION (1986-1991)

| | Population | | Change 1986-1991 | |
|---|---|---|---|---|
| Area | 1986* | 1991 | Number | Percent |
| Brevard | 357,000 | 428,200 | 71,200 | 19.9 |
| Lake | 130,100 | 153,000 | 22,900 | 17.6 |
| Orange | 577,900 | 673,200 | 95,300 | 16.5 |
| Osceola | 82,600 | 115,200 | 32,600 | 39.5 |
| Seminole | 241,300 | 302,100 | 60,800 | 25.2 |
| Volusia | 319,000 | 373,400 | 54,400 | 17.1 |
| TOTAL | 1,707,800 | 2,045,100 | 337,300 | 19.8 (average) |

* April 1986 estimate (rounded to nearest 100).

(Source: ECFRPC Undated)

3.1.6.2 Economics

The region's economic base is tourism and manufacturing. Tourism related jobs, although difficult to define, include most jobs in amusement parks, hotels, motels, and campgrounds as well as many jobs in retail trade and various types of services. Manufacturing jobs, while probably outnumbered by tourism jobs, may provide more monetary benefits to the region because of higher average wages and a larger multiplier effect (as jobs are added to the economy in one sector, needs are created which lead to an expansion of employment in other sectors) (ECFRPC 1987).

## Economic Base

Tourism in the region now attracts more than 20,000,000 visitors annually. Walt Disney World and Sea World, near Orlando, along with KSC, are among the most popular tourist attractions in the state (ECFRPC 1987).

Manufacturing employs approximately 100,000 people regionwide. Orange and Brevard counties account for about 70 percent of this employment. Retail and wholesale trade provide jobs for more than half (58.9 percent in 1984) of the regions' employed persons. Other economic sectors that provide significant employment in the region include: construction (7.5 percent), transportation, communication and utilities (5.6 percent), finance, insurance, and real estate (5.9 percent), and agriculture (2.7 percent).

Commercial fisheries of the two regional counties bordering the ocean (Brevard and Volusia) landed a total of 21,401,683 pounds of finfish, invertebrates (clams, crabs, lobsters, octopus, oysters, scallops, squid, etc.), and shrimp in 1988 (State of Florida 1989). Brevard and Volusia ranked third and fourth, respectively, among the east coast counties of Florida in total 1988 finfish landings. Brevard led east coast counties in invertebrate landings with about 13.2 million pounds. Volusia County ranked fifth with about 0.4 million pounds. Brevard ranked third on the east coast with 1.1 million pounds of shrimp; Volusia was fifth with about 0.2 million pounds.

The region's agricultural activities include citrus groves, winter vegetable farms, pastureland, foliage nurseries, sod, livestock, and dairy production (ECFRPC 1987). In the central region, 30 percent of the land is forested and supports silviculture, including harvesting of southern yellow pine, cypress, sweetgum, maple, and bay trees. Large cattle ranches occupy almost all of the rural land in Osceola county (ECFRPC 1987). Agricultural employment declined in 1986 to 2.2 percent of the region's employment base (ECFRPC Undated).

## KSC's Contribution to the Economy of the State of Florida

Contracts and employment at KSC added $1.24 billion to Florida's economy during the Federal government's Fiscal Year 1989, ending September 30, 1989. Of these expenditures, $1.07 billion went to contractors operating on-site at the space center, $7 million went to off-site business in Brevard County, and about $14 million involved other purchases and contracts awarded to Florida businesses outside of Brevard County. At least 70 percent of the on-site and Brevard County expenditures were estimated to have stayed in the local area in the form of payrolls and purchases (KSC 1989).

Civil service salaries through the end of FY89 amounted to $102 million, an increase of about $13 million over the previous year. Permanent Federal employees at KSC edged over the 2,400 mark during the period. While 3,800 individuals were employed through construction and tenant jobs at KSC, the majority of workers at KSC are employed by the on-site contractors and number almost 12,000. Overall, approximately 18,000 workers were employed at KSC through the close of the Fiscal Year (KSC 1989).

Regional Employment

About 49 percent of the residents in the region are employed, ranging from 56 percent in Orange County to 33 percent in Lake County with 55 percent in Seminole, 49 percent in Osceola, 45 percent in Brevard, and 41 percent in Volusia. The region's labor force and employment have risen each year since the mid-1970s, and employment is expected to continue to increase through 1991 to a total of 1.08 million civilian jobs by 1991 from 0.83 million in 1986. The region's unemployment rate in 1986 was 5.1 percent (ECFRPC Undated).

Regional Income

Income in the region has been increasing faster than inflation. The 1985 to 1986 average annual wage rose 3.7 percent (about two times faster than the inflation rate of 1.9 percent). The 1986 average wage over all sectors was $17,604. Per capita income in the region has risen steadily since 1979 from $7,799 to $12,273 in 1984. The highest income was in Orange County ($12,901), followed by Brevard ($12,235) and Osceola ($11,026). The regional per capita income for 1987 to 1991 is projected to increase at a rate somewhat greater than inflation, perhaps surpassing the national average in 1991 (ECFRPC Undated).

### 3.1.6.3 Transportation

The region's airports, for the most part, still are able to accommodate increasing numbers of passengers. Orlando International Airport, already the 43rd busiest airport in the world in number of passengers, is an exception. The Greater Orlando Airport Authority has recently announced plans to double its capacity to 24,000,000 passengers annually. Two other major airports are Daytona Beach Regional and Melbourne Regional (ECFRPC 1987).

The region's road network includes five major limited access highways: Interstate 4, Interstate 95, Florida's Turnpike, the Spessard L. Holland East-West Expressway, and the Martin L. Andersen Beeline Expressway. In addition, numerous Federal, State, and county roads are located in the region (ECFRPC 1987).

The remainder of the region's transportation network is varied. Rail service for freight is available in all counties, but passenger service is limited. Ports at Cape Canaveral and Sanford provide access for water-borne shipping and cruises. Mass transit or paratransit is currently operating in all counties of the region except for Osceola (ECFRPC 1987).

### 3.1.6.4 Public and Emergency Services

Nearly 90 percent of the people in the region rely upon public supplies of potable water, while the remainder use private wells. Problems with saltwater intrusion into ground water is already evident, especially in coastal Brevard County (ECFRPC 1987).

Health care within the region is available at 28 general hospitals, three psychiatric hospitals, and two specialized hospitals. Over 6,600 beds are provided in the general hospitals. Doctors, dentists, and other heath care professionals, as well as nursing homes are located throughout the region (ECFRPC 1987).

### 3.1.6.5 Historical/Cultural Resources

There are 45 sites within the region that are listed in the National Registry of Historic Places, 2 in the National Registry of Historic Landmarks, and one area (Kissimmee River Prairie) that is a potential addition to the National Registry of Natural Landmarks.

## 3.2 LOCAL ENVIRONMENT

The local environment is defined as the Cape Canaveral Air Force Station (CCAFS) and the Kennedy Space Center (KSC). The following brief descriptions use the Air Force Environmental Assessment for the Complementary Expendable Launch Vehicle (later renamed the Titan IV) at CCAFS (USAF 1986), the 1988 supplement to that document addressing an increase in the number of Titan IV launches from CCAFS (USAF 1988), and the KSC Environmental Resources Document (NASA 1986) as primary sources for data and figures.

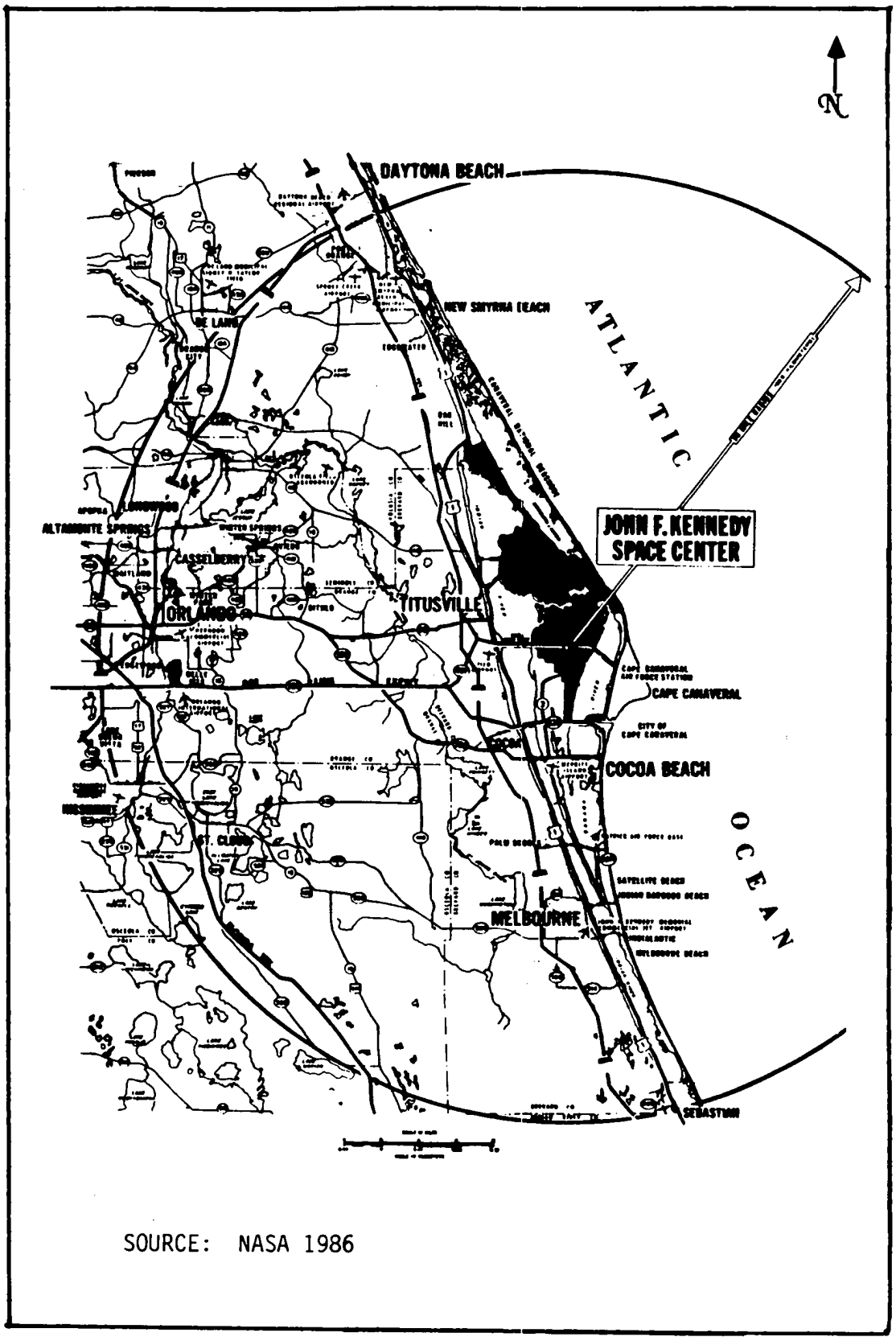
The KSC/CCAFS area is located on the east coast of Florida, in Brevard County near the City of Cocoa Beach, approximately 15 miles north of Patrick Air Force Base (PAFB), about 30 miles south of Daytona Beach and 40 miles due east of Orlando (see Figure 3-4). The local area is part of the Gulf-Atlantic coastal flats and occupies Cape Canaveral and the north end of Merritt Island, both of which are barrier islands.

### 3.2.1 Land Use

KSC (Figure 3-5) occupies almost 140,000 acres, 5 percent of which is developed land (6,558 acres) and the rest (133,444 acres) is undeveloped. Nearly 40 percent of KSC consists of open water areas, such as portions of Indian River, the Banana River, Mosquito Lagoon and all of Banana Creek.

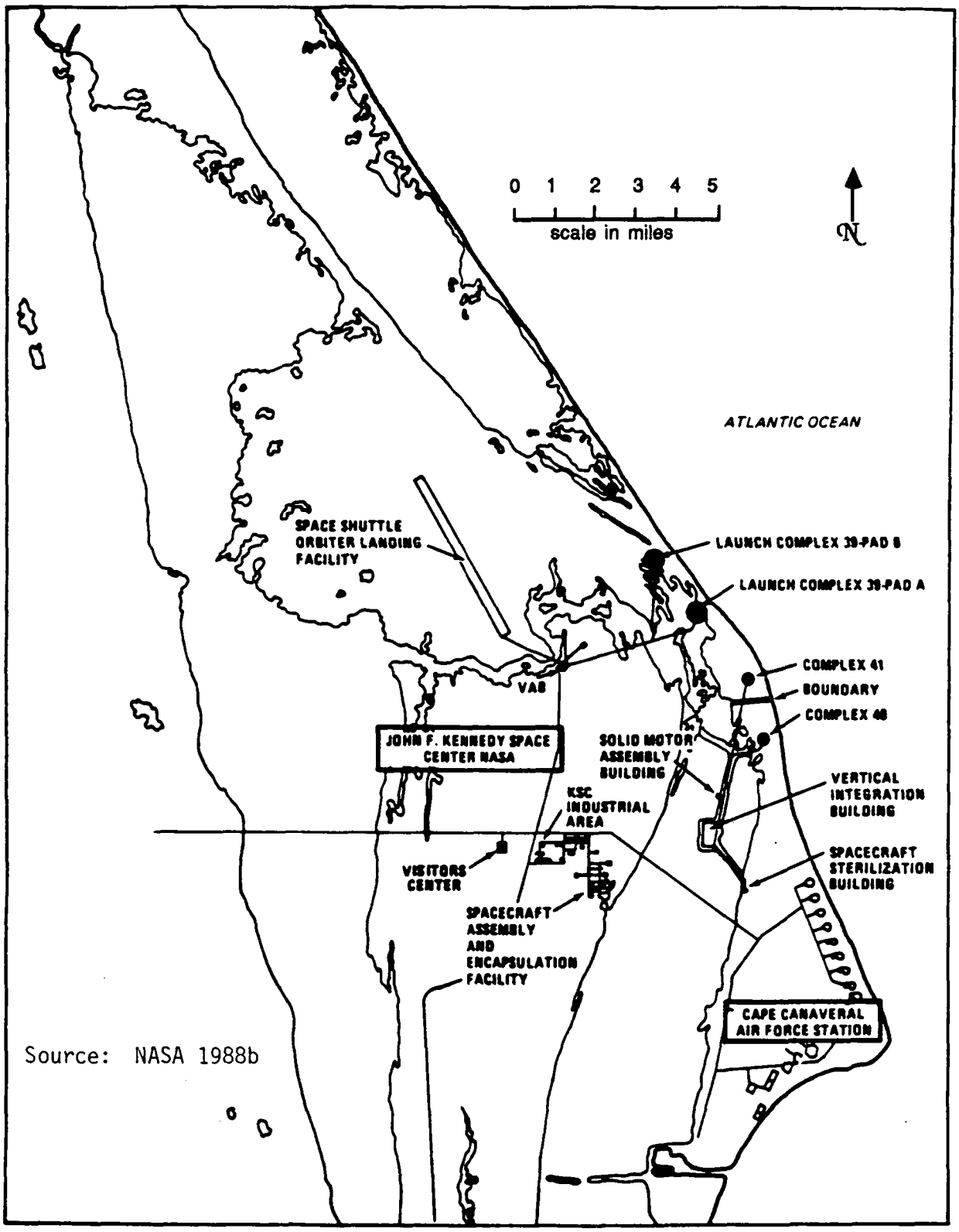
The National Aeronautics and Space Administration (NASA) maintains operational control over about 4.7 percent of KSC (6,507 acres). This area comprises the functional area that is dedicated to NASA operations. About 62 percent of this operational area is currently developed as facility sites, roads, lawns, and maintained right-of-ways. The undeveloped operational areas are dedicated as safety zones around existing facilities or held in reserve for planned and future expansion. For areas not directly utilized for NASA operations, land planning and management responsibilities have been delegated to the National Park Service (Cape Canaveral National Seashore within KSC) and the United States Fish and Wildlife Service (Cape Canaveral National Seashore outside KSC, and the 75,400 acre Merritt Island National Wildlife Refuge). These agencies exercise management control over agricultural, recreational, and various environmental management programs at KSC.

CCAFS occupies approximately 15,800 acres (a 25 square mile area) of the barrier island that contains Cape Canaveral (USAF 1986). Approximately 3,800 acres or 25 percent of the Station is developed and consists of launch complexes and support facilities (see Figure 3-6). The remaining 75 percent (about 12,000 acres) consists of unimproved land. The Titan IV Launch Complex 41 is located at the northernmost section of CCAFS, occupying 28.4 acres of land. This complex was previously used along with Launch Complex 40 for test flights of the Titan III A, III C, and Centaur Vehicles in the early 1960s.




SOURCE: NASA 1986

FIGURE 3-4. LOCATION OF KSC AND CCAFS RELATIVE TO THE REGION




Source: NASA 1988b

FIGURE 3-5. GENERAL LAND USE AT KENNEDY SPACE CENTER

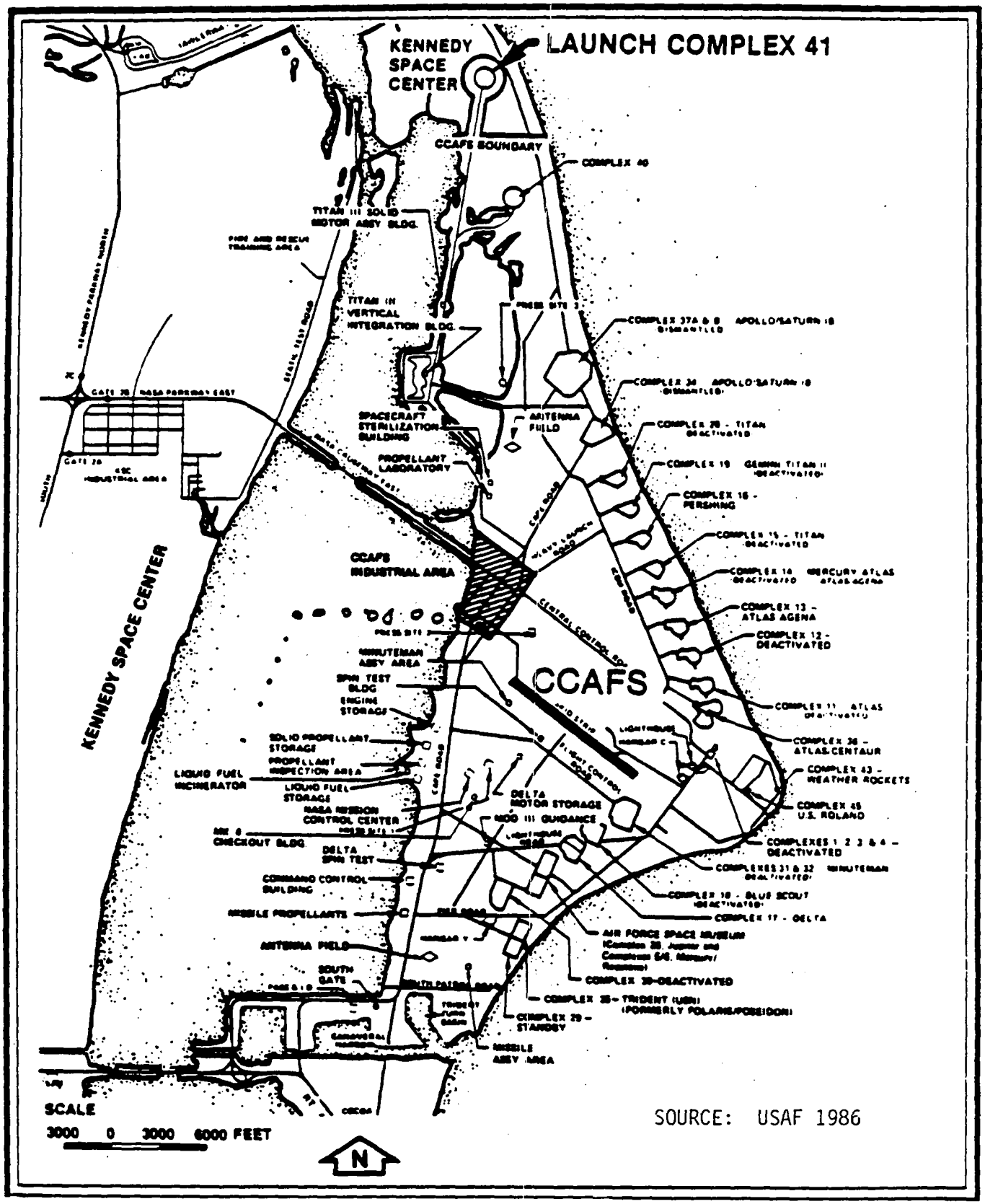



FIGURE 3-6. EXISTING LAND USE AT CCAFS

### 3.2.2 Meteorology and Air Quality

Like the region, the climate of KSC and CCAFS is subtropical with summers that are hot and humid, and winters that are short and mild. Mean temperatures range from the low 60s in the winter months to the low 80s in the summer months. Precipitation is moderately heavy with an average annual rainfall of 45.2 inches. Hail falls occasionally during thunderstorms, but hailstones are usually small and seldom cause much damage. Snow is rare.

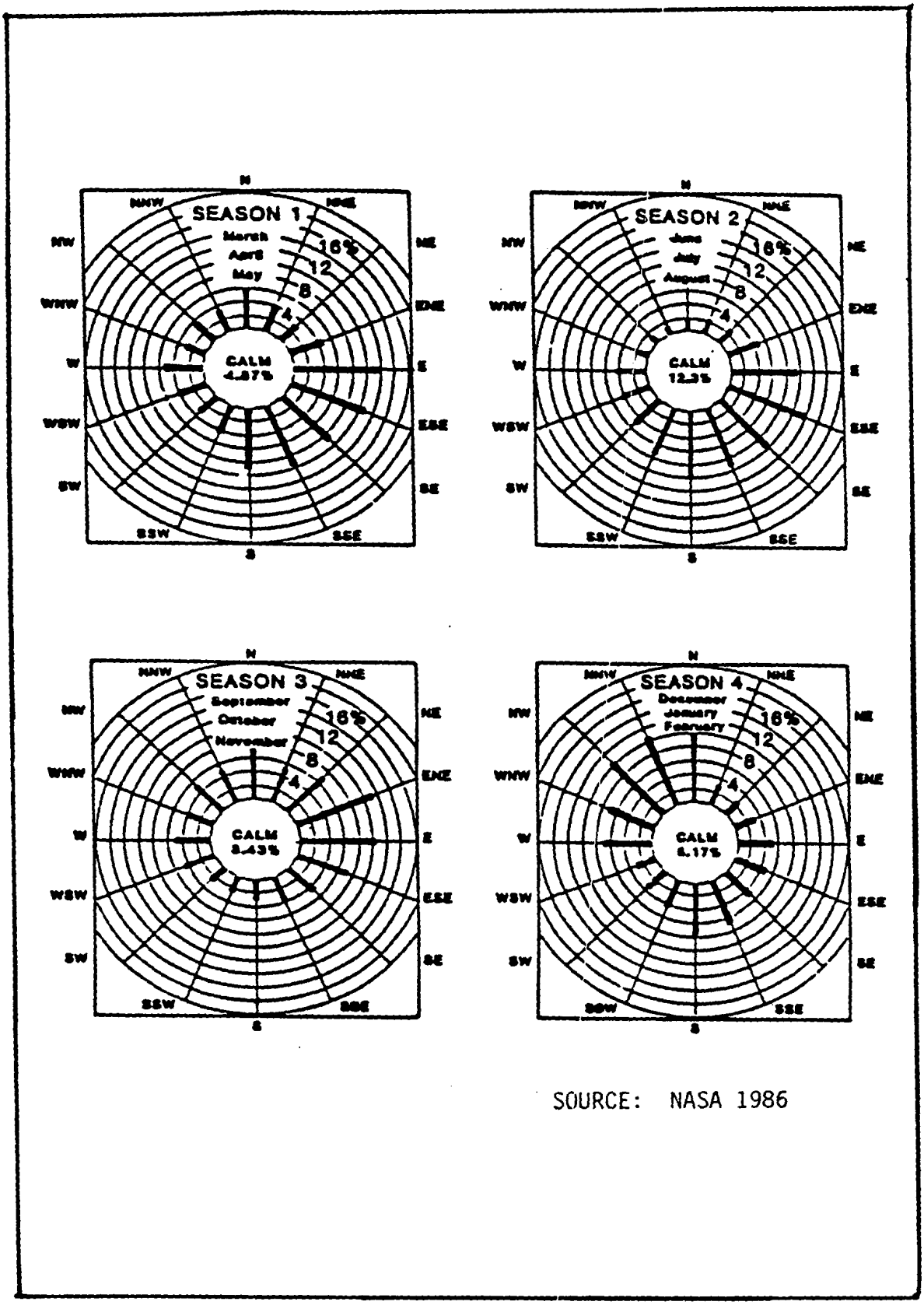
In general, the winds in September through November occur predominantly from the east to northeast (see Figure 3-7). Winds from December through February occur from the north to northwest, shifting to the southeast from March through May, and then to the south from June through August. It should be noted that the radiological impact assessments found in Section 4 and Appendix B, use launch window-specific wind roses (see Figure 3-7) and meteorological conditions. While those specific wind roses are consistent with the seasonal conditions illustrated here, they do vary slightly for individual launch windows. Sea breeze and land breeze phenomena occur commonly during the day due to unequal solar heating of the air over land and over ocean. Land breeze occurs at night when air over land has cooled to a lower temperature than that over the sea. Temperature inversions occur infrequently (approximately 2 percent of the time).

Tornadoes may occur but are rare. The U.S. Air Force (USAF 1986) cited a study which concluded that the probability of a tornado hitting a point within the Cape Canaveral area in any given year is 0.00074, with a return frequency of approximately once every 1,300 years.

Tropical depressions and hurricanes occur throughout the wet season in Florida. While the possibility for winds to reach hurricane force (74 miles per hour or greater) in any given year in Brevard County is approximately 1 in 20 (USAF 1986), only 24 hurricanes have passed within 115 miles of KSC and CCAFS since 1887 (NASA 1986). Hurricane David (September 1979) and Hurricane Hugo (September 1989) were the last hurricanes to affect the area.

Air quality at KSC/CCAFS is considered good, primarily because of the distance of the launch sites from major sources of pollution. There are no Class I or nonattainment areas (for ozone, $NO_x$, $SO_2$, lead, CO, and particulates) within about 60 miles of KSC/CCAFS, except Orange County to the west, which is a nonattainment area for ozone (USAF 1986).

The ambient air quality at KSC is influenced by NASA operations, land management practices, vehicle traffic, and emission sources outside of KSC (NASA 1986). Daily air quality conditions are most influenced by vehicle traffic, utilities fuel combustion, standard refurbishment and maintenance operations, and incinerator operations. Air quality at KSC is also influenced by emissions from two regional power plants which are located within a 10 mile radius of KSC. Space launches, training fires, and fuel load reduction burns influence air quality as episodic events.




SOURCE: NASA 1986

FIGURE 3-7. WIND ROSES INDICATING SEASONAL WIND DIRECTIONS -- LOWER ATMOSPHERIC CONDITIONS: CAPE CANAVERAL/MERRITT ISLAND LAND MASS

Ambient air quality at KSC is monitored by two Permanent Air Monitoring System (PAMS) stations (NASA 1986). PAMS A is located at the Environmental Health Facility Site, about 5 miles south of Launch Complex 39, and PAMS B is located east of Kennedy Parkway and north of Banana Creek, about 4 miles west of Launch Complex 39.

A summary of air quality parameters collected from the PAMS A facility in 1985 is provided in Table 3-3. The primary standard for $NO_2$ was exceeded in January. The 109 ug/$m^3$ of $NO_2$ was 221 percent greater than the highest level recorded in the State during the year. KSC 24-hour maximum levels for $SO_2$ during 1984 and 1985 were also among the highest along the east coast of Florida. $NO_2$ and $SO_2$ levels and prevailing westerly winds indicate that power plants to the west of KSC are the primary source of these emissions (NASA 1986).

Although never exceeding established standards, ozone is the most consistently "high" criteria pollutant at KSC (NASA 1986). There have been several ozone exceedances in recent years.

### 3.2.3 Hydrology and Water Quality

#### 3.2.3.1 Surface Waters

Major inland water bodies in the CCAFS and KSC area are the Indian River, Banana River, and Mosquito Lagoon (Figure 3-8). These water bodies are shallow lagoons, except for the portions maintained as part of the Intercoastal Waterway, between Jacksonville to the north and Miami to the south. The Indian and Banana Rivers join at Port Canaveral and form a combined area of 150,000 acres in Brevard County, with an average depth of 6 feet. This area receives drainage from 540,000 acres of surrounding area (USAF 1986).

The surface water shorelines at KSC are dominated by mosquito control impoundments. The water levels in these impoundments are raised and lowered seasonally as a control technique to reduce mosquito populations. These impoundments are typically fringed by mangrove or salt marsh communities. The shallow submerged bottoms range from unvegetated sand shell bottoms to meadows of seagrasses.

The Banana River and Indian River were historically connected by Banana Creek. This connection was severed in 1964 with the construction of the Launch Complex 39 crawlerway. Navigation locks within Port Canaveral virtually eliminate any significant oceanic influence on the Banana River. Public navigation on the Banana River is prohibited north of State Road 528 (see Section 3.2.5.3).

TABLE 3-3. KSC AIR QUALITY DATA FROM PERMANENT AIR MONITORING SYSTEM STATION A, 1985 ANNUAL REPORT

| PARAMETER | FEDERAL[d] AND STATE STANDARD | MONTH* Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OZONE (ppb) | Primary 120 (HR-AVG)[a] | 64 (96.9%) | 77 (98.9%) | 87 (91.6%) | 78 (44.5%) | 93 (76.2%) | 83 (17.9%) | 102 (71.7%) | 97 (95.2%) | 79 (99.2%) | 86 (95.9%) | 82 (93.3%) | 80 (94.0%) |
| SULFUR DIOXIDE (ppb) | Primary 140 (24-HR)[b,d] Secondary 500 (3-HR)[b] | 4 15 (97.0%) | 3 4 (42.9%) | 5 7 (82.4%) | 15 20 (90.6%) | 10 14 (68.1%) | 11. 12. (51.8%) | 7 11 (50.0%) | 1 3 (91.5%) | 4 11 (98.3%) | 2 4 (96.0%) | 2 8 (87.5%) | 18 27 (55.9%) |
| NITROGEN DIOXIDE (ppb)** | Primary[c] 50 | 345 (96.2%) | 125 (99.3%) | 21 (91.7%) | 31 (90.8%) | 28/54 (73.1%) | 13 (71.0%) | 5 (27.0%) | 23 (83.2%) | 49 (78.9%) | 71 (95.7%) | 34 (78.1%) | 25 (93.8%) |
| CARBON MONOXIDE | 35 (HR-AVG)[a] 9 (8-HR)[b] | 1.23 0.833 (97.3%) | 1.19 1.12 (99.3%) | 1.11 0.982 (91.8%) | 1.11 0.895 (91.8%) | 2.78 0.829 (92.6%) | 2.32 0.625 (45.8%) | 1.00 0.537 (86.7%) | 1.25 0.611 (91.9%) | 1.19 0.728 (98.9%) | 0.95 0.588 (96.4%) | 0.75 0.619 (93.2%) | 1.13 0.772 (93.8%) |

SOURCE: NASA 1986.

KEY:

a - Maximum hourly average concentration (not to be exceeded more than once per year).

b - Maximum time-period average concentration (not to be exceeded more than once per year).

c - Annual arithmetic mean.

d - Federal and State Standard Values are identical except for $SO_2$; State Primary (24-hour) is 100 ppb.

* 21 days are required to yield a valid month.

** No exceedence level set for $NO_2$ to date. 50 ppb is considered significantly high.

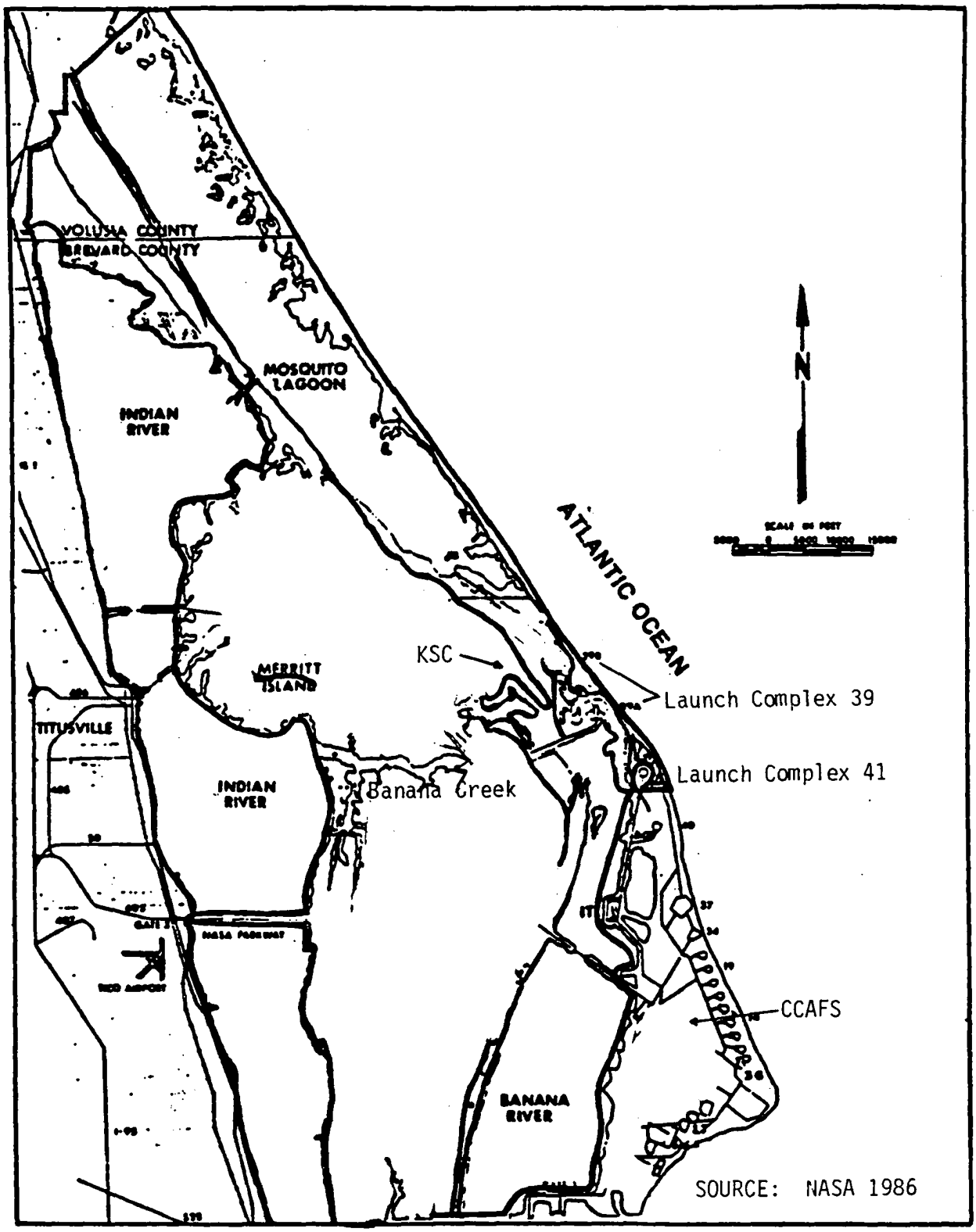



FIGURE 3-8. MAJOR SURFACE WATER BODIES NEAR KSC

### 3.2.3.2 Surface Water Quality

In compliance with the Clean Water Act, the state of Florida has classified the surrounding surface waters, according to five classifications based on their potential use and value.

All of the Mosquito Lagoon area within KSC boundaries and the northern-most segment of the Indian River are designated as Class II waters (Shellfish Propagation and Harvesting) (see Figure 3-9). Class II waters establish stringent limitations on bacteriological and fluoride pollution. The discharge of treated wastewater effluent is prohibited, and dredge and fill projects are regulated to protect the area from significant damage. The remainder of surface waters surrounding KSC are designated as Class III (Body Contact Recreation and Fish and Wildlife Propagation) waters (Figure 3-9).

Banana Creek water quality (Class III) is influenced by non-point source runoff from the Shuttle Landing Facility, the Vertical Assembly Building area, Kennedy Parkway, and undeveloped areas of the Merritt Island National Wildlife Reserve. Banana Creek has experienced fish kills in the summer when high temperature and extensive cloud cover reduce the dissolved oxygen levels in the shallow waters of the Creek.

There are about 21,422 acres of mosquito control impoundments in 75 cells at KSC. These impoundments dominate the shoreline of KSC. Water levels are managed by the USFWS for mosquito control purposes.

Limited water quality data and the applicable standards for the Indian River, Banana Creek, the Banana River, and Mosquito Lagoon are provided in Table 3-4. These data indicate that with the exception of the mosquito control impoundments north of Pad 39-B, the State of Florida standards are not exceeded.

The surface waters within the Merritt Island National Wildlife Refuge have been designated as Outstanding Florida Waters (OFWs) (see Figure 3-10). The OFW designation supersedes other surface water classifications, and water quality standards are based on ambient water quality conditions or the designated surface water standard, whichever is higher. This level of protection prohibits any activity that would reduce water quality below the existing levels. The entire Mosquito Lagoon has been designated by the State of Florida as an Aquatic Preserve (see Figure 3-11).

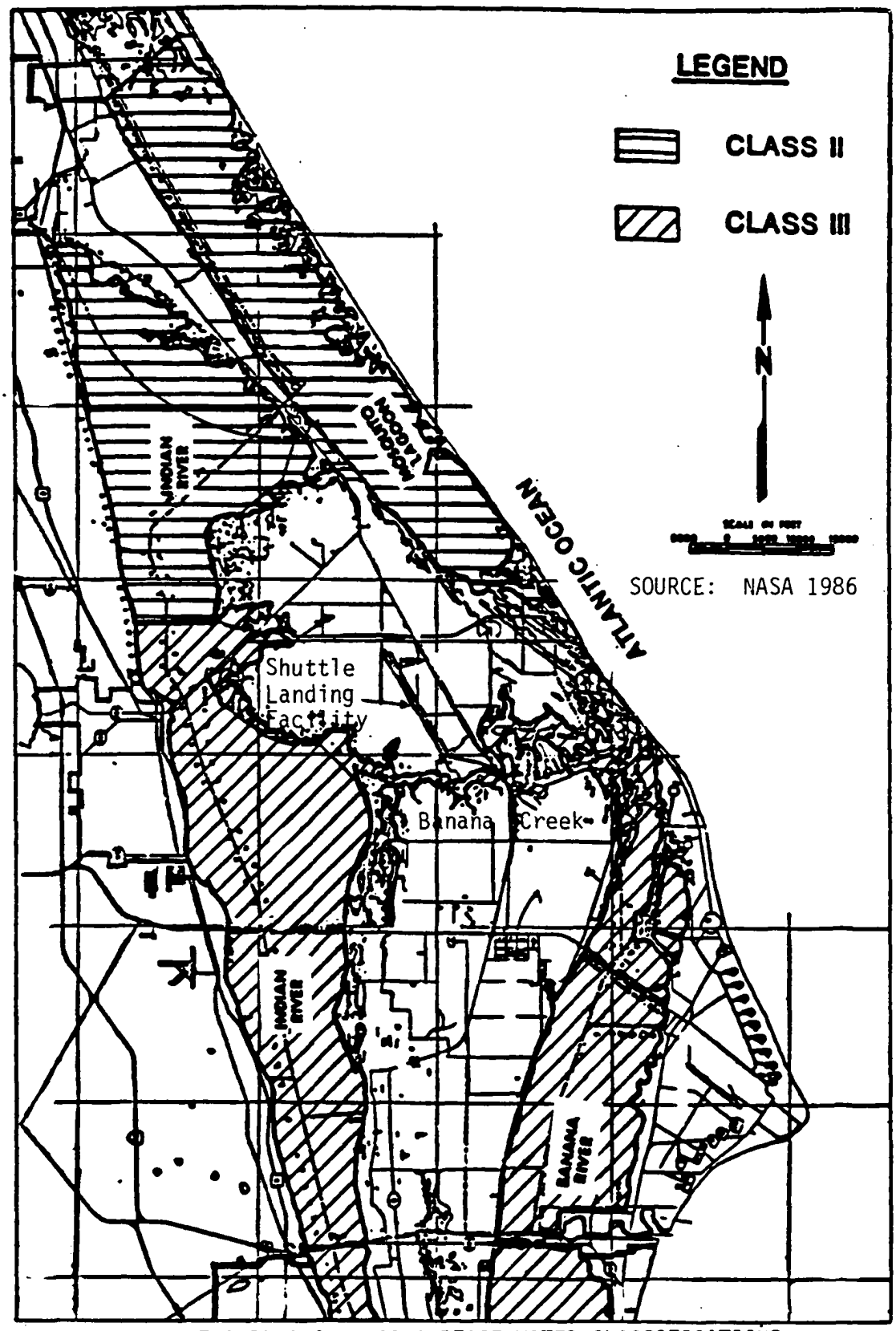



FIGURE 3-9. KSC SURFACE WATER CLASSIFICATIONS

## TABLE 3-4. SURFACE WATER QUALITY AT KSC*

| Water Body | Salinity (ppt) | pH | Dissolved Oxygen | Nitrogen | Phosphorous | Turbidity (JTU) |
|---|---|---|---|---|---|---|
| Indian River (Titusville - north) (FDER Class II) | 30.2 | 8.2 | 6.9 | 0.03 | 0.06 | 3.64 |
| Indian River (Titusville - south to NASA Parkway West) (FDER Class III) | 28.4 | 8.1 | 6.9 | 0.04 | 0.06 | 3.75 |
| Indian River (NASA Parkway West south to Bennett Causeway) (FDER Class III) | 27.8 | 8.1 | 7.2 | 0.06 | 0.05 | 5.0 |
| Mosquito Lagoon (at KSC) (FDER Class II) | 31.8 | 8.2 | 6.9 | 0.03 | 0.08 | 4.9 |
| Banana Creek (FDER Class III) | 11.4 | 8.2 | 9.8 | 0.003 | 0.38 | 7.5 |
| Mosquito Control Impoundments (north of Launch Complex 39) | 9.4 | 8.8 | 11.1 | <0.02 | 0.31 | 14.8 |
| Banana River (NASA Causeway, north to near Titan IV Launch Complex 41) (FDER Class III) | 25.9 | 8.2 | 6.9 | 0.03 | 0.05 | 4.3 |
| FDER Class II Standards | chlorides 10% above background (marine) | 6.5-8.5 (1 unit variation) | 5.0 Mean 4.0 Min. | (See note A) | 0.0001 (elemental) (See note C) | 29 NTU above background |
| FDER Class III Standards | chlorides 10% above background (marine) | 6.5-8.5 (fresh) 6.5-8.5 (marine) (1 unit variation) | 5.0 Min. (fresh) 4.0 Min. (marine) | (See note B) | 0.0001 (elemental) (marine) (See note D) | 29 NTU above background |

*All measurements are in mg/l unless otherwise noted.

NOTES:
A. No alteration so as to cause imbalance in natural population.
B. No alteration so as to cause imbalance in natural population.
C. Total P - no alteration so as to cause imbalance in natural population.
D. Total P - no alteration so as to cause imbalance in natural population.

Source: NASA 1986.

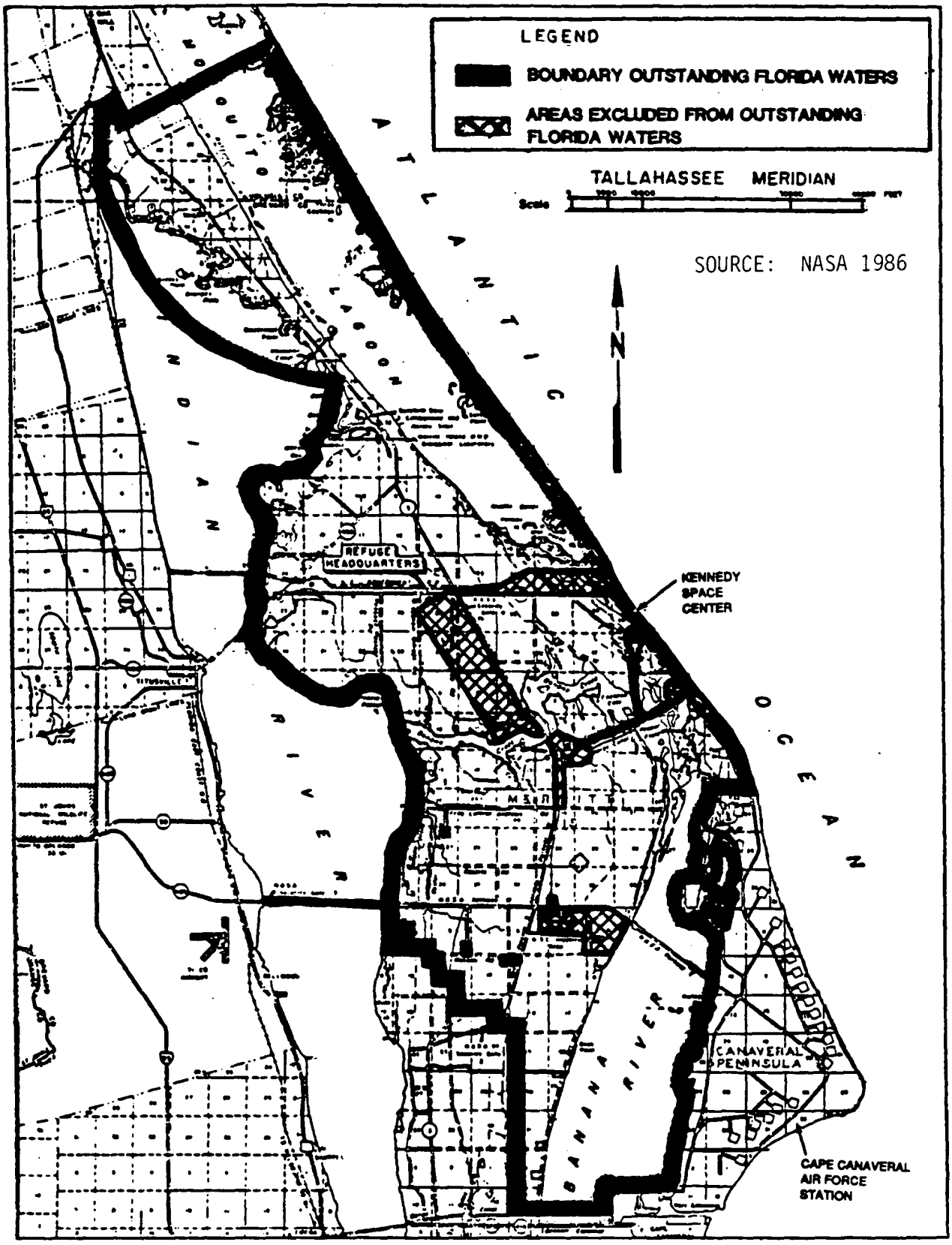



FIGURE 3-10. KSC OUTSTANDING FLORIDA WATERS

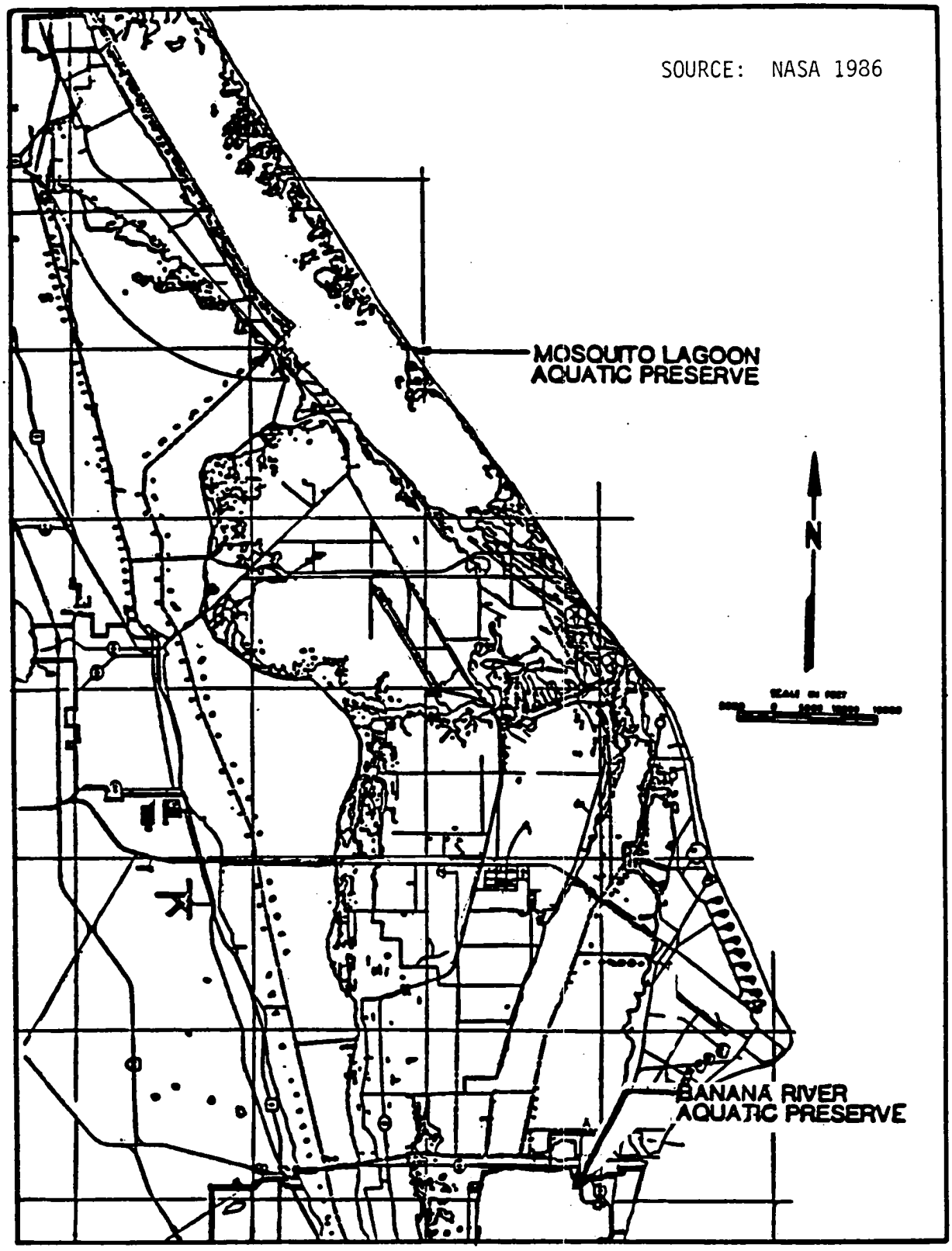



FIGURE 3-11. KSC AREA AQUATIC PRESERVES

The Florida Department of Natural Resources (FDNR) in its capacity to manage marine fisheries has established water classifications that regulate the harvesting of shellfish. Shellfish may be harvested from "approved" or "conditionally approved" areas only, with "conditionally approved" areas closed to harvesting for 72 hours after rainfalls which exceed predetermined amounts. Prohibited and unclassified areas can not be harvested. Shellfish harvesting classification of the waters surrounding KSC/CCAFS are illustrated in Figure 3-12.

Launch Complex 41 at the Cape Canaveral Air Force Station (CCAFS) is bordered by the Banana River Aquatic Preserve to the west and the Atlantic Ocean to the east. The Banana River is classified by the State of Florida as a Class III water for body contact recreation and the propagation and maintenance of diverse fish and wildlife. Surface runoff from Launch Complex 41 flows toward the Banana River. Basic water quality data for the Banana River can be found in Table 3-4.

### 3.2.3.3 Ground Waters

Three geohydrologic units underlie KSC and the CCAFS. In descending order, these units are: a Surficial Aquifer, Secondary Semi-Confined Aquifers (found in the confining layer underlying the Surficial Aquifer), and the Floridan Aquifer.

#### Surficial Aquifer

The Surficial Aquifer (an unconfined hydrogeologic unit) is contiguous with the land surface and is recharged by rainfall along the coastal ridges and dunes, with little recharge occurring in the low swampy areas. The recharge area at KSC/CCAFS for the Surficial Aquifer is shown in Figure 3-13.

In general, water in the Surficial Aquifer near the groundwater divide of the island has potential gradients that tend to carry some of the water vertically downward to the deepest part of the Surficial Aquifer and potentially to the upper units of the Secondary Semi-Confined Aquifers (NASA 1986). East and west of this zone, water in the Surficial Aquifer has vertical and horizontal flow components. Farther toward the coastline, circulation becomes shallower until, at some point, flow is essentially horizontal to the water table (Figure 3-14). Major discharge points for the Surficial Aquifer are the estuary lagoons, shallow seepage occurring to troughs and swales, and evapotranspiration. Inland fresh surface waters are primarily derived from surficial groundwater.

#### Secondary Semi-Confined Aquifers and the Floridan Aquifer

Groundwaters under artesian and semi-confined conditions, the Floridan and Secondary Aquifers, have upward flow potentials. Because of the thickness and the relatively impermeable nature of the confining units, however, it is thought that no significant inter-aquifer leakage is occurring from the Floridan Aquifer naturally. The general horizontal direction of flow in the Floridan Aquifer is northerly and northwesterly. The great elevation differential between the Floridan Aquifer recharge areas (e.g., Polk and Orange Counties) and discharge areas along the Atlantic Coast provides the

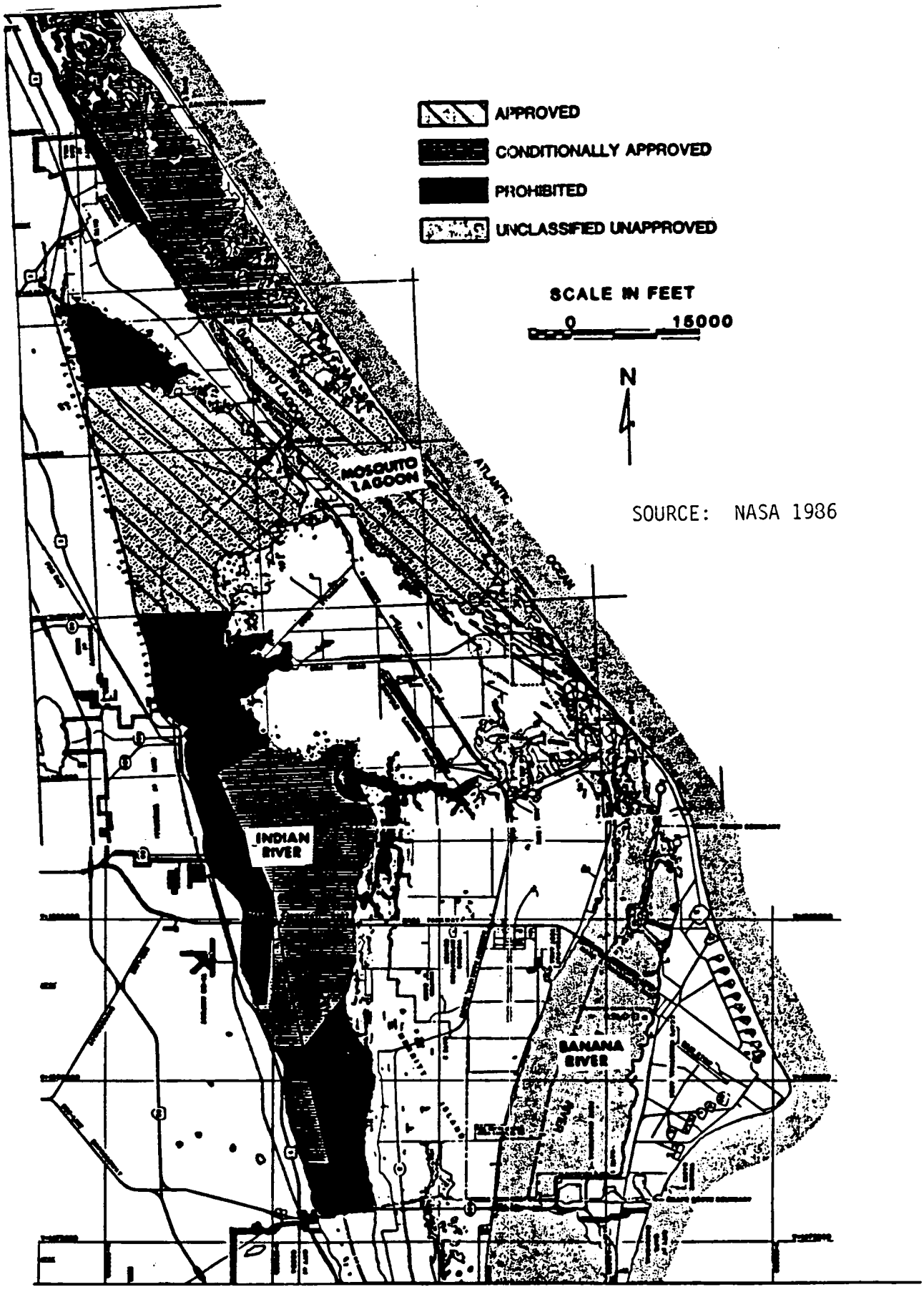



FIGURE 3-12. KSC SHELLFISH HARVESTING AREAS

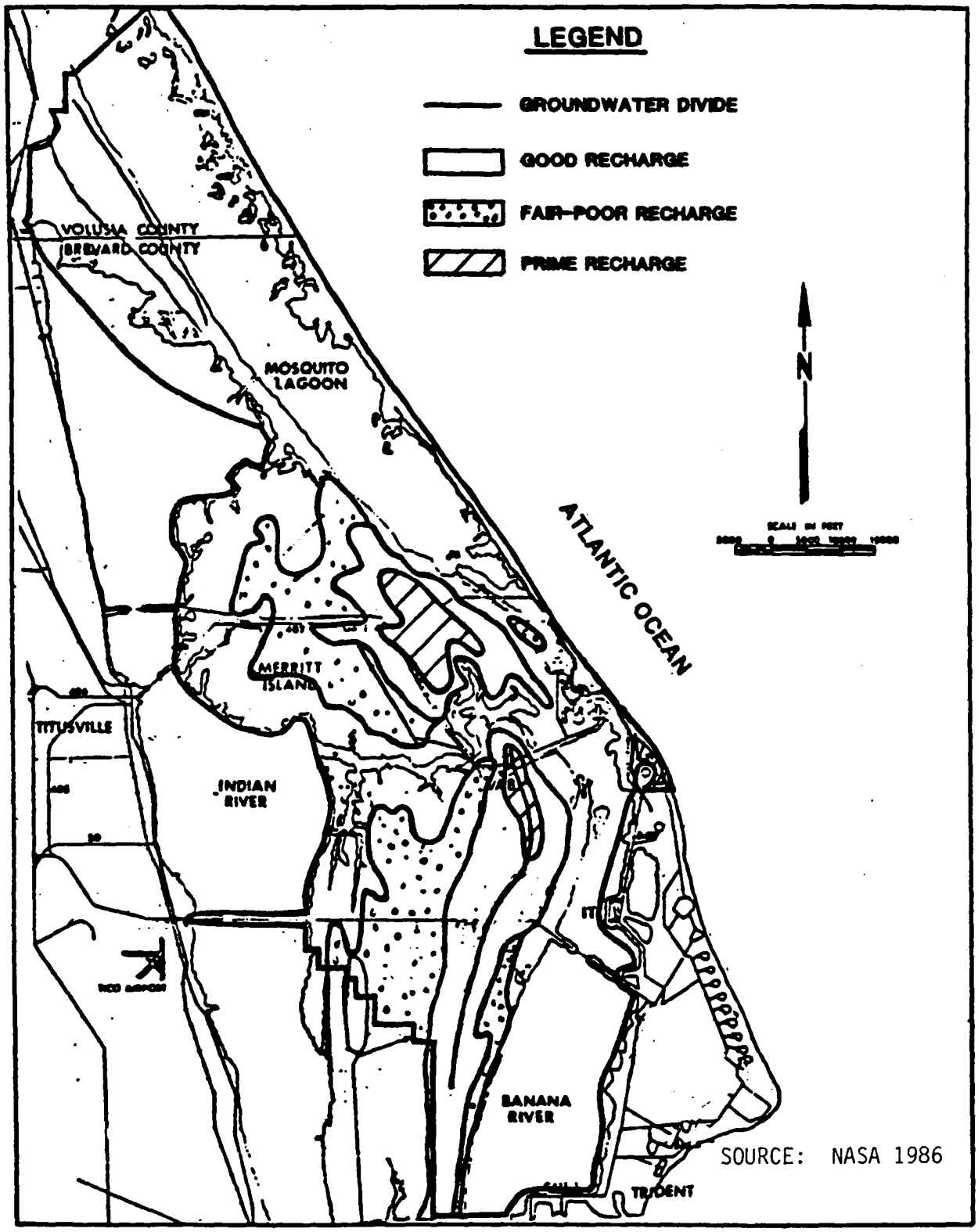



FIGURE 3-13. POTENTIAL RECHARGE FOR SURFICIAL AQUIFER

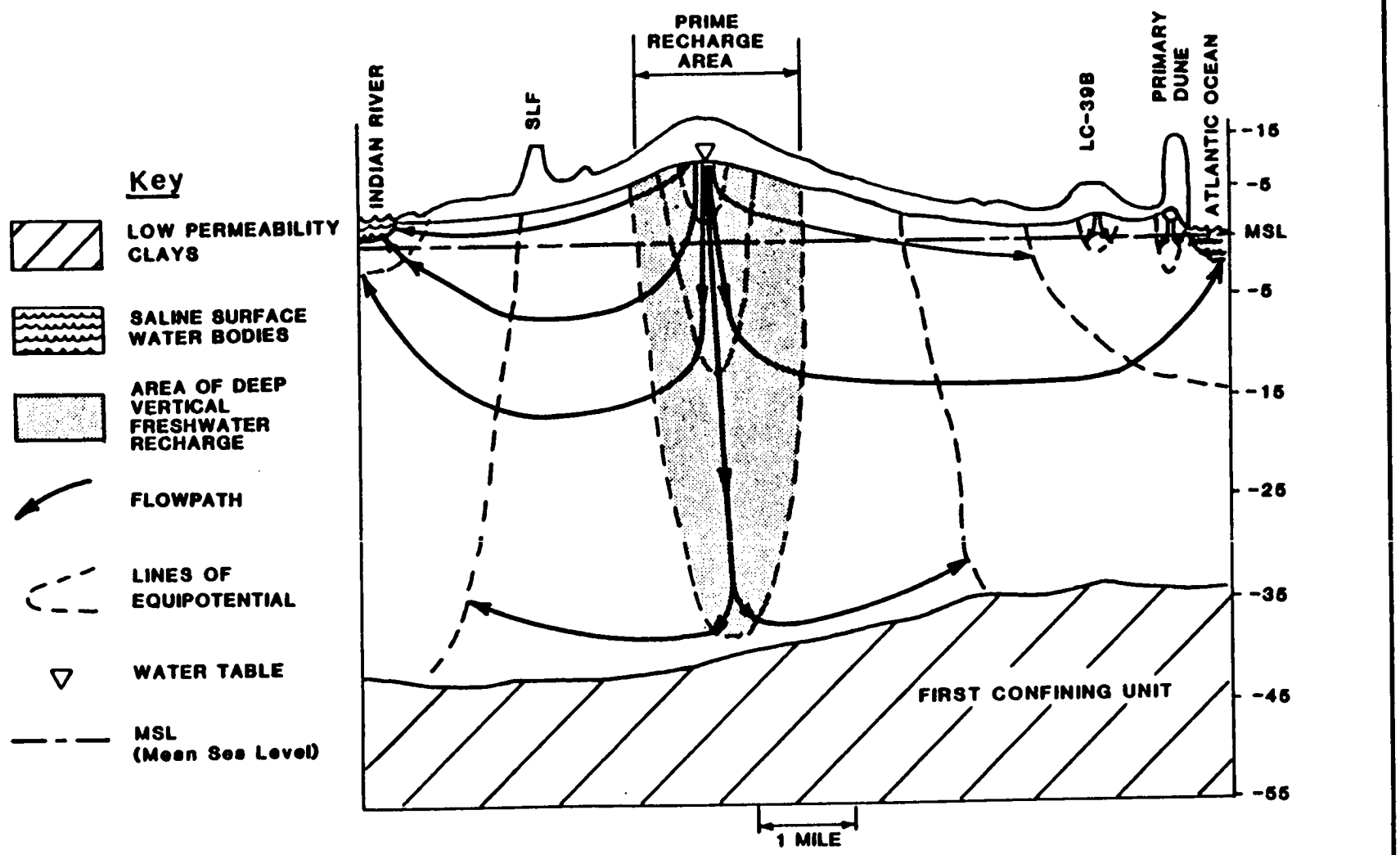



FIGURE 3-14. QUALITATIVE FLOW NET FOR THE SURFICIAL AQUIFER ILLUSTRATING GROUNDWATER CIRCULATION. NOTE AREAS OF DEEP VERTICAL RECHARGE.

SOURCE: NASA 1986

potential for the flowing artesian pressure experienced at KSC. Recharge to the Secondary Aquifers is dependent on leakage through the surrounding lower permeability beds.

3.2.3.4 Quality of Groundwater

Water from the Floridan Aquifer at KSC and CCAFS is highly mineralized (principally chlorides) and is not used as a potable water source.

Florida groundwater criteria have been established as four classes: Class G-I through G-IV, with Class G-I being the most restrictive. The majority of the State's groundwaters are classified as G-II (potable water use), and for all practical purposes, there are no G-I or G-IV classifications in Florida.

Overall, water in the surficial unconfined aquifer at CCAFS is of good quality and meets State of Florida Class groundwater quality standards for potable water use with the exception of chloride, iron, and total dissolved solids. The elevated concentrations of these parameters are due to the influence of adjacent saline surface waters. No potable water wells are located at Launch Complex 41 or in its vicinity. At KSC, high chloride concentrations occur on the north, east, and west fringes due to intrusion from surrounding saline water bodies. Thus, water quality improves towards the north-south axis of KSC because this is where prime areas of freshwater recharge occur and where potentiometric (water table) heads have prevented seawater intrusion.

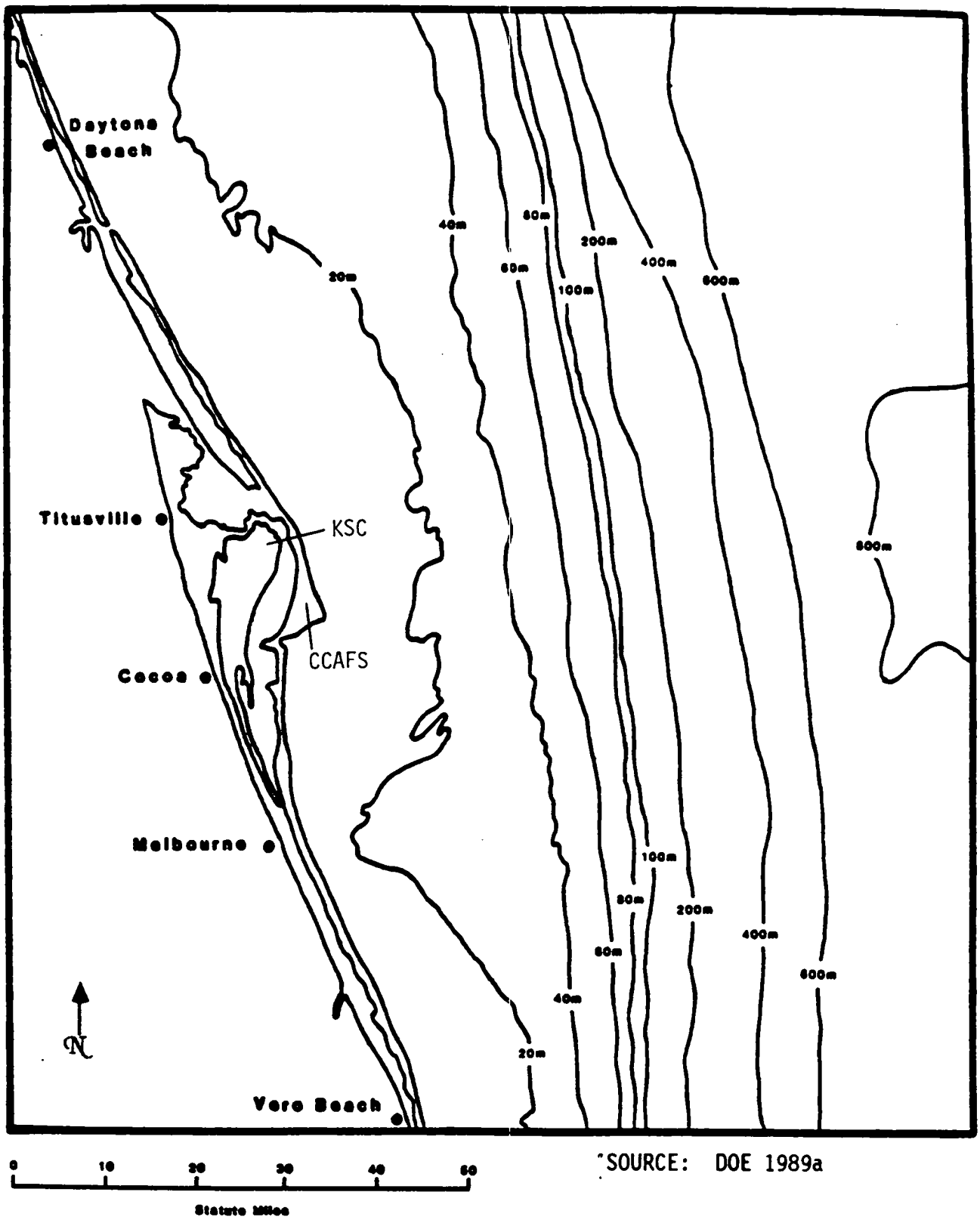
Preliminary data for the Secondary Semi-Confined Aquifer show that some of these aquifers may be marginal water sources; however, it appears that they are not capable of sustaining large scale development.

3.2.3.5 Offshore Environment

The Atlantic Ocean offshore environment at KSC/CCAFS can be described according to its bottom topography and characteristics of ocean circulation in the area.

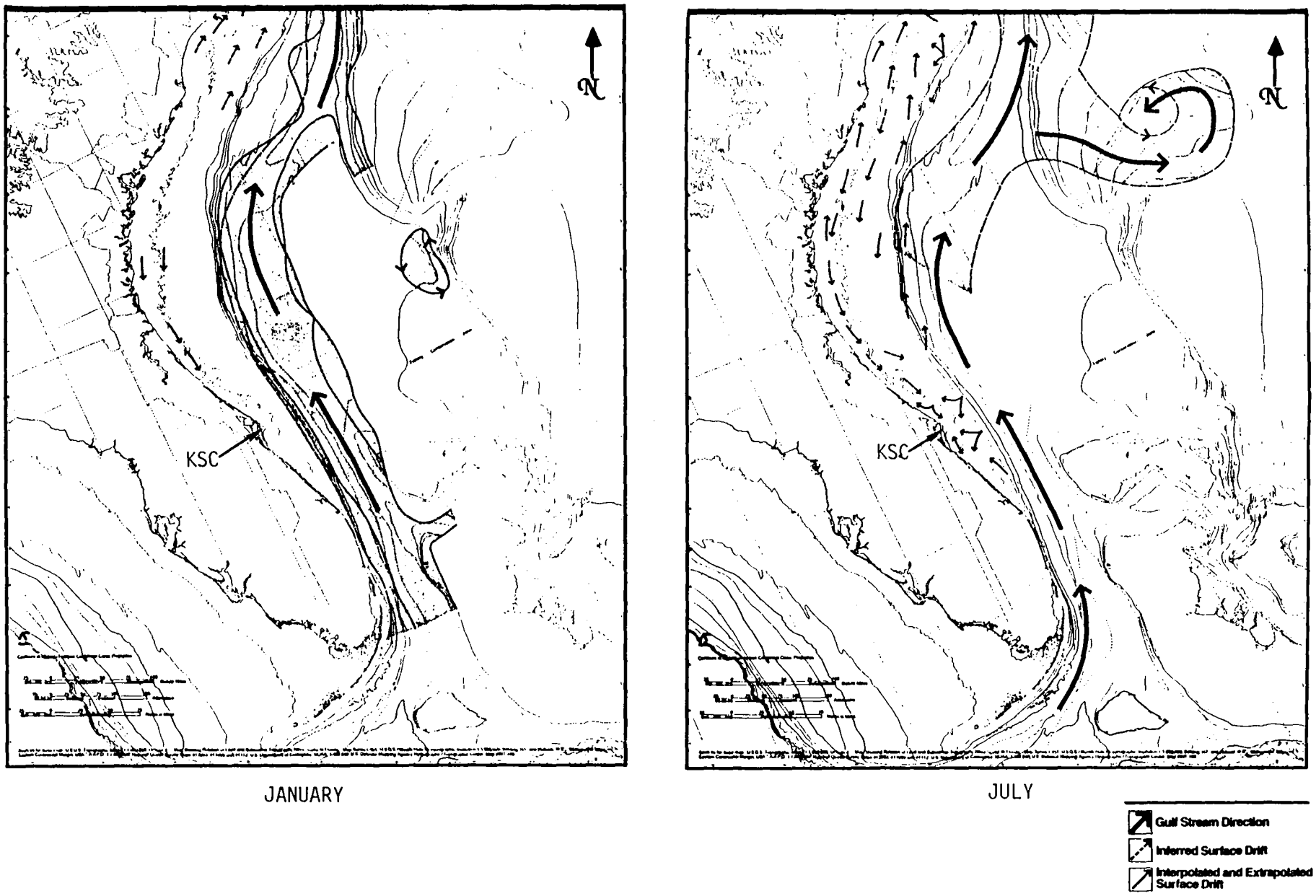
Out to depths of about 60 feet, sandy shoals dominate the underwater topography. The bottom continues seaward at about the same slope out to about 34 miles where the bank slopes down to depths of 2,400 to 3,000 feet to the Blake Plateau. The Blake Plateau extends out to about 230 miles from the shore at KSC/CCAFS. Figure 3-15 shows the bathymetry of the offshore areas.

Offshore currents in general reflect the general northern flow of the Gulf Stream, as illustrated by Figure 3-16 (NOAA 1980). Studies of water movements in the area indicate a shoreward direction of the current for the entire depth, surface to bottom, in the region out to depths of 60 feet (18 nautical miles) at speeds of several miles per day. Wind-driven currents generally determine the current flow at the surface. During the autumn (Oct.-Nov.) the prevailing winds are out of the northeast, with occasional episodes of winds out of the south. The prevailing winds transport surface waters toward the shore, with an offshore component in shallow bottom waters which diminishes rapidly with distance offshore (INSRP 1989). The net effect is




SOURCE: DOE 1989a

FIGURE 3-15. OFFSHORE WATER DEPTH NEAR KSC/CCAFS




Source: NOAA 1980

FIGURE 3-16. OCEAN CURRENTS AND WATER MASSES OFFSHORE OF KSC FOR JANUARY AND JULY

that material suspended in the water column tends to be confined to the area near the coast as is the heavier material found on the bottom.

The occasional episodes of northward winds results in a net movement of subject waters offshore, with an inshore movement of the higher density bottom waters. Materials suspended in the surface waters are transported in an offshore direction, with the heavier bottom materials moving in shore.

In the region out to the sloping bank, the flow is slightly to the north tending to move eastward when the winds blow to the south. Water over the Blake Plateau flows to the north most of the time and is known as the Florida current of the Gulf Stream (USAEC 1975).

### 3.2.4 Geology and Soils

KSC/CCAFS is located on a barrier island composed of relict beach ridges. This island parallels the shoreline separating the Atlantic Ocean from the Indian River, Indian River Lagoon, and Banana River. The area is underlain by limestone formations a few thousand feet thick. The formations, from oldest to youngest, respectively are: the Avon Park and the Ocala; overlying the artesian Floridan Aquifer are the confining beds of the Hawthorn Formation; the confining beds are overlain by Pleistocene and Recent Age unconsolidated deposits.

Soils in the area of KSC/CCAFS have been mapped by the U.S. Department of Agriculture Soil Conservation Service (SCS). Five major soil associations have been identified by the SCS. (The locations of the major soils associations can be found in NASA 1986.) The soils in the immediate vicinity of Launch Complex 39 at KSC consist of poorly drained, nearly level saline to brackish soils. The principal soils association at Launch Complex 41 are moderately to excessively drained, sandy soils on level or moderately sloping topography.

### 3.2.5 Biological Resources

#### 3.2.5.1 Terrestrial Biota

Vegetation communities and related wildlife habitats are representative of barrier island resources of the region (Figure 3-17). Major natural communities include beach, coastal strand and dunes, coastal scrub, and wetlands. Coastal hammocks and pine flatwoods found on KSC to the northwest increase the ecological diversity and richness of the area. About 90 percent of the total KSC land area (about 73,300 acres) is undeveloped, and falls into these community types. About 77 percent (about 12,000 acres) of CCAFS is undisturbed or has reverted back to natural conditions.

##### Major Plant Communities and Related Habitat

The principal communities in the vicinity of Launch Complex 39 at KSC and 41 at CCAFS are beach, coastal strand and dune, coastal scrub, and wetlands. Beaches of KSC and CCAFS are largely unvegetated, but provide significant wildlife resources. The tidal zone supports a high number of marine invertebrates, as well as small fish that are food for many shore birds.

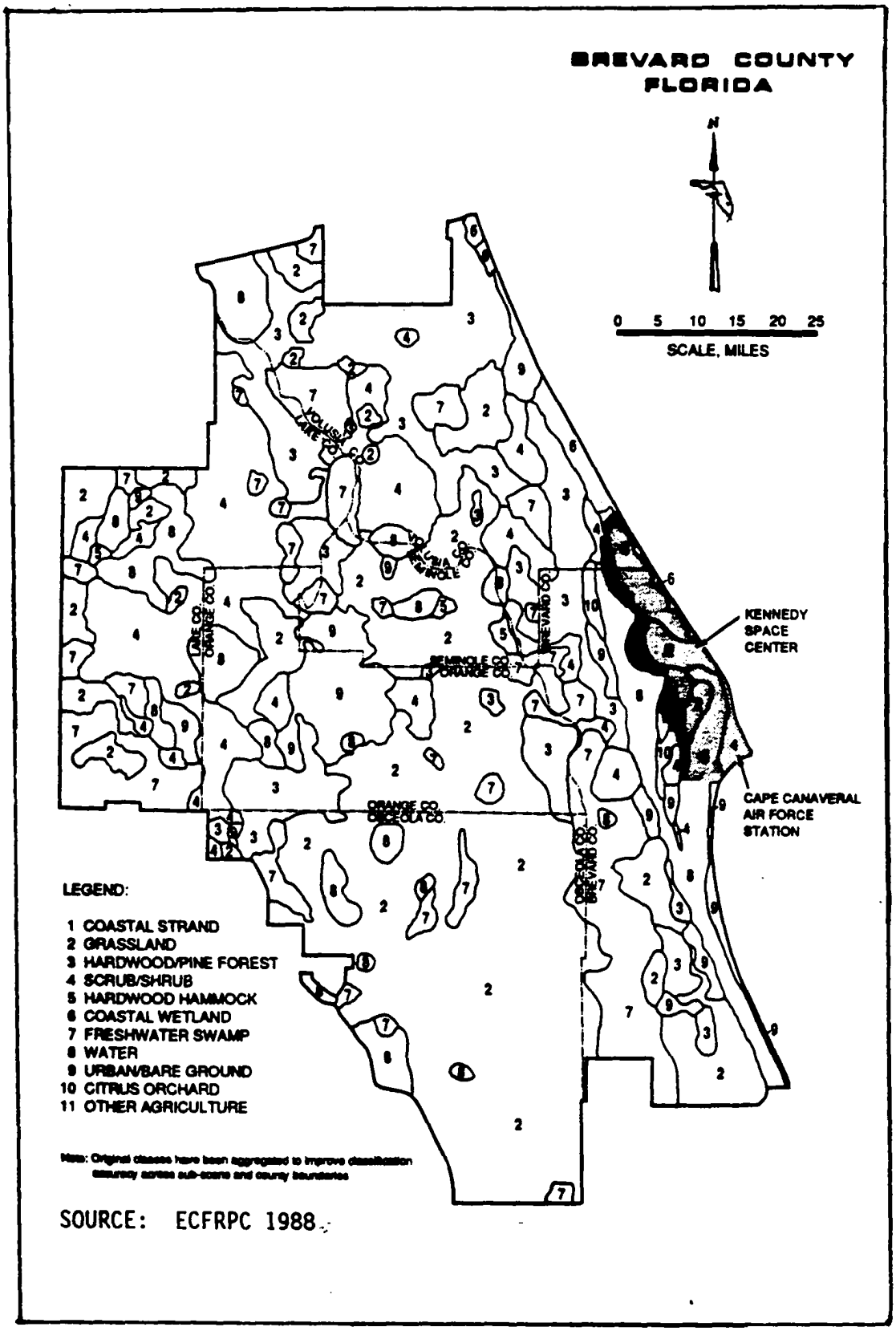



FIGURE 3-17. GENERAL LAND COVER TYPES AT KSC/CCAFS AND VICINITY

Several species of gulls, terns, sandpipers, and other birds use beaches of the Cape Canaveral area. In addition, research indicates that these beaches are very important to nesting sea turtles (see Section 3.2.5.3).

Coastal strand and dune communities are marked by extremes in temperature and prolonged periods of drought. Vegetation on the dunes are dominated by sea oats. Other grasses, such as slender cordgrass and beach grass, also occur. Shrubs such as beach berry and marsh elder, occur in the dune community along with herbs, such as beach sunflower and camphorweed. The strand occurs between the coastal scrub community and the salt spray zone of the dune system. Growth characteristics of strand vegetation produces a low profile that is maintained by nearly constant winds. Plants that can tolerate strand conditions are saw palmetto, wax myrtle, tough buckthorn, cabbage palm, partridge pea, prickly pear, and various grasses.

Coastal scrub is the largest natural community at CCAFS, covering approximately 9,400 acres at CCAFS and almost 20,000 acres at KSC. The coastal scrub association is characterized by xeric tree species, including scrub oak, live oak and sand live oak, and myrtle oak. The scrub community is a harsh environment limited by low soil moisture conditions. Herbaceous and shrub vegetation is sparse and includes wire grass, saw palmetto, tar flower, lantana, wax myrtle, greenbriar, prickly pear, gopher apple, and others.

Wetlands within and surrounding the launch area are important wildlife resources. About 78 percent of KSC, for example, is considered wetland habitat. Wetland types that are found in the area include freshwater ponds and canals, brackish impoundments, tidal lagoons, bays, rivers, vegetated marshes, and mangrove swamps. These wetlands provide resources for a vast assemblage of marine organisms, waterfowl, and terrestrial wildlife.

Pine flatwoods occur principally in the northwest and central portions of KSC. Dominant tree species are pines, including slash pine, longleaf, and sand pine.

Coastal hammocks are characterized by closed canopies provided by cabbage palms, which is the dominant tree species. Additional tree species in hammocks are red bay, live oak, and strangler fig.

Ruderal vegetation dominates sites disturbed by or created by past human activity, such as construction and agriculture. Vegetation communities include Brazilian pepper, Australian pine, wax myrtle and melaleuca. Citrus groves, the only agricultural community currently occurring within KSC, occupy about 2,500 acres of land, slightly over 3 percent of the total KSC land area. The groves occur in the northern portion of KSC along Mosquito Lagoon and on the Merritt Island portion of KSC south of Banana Creek.

Wildlife

Nearly 60 species of reptiles and amphibians are known to inhabit the area. Three of the resident species (the American alligator, the eastern indigo snake, and the Atlantic salt marsh snake) are federally protected.

KSC and the surrounding coastal areas provide habitat for nearly 300 bird species. Nearly 90 species are resident breeders while over 200 species

overwinter at KSC. The breeding, wintering, and migratory bird species and their relative occurrence within 17 habitat types at KSC have been documented and are found in NASA 1986.

The expansive areas of wetlands provide ideal feeding, roosting and nesting habitat for nearly two dozen species of wading birds. Many of the wetlands within the Merritt Island National Wildlife Refuge are managed to provide wintering habitat for approximately 200,000 waterfowl.

Colonial nesting birds occur within 11 rookeries at and near KSC/CCAFS, with 4 rookeries located within 2 miles of Launch Complexes 39 and 41. Among the species utilizing these locations are egrets, ibis, heron, cormorant, and anhingua.

More than 20 species of mammals are known to inhabit the Merritt Island land mass. Mammals include mice, voles, raccoons, opossum, rabbit, wild hog, and aquatic mammals, such as the manatee and bottlenose dolphin.

3.2.5.2 Aquatic Biota

The coastline from Daytona south to Melbourne and extending seaward to a depth of 100 fathoms is one of the most productive marine fishery areas along the southern Atlantic Coast. The inshore waters support an important sea trout and redfish sport fishery. The lagoons and rivers support commercial fishery operations for blue crab and black mullet.

Shellfishing is an important component of the commercial and recreational fishing effort. In 1988 Brevard County produced about 86 percent of total State landings of hard clams (quahogs) and scallops (State of Florida 1989). The commercial scallop fishery predominates off shore; it is estimated that 10.8 million pounds of calico scallops were harvested off Cape Canaveral in 1988, or almost 90 percent of the total State landings. A number of renewable oyster leases are held in the waters near KSC. The southern quahog is the most frequently taken species with large numbers being gathered from the tidal mud flats by both commercial and recreational fishermen. See Figure 3-12 for shellfish harvesting areas around KSC/CCAFS.

The lagoon system surrounding KSC provides both recreational fin and shrimp fishing. It is estimated that, in 1985, 90,300 recreational fishermen utilized the fishery resources surrounding KSC. The fish fauna of the Indian River lagoon system has received considerable attention. The fresh and brackish waters associated with the KSC area are reported to support 141 species.

Benthic macroinvertebrates of the northern Indian and Banana Rivers can be classified as estuarine-marine animals. A total of 122 species of benthic macroinvertebrates have been reported from brackish lagoons surrounding Launch Complex 39A and the northern Banana River. Although shrimp species of commercial importance were collected, the northern Indian River is not considered an important nursery area for these species. Mosquito Lagoon, however, is considered an important shrimp nursery area. Blue crabs also were determined to spawn in the area.

### 3.2.5.3 Endangered and Threatened Species

The USFWS and Florida Game and Fresh Water Fish Commission (FGFWFC) protect a number of wildlife species listed as endangered or threatened under the Federal Endangered Species Act of 1973 (as amended), and under the Florida Endangered and Threatened Species Act of 1977 (as amended), respectively. A list of the protected species at KSC/CCAFS is found in Table 3-5. The Federal list contains seven species as endangered and three species as threatened. The State of Florida lists two additional species as threatened.

A review of CCAFS endangered or threatened species shows that only three species (southeastern Kestrel, Florida scrub jay, eastern indigo snake) potentially occur in the immediate vicinity of Launch Complex 41. An additional three species (woodstork, bald eagle, peregrine falcon) may occasionally occur in wetlands located to the east of the complex.

Caribbean manatees, green turtles, ridley turtles, and loggerhead turtles are known to occur in the Banana River, Mosquito Lagoon, and along Atlantic Ocean beaches. Of the remaining two species, dusky seaside sparrow is now thought to be extinct, and the red-cockaded woodpecker is not expected to occur in the vicinity of Launch Complex 41 due to the absence of suitable habitat.

Ten nesting locations that have been used by the bald eagle have been located at KSC. A 1985 survey noted that 5 locations were active, with 10 adults producing 7 eaglets. Nesting typically occurs between October and mid-May. Eagles are susceptible to disturbance during the mating and rearing cycle from courtship through about the first 12 weeks of nesting.

With respect to the West Indian Manatee, the following areas at KSC/CCAFS have been designated as Critical Habitat by the USFWS: the entire inland section of water known as the Indian River, from its northernmost point immediately south of the intersection of U.S. Highway 1 and SR-3; the entire inland section of water known as the Banana River; and all waterways between the Indian and Banana Rivers (exclusive of those existing manmade structures or settlements that are not necessary to the normal needs of the survival of the species). On March 11, 1990, the U.S. Fish and Wildlife Service established the waters of the Banana River north of State Road 528 as a manatee refuge. This area will be actively managed for this species, and public boat traffic is prohibited.

Osprey, listed by the Convention on International Trade in Endangered Species of Wild Flora and Fauna were thought to be actively utilizing a total of 25 nesting sites near KSC. The closest site was a nesting area about 2 miles to the west of KSC Launch Complex 39 (about 3 miles approximately northwest of CCAFS Launch Complex 41).

## 3.2.6 Socioeconomics

### 3.2.6.1 Population

The demographics of the local area sites are based upon the workforce employed at CCAFS and KSC and are influenced by the influx of people and their distribution prior to and during launches. During a launch, approximately

TABLE 3-5. ENDANGERED AND THREATENED SPECIES RESIDING OR SEASONALLY OCCURRING ON KSC/CCAFS AND ADJOINING WATERS

| Species | Status | | |
|---|---|---|---|
| | USFWS* | FGFWFC** | |
| **Mammals** | | | |
| Caribbean manatees (*Trichechus manatus*) | E | E | |
| **Birds** | | | |
| Wood stork (*Mycteria american*) | E | E | |
| Bald eagle (*Haliaeetus leucocephalus*) | E | T | |
| Peregrin falcon (*Falco peregrinus*) | T | E | |
| Southeastern kestrel (*Falco sparverius*) | - | T | |
| Red-cockaded woodpecker (*Picoides borealis*) | E | T | |
| Florida scrub jay (*Ahpelocoma coerulesens*) | - | T | |
| Dusky seaside sparrow (*Ammospiza maritima*) | E | E | (last known individual died in captivity in 1987) |
| **Reptiles** | | | |
| Atlantic green turtle (*Chelonia mydas*) | E | E | |
| Atlantic ridley turtle (*Lepidochelys kempi*) | E | E | |
| Atlantic loggerhead turtle (*Caretta caretta*) | T | T | |
| Eastern indigo snake (*Drymarchon corais*) | T | T | |

Source: USAF 1986

Key
*U.S. Fish and Wildlife Service
**Florida Game and Fresh Water Fish Commission
E = Endangered.
T = Threatened.

6,000 employees may be onsite. The population may increase during launches of special interest by more than 100,000 spectators, varying with the time of day and year, and the weather. These individuals occupy nearby beach areas and line the public roads in the area. Onsite population at launch time is increased by about 17,300 visitors and press personnel (Harer 1988). These additional people are distributed among various viewing areas as follows:

- 2,000 people at the #1 VIP Site (Static Test Area)
- 9,000 people at the #2 VIP Site (east of the Banana River Causeway drawbridge; total could increase to 11,000-13,000 people if #1 VIP Site cannot be used)
- 2,000 press members at the site west of the Banana River drawbridge
- 4,000 people at the Indian River Causeway Site (east of the drawbridge for 1 mile)
- 250 people at the O&C Building and 50 people at the LCC Building.

3.2.6.2 Economy

The economy of the surrounding area is influenced by the presence of both CCAFS and KSC, but the area's dependence upon them has lessened in recent years. NASA civilian employment in Brevard County accounted for about 11 percent of county employment in 1987, whereas in 1967 it accounted for about 25 percent of county employment (Brevard County 1988a). KSC contracts, however, provide a substantial amount of income, totaling about $720 million in 1987.

3.2.6.3 Transportation

The area is serviced by Federal, State, and local roads. Primary highways include Interstate 95, US-1, State Route (SR)-A1A, and SR-520. Urban areas on the beaches and Merritt Island are linked by causeways and bridges. Road access to KSC is from SR-3 and the Cape Road from the south, NASA Causeway (SR-405) and the Beach Road (SR-406) from the west, and Kennedy Parkway from the north. There are about 211 miles of roadway at KSC; 163 miles paved and 48 miles unpaved. CCAFS is linked to the highway system by the South Gate via SR-A1A, NASA Causeway, and Cape Road.

Rail transportation in the area is provided by Florida East Coast Railway. A mainline traverses the cities of Titusville, Cocoa, and Melbourne. Launch Complex 41 is serviced by a branch line from Titusville through KSC. At KSC, approximately 40 miles of rail track provide heavy freight transport to KSC.

Melbourne Regional Airport is the closest air transportation facility and is located 30 miles south of CCAFS. CCAFS contains a skid strip used for Government aircraft and delivery of launch vehicles. Any air freight

associated with operation of Launch Complex 41 uses the CCAFS skid strip. Ferrying and support aircraft serving KSC utilize the Shuttle Landing Facility.

Port Canaveral is the nearest navigable seaport and has a total of 1,578 feet of dockage available at existing wharf facilities.

3.2.6.4 Public and Emergency Services

A mutual agreement exists between the City of Cape Canaveral, KSC, and the Range Contractor at CCAFS for reciprocal support in the event of an emergency or disaster. Two fire stations located in the Vertical Assembly Building (VAB) Area and the Industrial Area provide for effective coverage of KSC.

Security operations include access control, personnel identification, traffic control, law enforcement, investigations, classified material control, and national resource protection. The Brevard and Volusia County Sheriff's departments, the USFWS and the National Park Service supplement KSC security forces in patrolling non-secure areas of KSC (e.g., Cape Canaveral National Seashore, Merritt Island National Wildlife Refuge) (NASA 1986).

Medical services are provided at the facilities and by hospitals at Patrick Air Force Base and in Cocoa, Titusville, and Melbourne. CCAFS is equipped with a dispensary under contract to NASA. Medical services are provided to KSC by an Occupational Health Facility and an Emergency Aid Clinic.

No public school facilities are present on CCAFS or KSC. All school-age children of the KSC and CCAFS workforce attend school in the vicinity in which they live.

No recreational facilities are present on CCAFS, except for those associated with the Trident Submarine Wharf, a service club, and a naval recreation facility. Cultural facilities on station include the Air Force Space Museum, tow facilities, and Mission Control, all located at the southern portion of the base. Offbase military and civilian personnel utilize recreational and cultural facilities available within the communities.

KSC has a 238 acre recreational area (Complex 99) located on the Banana River near the southern limit of KSC property (NASA 1979). The Visitor's Information Center at KSC, located about 6 miles east of U.S. Highway 1, provides exhibits, lectures and audio-visual displays, and bus tours on the facility for visitors.

KSC and CCAFS obtain their potable water from the City of Cocoa water system under a contract that provides for some 9 million gallons per day. Approximately half that amount is normally used by the two facilities. The on-site distribution systems are sized to accommodate the constant high volume flow required by the launch deluge system. The city's well field in Orange County has a capacity of 32 million gallons per day (USAF 1986).

KSC also enforces procedures, plans and personnel training with respect to the use and handling of radioactive sources. Comprehensive radiological

contingency plans have been developed to address all launch phase accidents that could potentially involve the Radioisotope Thermoelectric Generator (RTG) aboard the Ulysses spacecraft. These plans conform to the requirements of the Federal Radiological Emergency Response Plan that involves the efforts of numerous government agencies including NASA, DOE, the Department of Defense, the U.S. Environmental Protection Agency and the State of Florida.

### 3.2.6.5 Historic/Archaeologic Resources

A map showing the relative locations of State listed archaeologic sites is provided in Figure 3-18.

A systematic survey of areas in the Merritt Island National Wildlife Refuge was conducted in 1978 (NASA 1986). No significant cultural resources were found other than four historic sites: Sugar Mill Ruins, Fort Ann, the Old Haulover Canal, and the Dummett homestead.

Two locations were assessed in 1981 (NASA 1986). One area covered 6 acres where Peacock Pocket Road marks the east boundary and SR-402 borders on the north; the other area was located on the south edge of SR-402 approximately 2,300 feet west of Peacock Pocket Road. No significant archaeological sites were found on either of the two locations. No significant cultural resources were found as the result of other surveys, which included a 1982 survey of the United Space Booster Facility tract on Merritt Island and of the Space Shuttle Solid Rocket Booster Facility site.

An archaeological/historical survey of CCAFS was conducted in 1982 (USAF 1986). It was determined that Cape Canaveral had been inhabited for 4,000 to 5,000 years. The survey located 32 prehistoric and historic sites and several uninvestigated historic localities. The initial results of the field survey indicated that many of the archaeological resources had been severely damaged by construction of roads, launch complexes, powerlines, drainage ditches, and other excavation. None of these sites are located in the vicinity of Launch Complex 41.

Recently, NASA developed a site along Banana Creek to allow VIPs to view Shuttle launches. Because it was determined that this site contained state listed archaeologic site BR170, NASA funded an extensive archaeologic dig of this site that was complete in 1988 in conjunction with the development of the area.

## 3.3 GLOBAL COMMONS

This section provides a general overview of the global commons in terms of overall population distribution and density, general climatological characteristics, and surface type (i.e., ocean, rock, soil), and also provides a brief discussion of the global atmospheric inventory of plutonium. The information provided was extracted primarily from the "Overall Safety Manual" prepared for the U.S. Atomic Energy Commission in 1975 (USAEC 1975). The "Overall Safety Manual" utilized worldwide population statistics and other information compiled into 720 cells of equal size. The cells were derived by

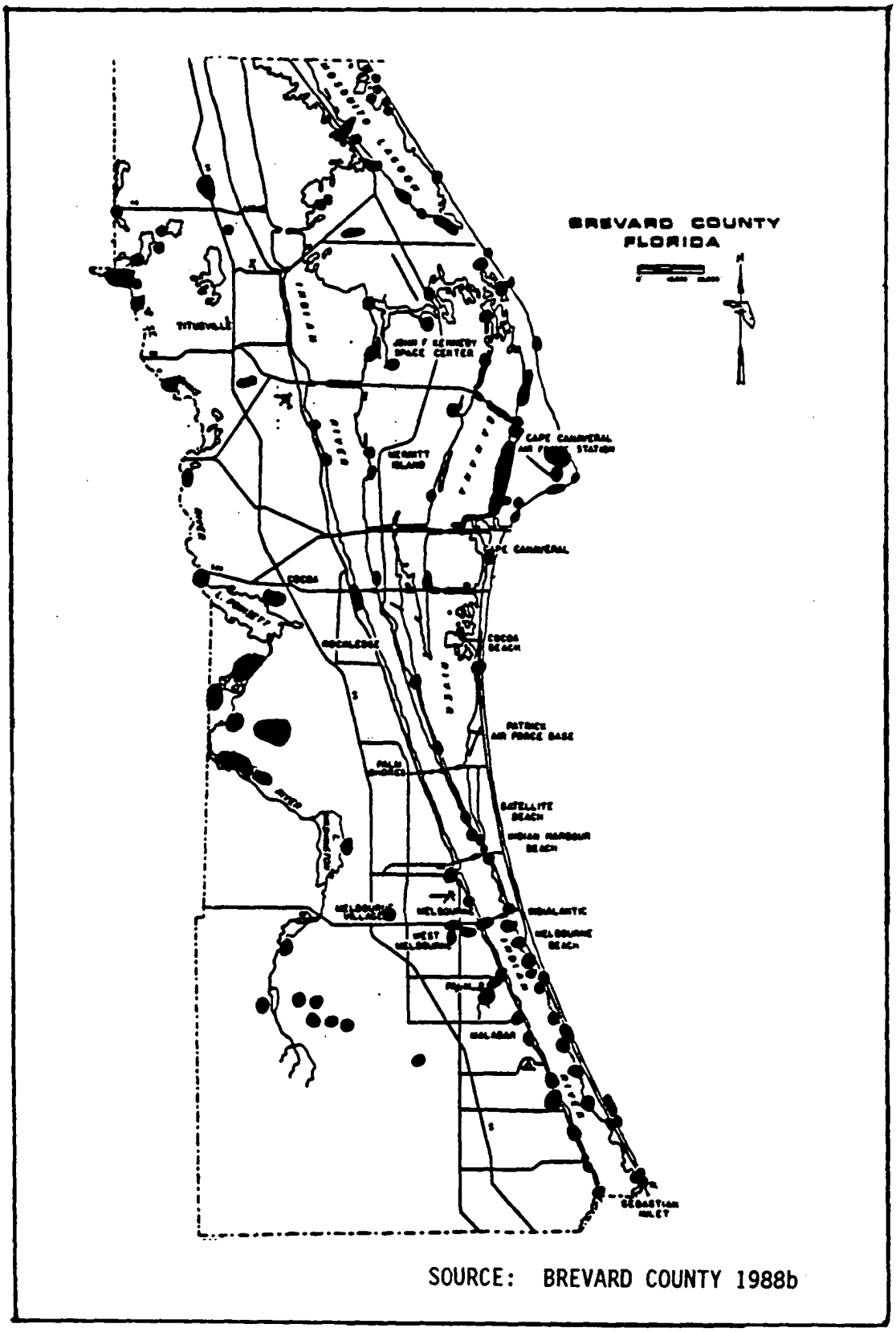



FIGURE 3-18. GENERAL LOCATIONS OF HISTORICAL/ARCHAEOLOGICAL RESOURCES IN THE VICINITY OF KSC/CCAFS

dividing the entire Earth from pole to pole into 20 latitude bands of equal area. Each latitude band was then segmented into 36 equal size cells for a total of 720 cells. Given that each of the cells covered an area of the Earth equal to 273,528 square miles, it has been assumed for the purposes of this discussion that while worldwide population, for example, has certainly changed since the reference was prepared, the change is not significant relative to a given 273,528 square mile cell.

### 3.3.1 Population Distribution and Density

Figure 3-19 illustrates the distribution of the Earth's population across each of the 20 equal area latitude bands. It should be noted that the population scale is logarithmic. Figure 3-20 illustrates the land-adjusted population densities within the latitude bands.

From these exhibits it can be seen that, with the exception of the four more southern latitude bands, the total population among the bands varies by about one order of magnitude. In addition, Figure 3-19 indicates that the bulk of the population within most of the bands can be found in rural areas. The greatest population densities (Figure 3-20) occur in a relatively narrow grouping of the four northern bands between latitudes 17 and 44 degrees north (bands 4 through 7).

### 3.3.2 Climatology

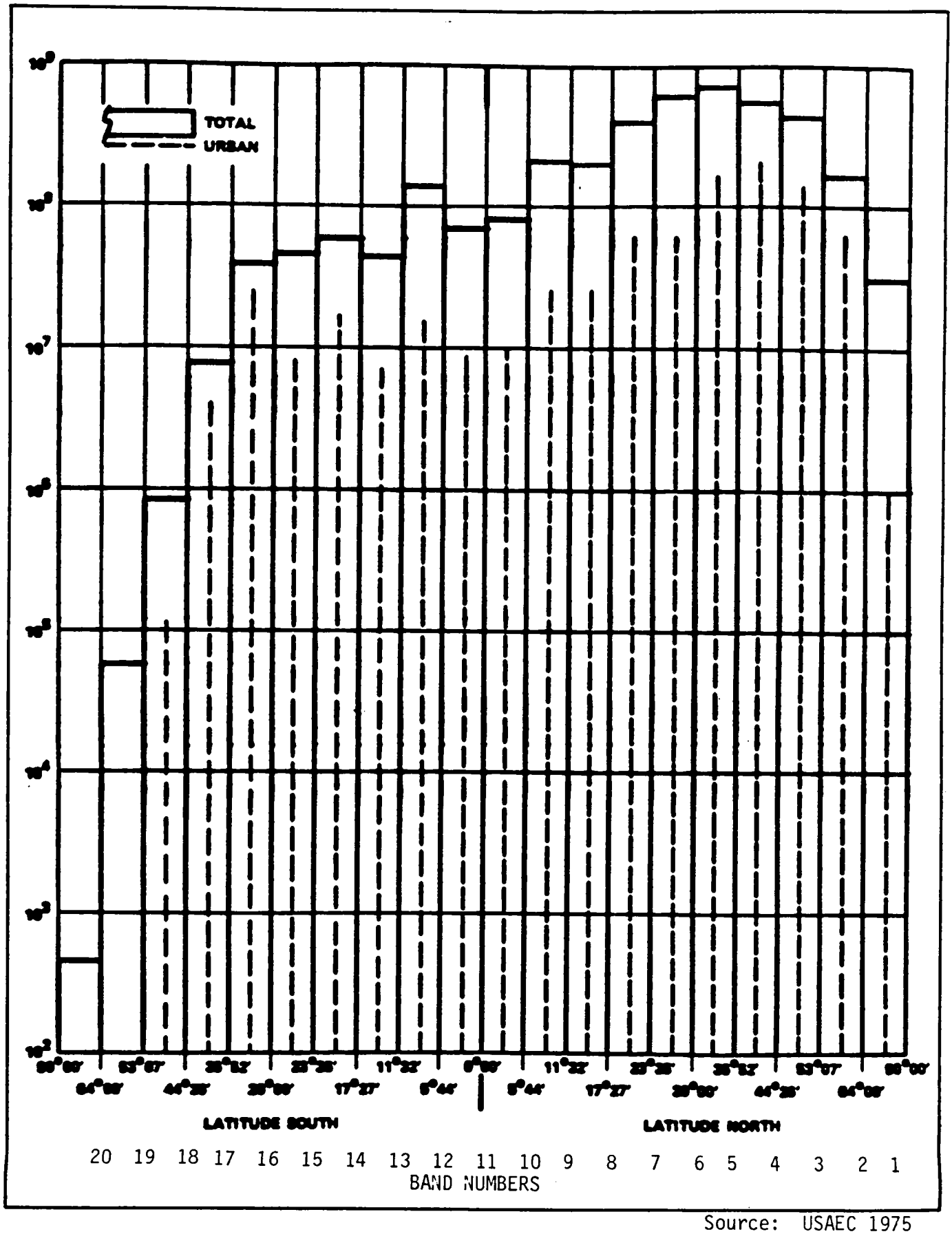
Worldwide climatic types, which range from the perpetual frost of the polar climates to the dry desert climates, are illustrated in Figure 3-21.

### 3.3.3 Surface Types

The distribution of surface types, worldwide, is an important characteristic in considering the potential consequences of accident scenarios analyzed for the Ulysses mission. Table 3-6 provides a breakdown, by each of the 20 equal area latitude bands noted previously, of the total land fraction and the total ocean fraction broken down by two ocean depth categories - surface depth, i.e., 75 meters (246 feet) average depth; and intermediate depth, i.e., 500 meters (1,640 feet) average depth. The land fraction was further subdivided by the fraction consisting of soil cover and rock cover. For the most densely populated bands (bands 4 through 7), it can be seen that the land fraction varies from about 34 percent (band 7) to about 46 percent (band 4), and within those four bands the soil fraction is dominant (75 percent in band 4 to 92 percent in band 7). It can also be seen (by subtracting the total land fraction from 1.0) that the bulk of the Earth's surface is covered by water.

### 3.3.4 Worldwide Plutonium Levels

Plutonium-238, the primary fuel of the Ulysses spacecraft RTG, already exists in the environment as a result of atmospheric testing of nuclear weapons and a 1964 launch accident. The following paragraphs describe the worldwide, national, and regional levels of plutonium in the environment. This information is relevant to analyzing the scope of postulated incremental releases of plutonium into the environment that could result from a Ulysses mission accident.




Source: USAEC 1975

FIGURE 3-19. TOTAL AND URBAN WORLD POPULATION BY EQUAL AREA LATITUDE BANDS

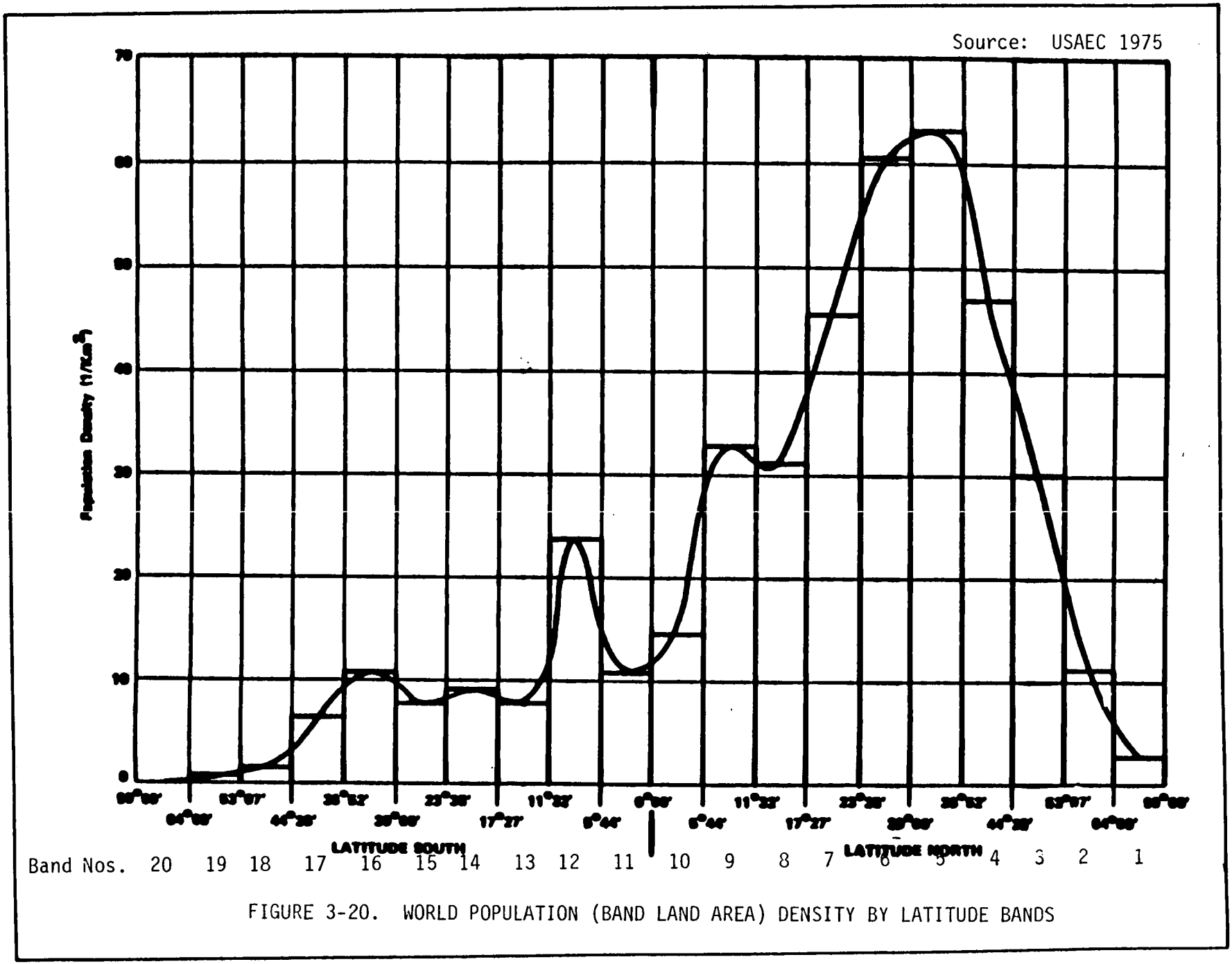
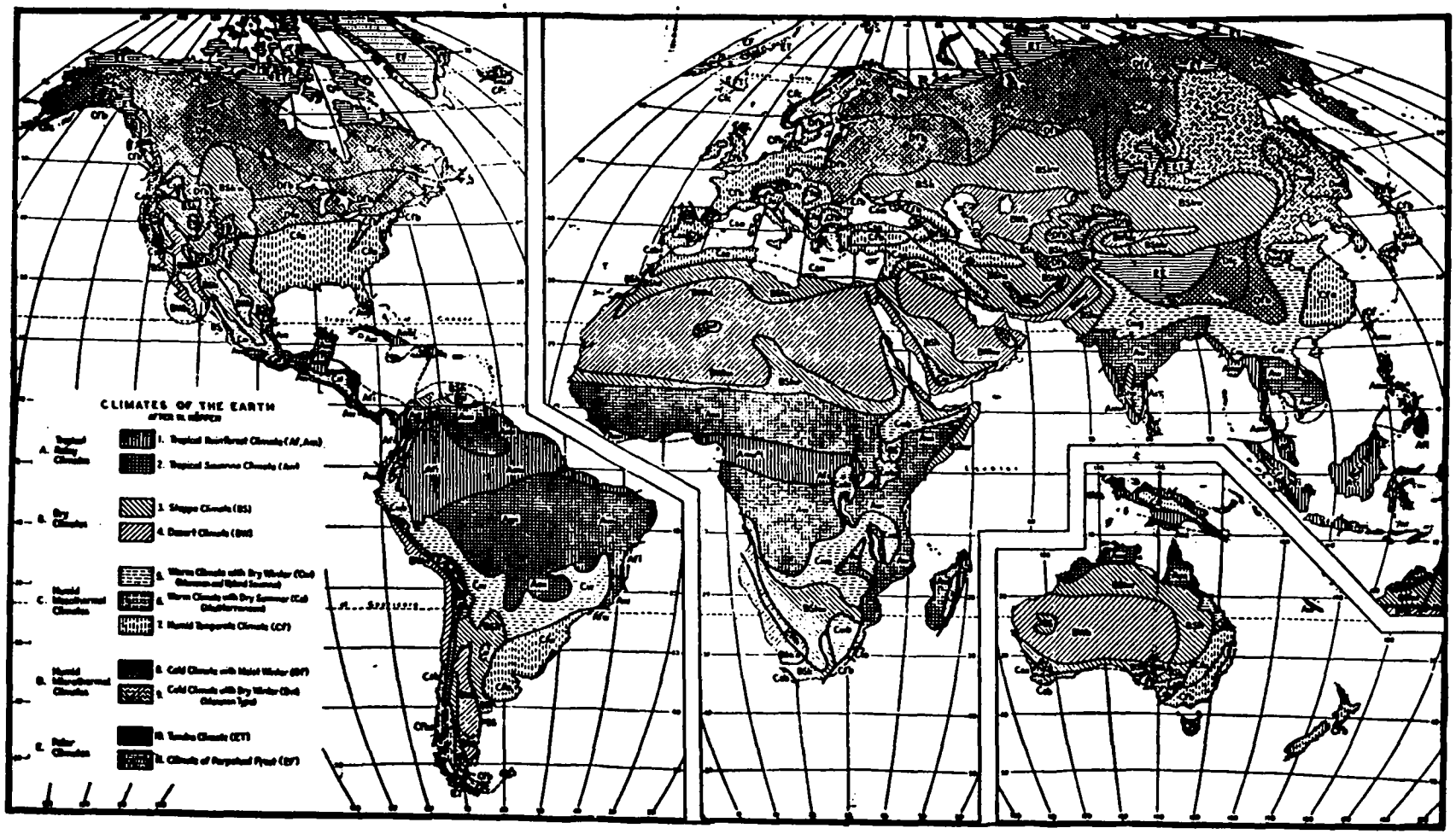



FIGURE 3-20. WORLD POPULATION (BAND LAND AREA) DENSITY BY LATITUDE BANDS




SOURCE: USAEC 1975

FIGURE 3-21. CLIMATES OF THE EARTH

TABLE 3-6. SURFACE TYPE DISTRIBUTIONS FOR EACH LATITUDE BAND

| Latitude Band | Total Land Fraction | Ocean Surface Depth Fraction | Ocean Intermediate Depth Fraction | Land Soil Fraction | Land Rock Fraction |
|---|---|---|---|---|---|
| 1 | 0.4739 | 0.1648 | 0.1444 | 0.0* | 1.00* |
| 2 | 0.5845 | 0.1247 | 0.0704 | 0.0* | 1.00* |
| 3 | 0.5665 | 0.0441 | 0.0452 | 0.749* | 0.251* |
| 4 | 0.4580 | 0.0349 | 0.0429 | 0.749 | 0.251 |
| 5 | 0.4353 | 0.0357 | 0.0290 | 0.847 | 0.153 |
| 6 | 0.3980 | 0.0312 | 0.0365 | 0.912 | 0.088 |
| 7 | 0.3391 | 0.0358 | 0.0334 | 0.924 | 0.076 |
| 8 | 0.2545 | 0.0214 | 0.0300 | 0.942 | 0.058 |
| 9 | 0.2444 | 0.0400 | 0.0368 | 0.923 | 0.077 |
| 10 | 0.2211 | 0.0400 | 0.0197 | 0.916 | 0.084 |
| 11 | 0.2500 | 0.0326 | 0.0263 | 0.956 | 0.044 |
| 12 | 0.2199 | 0.0387 | 0.0299 | 0.945 | 0.055 |
| 13 | 0.2169 | 0.0329 | 0.0200 | 0.915 | 0.085 |
| 14 | 0.2480 | 0.0128 | 0.0319 | 0.911 | 0.089 |
| 15 | 0.2231 | 0.0088 | 0.0155 | 0.908 | 0.092 |
| 16 | 0.1372 | 0.0185 | 0.0172 | 0.888 | 0.112 |
| 17 | 0.0465 | 0.0191 | 0.0256 | 0.704 | 0.296 |
| 18 | 0.0223 | 0.0172 | 0.0427 | 0.704* | 0.296* |
| 19 | 0.0034 | 0.0036 | 0.0115 | 0.0* | 1.00* |
| 20 | 0.5438 | 0.0077 | 0.0850 | 0.0* | 1.00* |

* Assumed Values

Source: USAEC 1975

Over the period 1945 through 1974, above-ground nuclear weapons tests produced about 440,000 curies of plutonium in the environment (EPA 1977, USAEC 1974). About 97 percent (about 430,000 curies) of this plutonium was Pu-239 and Pu-240 which are essentially identical both chemically and with respect to their radiological emission energies. The remainder (about 10,000 curies) consisted primarily of Pu-238 (about 9,000 curies), as well as Pu-241 and Pu-242. Consequently, above-ground nuclear testing represents the major source of the worldwide distribution of plutonium in the environment.

Table 3-7 indicates that the Pu-238 inventory from weapons tests (about 9,000 curies) was increased by a space nuclear source, specifically from the 1964 reentry and burn-up of a SNAP-9A Radioisotopic Thermoelectric Generator releasing 17,000 curies. This release of plutonium into the atmosphere was consistent with the RTG design philosophy of the time. Subsequent RTGs, including the RTG on the Ulysses spacecraft, have been designed to contain the Pu-238 fuel to the maximum extent possible recognizing that there are mass and configuration requirements relative to the spacecraft and its mission which must be weighed against the design and configuration of the power source and its related safety requirements. Since 1964, essentially all of the SNAP-9A release has been deposited on the Earth's surface (USAEC 1974). About 25 percent (approximately 4,000 curies) of that release was deposited in the northern latitudes, with the remaining 75 percent settling in the southern hemisphere. Table 3-7 does not account for the approximately 8,000 curies of Pu-238 released to the environment from the Chernobyl accident of April 1986 (DOE et al. 1987).

The SNAP-27 RTG released from the Apollo 13 spacecraft during reentry, survived intact and has since been resting in one of the deepest areas of the Pacific Ocean, the Tonga Trench with no evidence of any radioactive release (see Section 2.2.4.4).

The total plutonium released to the ocean environment by overseas nuclear reprocessing plants between 1967 and 1987 is on the order of 20,000 Ci (IAEA 1976; NCRP 1987; UNSCEAR 1977, 1982, 1988). Assuming that 15 percent of the total was Pu-238 (based upon the 1980-85 fraction in Britain's Sellafield releases), then about 3,000 additional Curies of Pu-238 have been added from these sources, bringing the total of Pu-238 dispersed into the environment up to about 29,000 Ci.

TABLE 3-7. MAJOR SOURCES AND APPROXIMATE AMOUNTS OF PLUTONIUM-238 DISTRIBUTED WORLDWIDE

| Sources | Amount (Curies) |
|---|---|
| Atmospheric Testing 1945-74<br>Deposited near testing sites and world wide | 9,000 |
| Space Nuclear - SNAP-9A, 1964 | 17,000 |
| Overseas Nuclear Reprocessing Plants | 3,000 (estimated; see text) |
| Total | 29,000 |

NOTE:

The SNAP-27 RTG from Apollo 13 landed intact in the Tonga Trench of the Pacific Ocean. The inventory of this RTG has not been included in the worldwide total since there have been no indications of release from this RTG; hence, it is considered unavailable to the biosphere (DOE 1980).

# 4. ENVIRONMENTAL CONSEQUENCES

## 4.1 ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION

### 4.1.1 Implications of Completion of Prelaunch Preparation of the Spacecraft

The activities associated with completing the preparations to the spacecraft primarily involve the completion of post-test spacecraft mechanical assembly, integration tests with the launch vehicle, and final launch preparation. There are no environmental consequences associated with these activities.

### 4.1.2 Environmental Consequences of Normal Launch of the Shuttle

The environmental consequences of normal operations and normal launches were most recently addressed in the Final (Tier 2) Environmental Impact Statement (EIS) for the Galileo mission (NASA 1989a), and are summarized in Table 4-1. The consequences of major interest associated with the normal launch of the STS were identified in the previously published EISs on the Space Shuttle Program (NASA 1978), the Kennedy Space Center (KSC) (NASA 1979), the KSC Environmental Resource Document (NASA 1986), and the Tier 1 EIS for the Galileo and Ulysses Missions (NASA 1988a). This EIS is to support decision-making associated with the Ulysses mission, a Shuttle payload, rather than the basic operation of the Shuttle system, per se. The following sections summarize and update, for information purposes only, NASA's understanding of the impacts of Shuttle operations.

#### 4.1.2.1 Effects of the Exhaust Gases on Vegetation and Shallow Water

During the first half minute after ignition, a ground cloud is formed. This cloud consists of exhaust from the solid rocket motors and Shuttle engines, products from afterburning of this exhaust, a large quantity of deluge water (used for acoustic vibration damping during launch), and most of the heat energy generated during the launch (NASA 1988a). This cloud contains high concentrations of HCl acid and particulates that can settle on and affect the local environment.

The ground cloud contains nearly 22 percent by weight of hydrogen chloride (HCl) and over 30 percent by weight of aluminum oxide particles (Dreschel and Hall 1985). Much of the deluge water sprayed during the launch is also found as water vapor or aerosol droplets in the cloud.

Most of the droplets and particles fall from the cloud and are deposited on the ground in the near-field environment (i.e., within about 0.3 to 0.6 miles of the launch site). Actual deposition of up to 100 $g/m^2$ of chlorides and 200 $g/m^2$ of particulates have been collected from the near-field area (Dreschel and Hall 1985, NASA 1986). The HCl gas in the ground cloud is scavenged and condensed into water droplets which can be very acidic (pH as low as 0.5). The deposition decreases rapidly with distance. The exhaust

TABLE 4-1. SUMMARY OF ENVIRONMENTAL CONSEQUENCES OF NORMAL LAUNCH OF THE STS AND BALANCE OF A NORMAL ULYSSES MISSION

| Environmental Components | Impacts |
|---|---|
| NORMAL LAUNCH | |
| Land Use | No significant adverse impacts on land uses not related to the launch. |
| Air Quality | Exhaust emissions consist principally of chlorides and particulates (aluminum oxide). Short-term degradation of air quality within launch cloud and near-field environment (about 1,600 feet from launch pad). No significant 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 significant effects on radio transmission. |
| Sonic Boom | No significant adverse impacts. |
| Hydrology and Water Quality | No significant adverse long-term impacts. Short-term increase in the acidity of nearby water impoundments. |
| Biological Systems | Short-term vegetation damage contributes to long-term decrease in species richness in near-field over time with Shuttle operations. Fish kills in nearby lagoons and mosquito control impoundments expected with each Shuttle launch. No significant adverse effects outside the near-field. |
| Endangered and Threatened Species | Studies to date indicate no significant adverse effects. |
| Socioeconomic Factors | No significant adverse effects. Short-term economic beneficial effects from tourism. |
| Radiation Exposure of Occupational Personnel and Public from Handling of RTG | No health effects to workers and public. Radiation from RTG is very short ranged. All movement and handling operations under strict control and supervision. |
| BALANCE OF NORMAL MISSION | No significant adverse effects. Some soluble products from residual solid rocket booster (SRB) fuel introduced into ocean environment. Impacts short-term and localized. Sonic boom during reentry from orbit and landing of STS. |

Source: NASA 1989a

products in the ground cloud are typically dispersed over an area extending about 9 miles from the launch site. In the far-field (i.e., areas of deposition extending beyond the near-field) chloride deposition has been measured at levels of 0.025 to 5.3 $g/m^2$; with particulate deposition measured at levels of 0.0003 to 0.108 $g/m^2$.

The acidic material deposited from the ground cloud in the near-field environment causes acute vegetation damage and can result in fish kills in nearby shallow waters (NASA 1986). Over time, with a succession of Shuttle launches, the near-field environment experiences significant 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. The Ulysses mission will contribute to the longer-term reduction in species richness and vegetative cover of the near-field area. The area outside the near-field (i.e., the far-field), where much less deposition will occur, can extend out to 9 miles 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.

Particulate emissions within the ground cloud can be expected to temporarily exceed Federal and State air quality standards (24-hour average is 150 $\mu g/m^3$); however, ambient air quality outside the launch cloud should not be significantly impacted. The two Permanent Air Monitoring Systems (PAMS) sites located between 3 and 5 miles to the west and southwest, respectively, of the launch complex, had not recorded any significant deterioration in air quality associated with the numerous Shuttle launches up to 1986 (NASA 1986).

The hydrogen chloride gas in the launch cloud, as well as gaseous HCl which revolatilizes from acidic droplets after deposition, can remain at levels as high as 9 ppm at the launch site for a few hours post-launch (Anderson and Keller 1990). The American Conference of Governmental Industrial Hygienists has determined a threshold limit value of 5 ppm as the occupational exposure limit (American Industrial Hygiene Association 1989). NASA is well aware of the potential impact of gaseous HCl on the launch site work force that returns to the area after a launch. The air quality of the area is sampled and monitored, including sampling for the gaseous HCl. The KSC Environmental Health Staff, depending upon the results of that sampling prescribe an array of worker protection measures (including self-contained breathing apparatus and skin protection measures), if indicated.

Surface waters in the near-field area affected by the heaviest deposition can also be affected by a Shuttle launch. Acidic deposition can cause a sudden drop in pH of shallower waters (NASA 1986). The sudden drop in pH is typically accompanied by a fish kill which usually involves smaller species. Fish kills associated with Shuttle launches have ranged from less than 100 individuals to more than 1,000 individuals depending on the pattern and season. A fish kill in shallow surface waters within the near-field can be expected to occur with launch of the Shuttle for the Ulysses spacecraft.

Each Shuttle launch requires about 863,000 gallons of deluge and washdown wastewater (NASA 1986). While much of the deluge water is vaporized and dispersed with the ground cloud, up to 326,000 gallons of washdown water (with an unknown amount of deluge water) is collected in tanks at the launch pad. 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.

4.1.2.2 Effects of Exhaust Gases on the Ozone Layer

The effects of Shuttle launches on atmospheric ozone were first addressed in the Shuttle Program EIS of 1978 (NASA 1978), were summarized in the Final (Tier 1) Environmental Impact Statement for the Galileo and Ulysses Missions (NASA 1988a) and again in the Galileo Mission EIS (Tier 2) (NASA 1989a), and again here in the Ulysses Mission EIS (Tier 2).

The NASA Upper Atmosphere Program presented a report to Congress dated January 25, 1990 (Prather et al. 1990). This report addresses the connection between Shuttle launches and potential ozone depletion, presenting the results of studies using 3 models to assess the effects of Shuttle exhaust plumes. The following discussion summarizes that report.

The solid rocket motor exhaust from the Shuttle is about 22 percent by weight hydrochloric acid (HCl). Each launch injects about 68,000 kg of HCl into the stratosphere. The current background chlorine level in the stratosphere is about 3 parts-per-billion (ppb), due to the photochemical degradation of natural and industrial hydrocarbons in the stratosphere. Approximately 300,000,000 kg of halocarbons are added to the stratosphere annually from industrial sources, thus the input from a Shuttle launch is minor in comparison (0.02 percent compared to industrial sources).

A single Shuttle launch has inconsequential effects on global ozone levels. The immediate exhaust plume from the Shuttle contains about 0.08 percent HCl by volume. If the exhaust plume were mixed within a 100 $km^2$ area of the stratosphere (10 km x 10 km), the resulting HCl concentration would exceed 1,000 ppb. However, an area this size constitutes only about 0.000001 percent of the midaltitude stratosphere, plus the chlorine released from the exhaust is in the form of HCl which must be chemically converted over time to more catalytically active forms to impact ozone levels. Since the flight path of the Shuttle is lateral as well as vertical, the exhaust are spread over a lateral trending corridor extending over a distance of more than 1,000 km in a day. Thus, a local "hole" in the ozone column over the launch site is not produced.

To have a significant effect on global stratospheric ozone levels, the exhaust plume would have to mix with the stratospheric environment and lead to perturbations over an area of at least 1,000 x 1,000 km. In the first few days post-launch, stratospheric winds will transport and disperse the exhaust plume over 1,000 km. The average increase in stratospheric chlorine within

that area would be about 2 percent, with a maximum of 5 percent over an area within 20° latitude by 20° longitude. Within one-month post-launch, however, the impact on ambient chlorine levels decreases rapidly to about 0.2 percent above background with lateral mixing in the stratosphere.

For illustrative purposes the long-term cumulative effects of a postulated series of nine Shuttle and six Titan IV launches, annually, were also estimated (Prather et al. 1990) by running their models over several model-years until a steady state distribution of chlorine additions to the stratosphere was reached. A launch schedule such as this would lead to a modest accumulation of additional chlorine in the stratosphere. Modeling indicated that the increase in stratospheric chlorine attributable to this launch schedule would range from 0.2 to 0.6 percent over the northern latitudes, with much less effect felt in the tropics and southern latitudes, (by about a factor of 2 or more). The associated ozone depletion would be even less; about 0.25 percent locally and less than 0.1 percent in the total column.

With respect to the "Antarctic ozone hole," the above postulated schedule of Shuttle/Titan IV launches would be expected to decrease stratospheric ozone levels in that area by less than 0.1 percent. Corresponding losses over the Arctic were estimated at less than 0.5 percent.

The potential role of aluminum oxide particulates from solid rocket motor exhaust on the stratosphere were also addressed (Prather et al. 1990). The finer particles (0.1 micron or less), do not settle out of the stratosphere rapidly, and have the potential to act as ice deposition nuclei in the lower stratosphere. They may also react with HCl in the exhaust to form chlorides which in turn could degrade ozone levels in the lower stratosphere.

### 4.1.3 Non-Radiological Consequences of Shuttle Launch Accidents

The nonradiological consequences of Shuttle accidents were addressed in the Shuttle Program EIS (NASA 1978), the Tier 1 Galileo and Ulysses missions EIS (NASA 1988a), and the Tier 2 Galileo EIS (NASA 1989a). The anticipated nonradiological consequences are summarized in Table 4-2. The Ulysses mission uses the Payload Assist Module-Special (PAM-S) third stage, but the presence of the PAM-S would not be expected to alter the previous analysis to any significant extent. Therefore, the nonradiological impacts of Shuttle launch accidents for the Ulysses mission are expected to be the same as documented in the Final (Tier 2) Galileo EIS.

As will be discussed below, accidents are possible which could result in the Ulysses spacecraft reentering the atmosphere. In this case it is expected that the spacecraft would break up and the hydrazine fuel from the spacecraft would be dispersed in the atmosphere. The hydrazine would not reach the Earth in concentrations sufficient to be of concern.

TABLE 4-2. NONRADIOLOGICAL CONSEQUENCES OF UNPLANNED EVENTS

| Event | Nonradiological Consequences |
|---|---|
| On-Pad Propellant Spills | No significant impact. Spills collected in sumps and catch basins for proper disposal. |
| On-Pad Fire/Explosion | Fire -- Ground-level concentrations of SRB propellant combustion products would be reduced by heat and cloud rise from main engine exhaust.<br><br>Explosion -- Significant blast effects could be experienced if sudden rupture of external tank occurred. Worst-case prediction indicates glass breakage at 4,000 meters from pad. |
| Ascent Accident | If vehicle departs radically from nominal flight path, Range Safety Office has capability to terminate flight (vehicle destruct) to prevent impact on land area. |
| External Tank Jettison | Tank jettisoned into ocean with early mission abort. No toxic materials in external tank (only hydrogen and oxygen). Only effect is from physical impact of tank. Aircraft and ships receive prior advisory on launch corridor. |
| Jettison of Solid Rocket Booster | Propellant combustion products same as for normal launch. Products disbursed into air or ocean water; unburned propellants would slowly disburse into ocean with localized toxic effects on biota. |
| Orbiter Landing Accident | Consequences similar to large airplane crash except less fire due to small fuel inventory on-board STS.<br><br>Ocean crash would release STS fuel (mono-methyl hydrazine) into the water. Some fish may succumb in localized area near STS, but no large-scale or permanent effects on ocean environment.<br><br>Small quantities of hydrocarbon on-board STS would float to the surface with no significant impact. |

### 4.1.4 Procedure for Analysis of Radiological Accidents and Consequences

The U.S. Department of Energy (DOE) conducts a detailed analysis of the safety of the Radioisotope Thermoelectric Generator (RTG) systems used on space missions. DOE documents the analysis for each mission in a Final Safety Analysis Report (FSAR). The elements of the analysis and the information flow are summarized in Figure 4-1. For the Ulysses mission, work on the FSAR (DOE 1990d, DOE 1990e, DOE 1990f, DOE 1990g) has been underway since mid-1989. The Ulysses mission will use the Shuttle/IUS launch configuration, as did the Galileo mission. So the analyses performed for Galileo contributed greatly to the analysis of the Ulysses mission. DOE prepared a Safety Status Report (DOE 1990a, DOE 1990b, DOE 1990c) to provide the basic safety data used in the Draft (Tier 2) EIS. The analytical steps and the information flow used in preparing this interim report were the same as those for the FSAR. Research, development, test, and evaluation (RDT&E) of RTGs has been an ongoing activity within DOE for over 3 decades and continues at the present time.

As indicated in Figure 4-1, the safety analysis for each specific mission begins with NASA's identification of accident scenarios and environments which may affect the RTG along with the probability of their occurrence. DOE then calculates the response of the RTG to the environments making use of the extensive DOE data base on RTG materials and their performance under a wide range of conditions. If an accident environment leads to a release of plutonium dioxide ($PuO_2$), that release is called a "source term." The amount of release, particle size distribution, and the location of the release are tabulated along with the conditional probability of the release. An analysis is then conducted to determine the health and environmental consequences of the release. Additional information on the safety analysis is contained in Appendices B and C.

#### 4.1.4.1 Accident Scenarios, Environments, and Probabilities

An extensive review of the potential failure modes in each of the major elements of the Shuttle system identified accidents which could result in accident environments posing a potential threat to the RTG. The accidents of concern were then arrayed by mission phase in which they could occur. (See Appendix B for a detailed discussion of the mission phases.) The probability of each of these accident scenarios occurring was estimated by NASA and provided to DOE for use in the FSAR (see FSAR, Volume II; DOE 1990f). These values were subsequently updated by NASA and incorporated into this FEIS (Appendix G). As indicated above, the safety evaluation of space nuclear power systems is an on-going activity within the DOE. Testing and analysis for the Galileo mission continued even after preparation of the mission's formal documentation (the Galileo FSAR and EIS). The results from that continued testing were published in the Galileo FSAR Supplement (DOE 1989b). The Supplement showed that the Galileo FSAR presented a conservative estimate of the risks. It should be noted that, on the basis of test and analysis data published in the Supplement, certain accident scenarios and environments were eliminated as contributors to fuel releases. These were principally:

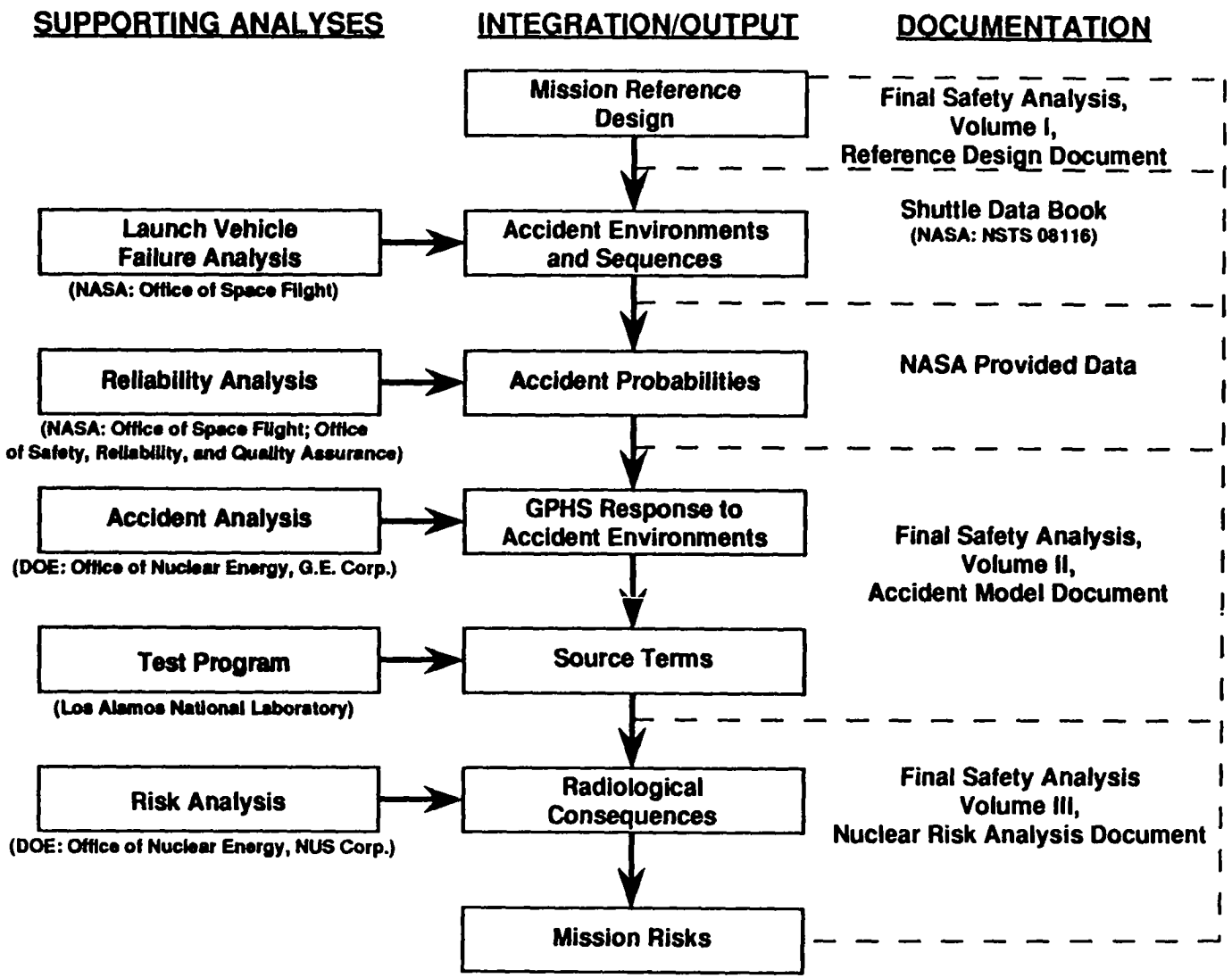



FIGURE 4-1. FINAL SAFETY ANALYSIS REPORT DEVELOPMENT PROCESS

- The RTG case and General Purpose Heat Source (GPHS) failure criteria for a solid rocket booster (SRB) fragment impact were revised to incorporate results from the Large Fragment Test series (Cull 1989). This indicated that, for all practical purposes, only edge-on impacts could cause a release.

- The amount of propellant that can mix with air in a vapor cloud explosion following an in-flight failure of the external tank (ET) was reduced based upon the findings of the NASA/DOE/DOD Interagency Explosion Working Group's evaluation of the Challenger and Titan 34-Daccidents (NASA et al. 1989). This had the effect of eliminating vapor cloud explosions as a threat to the RTG.

- The threshold for damage to the RTG from payload bay wall impact was found to be overly conservative by a factor of 5 for removal of the RTG case, and a factor of about 1.5 for removal of the case plus GPHS aeroshell and the graphite impact shell. This had the effect of eliminating Phase 0 fuel spill explosion and subsequent payload bay implosion as a threat to the RTG.

- Sequential Impact Tests conducted at LANL indicated that a previously impacted fueled clad could withstand a subsequent impact up to a distortion of over 40 percent without releasing plutonium dioxide. These data apply, for instance, to a fueled clad liberated from a GPHS module as a result of an SRB impact. The bare clad then falls to the ground experiencing a second (sequential) impact. The Galileo FSAR used a secondary impact release threshold of 15 percent. Incorporating the Sequential Impact Test data, the Supplement updated that release threshold to 35 percent. This had the effect of reducing ground releases following SRB fragment impact.

#### 4.1.4.2 Accident Source Terms and Consequences

Not all accidents will lead to a release. For instance, in an SRB case rupture scenario, the most probable result is that the SRB fragments will miss the RTG. To analyze possible accidents in detail, an extensive Monte Carlo based computer program was developed. This program is called the Launch Accident Scenario Evaluation Program (LASEP). The program allows for the generation of SRB fragments (by random failure or range destruct action) and tracks the trajectory of each fragment. If the fragment strikes the RTG, the program utilizes a model to calculate fueled clad distortion. Then, based on test data and analysis, the distortion is used to calculate the amount and particle size characteristics of any release.

After the first stage ascent phase, the accident scenarios of interest are those which result in reentry of the RTG. Extensive testing and operational experience indicate that RTG modules will survive suborbital and earth orbital reentry heating conditions without release of plutonium. The only situation in which release can occur is when a module survives reentry but lands on a very hard surface (rock or steel). So the analysis of the scenario is conducted on a probabilistic basis.

For the first stage ascent phase, the results of the source term analysis using LASEP were then used as input to the consequence analysis. This began with aggregation of the source terms according to atmospheric dispersion pathway (i.e., fireball, ground release, or at-altitude). Atmospheric dispersion models then estimated the transport and deposition of released material. The average source term for each phase or subphase was run for all 40 meteorological data sets of interest and the consequences were averaged over all 40 metrorological data sets to define the base case for further use in the integrated risk assessment. For Phases 2, 3, and 4, a modified dispersion calculation was performed again using average source terms to estimate consequences for these phases (see Appendix C). Phase 2, 3, and 4 point estimates also served in the base case for the integrated risk assessment.

4.1.4.3 Risk Assessment

The environmental consequences of normal Shuttle launches are well known and have been addressed in other NEPA documentation. The objective of this EIS is to address the radiological implication of accidents which may affect the Shuttle payload and its RTG power system. The assessment characterizes the distribution of possible accidents and the distribution of their possible radiological consequences. This assessment uses the techniques of probabilistic risk assessment. There is an extensive data base derived from the development, test, and evaluation of launch systems and from the test, operation, and evaluation of RTG systems and materials. The probabilistic approach used here incorporates modelling, simulation, and other analyses based upon the DOE's safety verification testing and analysis activities.

The consequence analysis for the early first stage ascent phase uses meteorological, geographic, and demographic data specifically for the Kennedy Space Center and the Cape Canaveral region of Florida.

After about 70 seconds mission elapsed time, any high altitude release will be dispersed worldwide. For these analyses, a globally averaged population distribution was used for land areas under the ground track of the mission (i.e., between 28 North and South latitude) for ground releases. High altitude releases lead to global dispersion but with small local doses.

The results of the analyses are summarized in Table 4-3, which lists the average source terms, and Table 4-4, which lists the consequences. Table 4-3 presents the source terms utilized in the Risk Analyses for the Ulysses mission (DOE 1990g). Tables 4-4 and 4-5 provide the estimated radiological consequences associated with those source terms. For the first stage ascent phase, the phase value is the probability weighted consequence summed over the five time intervals. For later phases, the consequences are taken to be uniform over the whole phase. Note that as in Appendix C, the first stage ascent phase is divided into five subphases based on the accident probabilities of the SRBs and the characteristics of the mission profile. The aim is to provide greater resolution in the analysis. In addition, the first stage ascent phase results are summarized in terms of an expectation (probability weighted) source term and probability weighted consequences.

# TABLE 4-3. SUMMARY OF AVERAGE SOURCE TERMS

| Mission Phase / Subphase | | Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | | | Average Source Term, Ci | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Initiating Accident | Conditional | Total | Fireball | Ground Level | At Altitude | Altitude (m) | |
| 1 | 0-10 | $1.46 \times 10^{-3}$ | $2.30 \times 10^{-3}$ | $3.36 \times 10^{-6}$ | 63.4 | 2.15 | - | - | a |
| | 11-20 | $3.65 \times 10^{-4}$ | $2.32 \times 10^{-3}$ | $8.47 \times 10^{-7}$ | - | 4.90 | 7.08 | 576 | b |
| | 21-70 | $6.62 \times 10^{-4}$ | $6.60 \times 10^{-4}$ | $4.37 \times 10^{-7}$ | - | 0.006 | 3.74 | 6,523 | c |
| | 71-105 | $2.60 \times 10^{-4}$ | $1.76 \times 10^{-3}$ | $4.58 \times 10^{-7}$ | - | - | 12.2 | 25,725 | d |
| | 106-120 | $1.71 \times 10^{-4}$ | $1.33 \times 10^{-2}$ | $2.27 \times 10^{-6}$ | - | - | 251 | 38,100 | d |
| Phase 1 | Expectation | - | - | $7.37 \times 10^{-6}$ | 28.9 | 1.54 | 79.1 | 13,787 | |
| 2 | - | $5.65 \times 10^{-3}$ | $1.09 \times 10^{-2}$ | $6.16 \times 10^{-5}$(*) | - | 0.063 | - | - | e,f |
| 3 | - | $5.75 \times 10^{-4}$ | $2.69 \times 10^{-1}$ | $1.55 \times 10^{-4}$(*) | - | 0.084 | - | - | f,g |
| 4 | - | $6.17 \times 10^{-3}$ | $2.69 \times 10^{-1}$ | $1.66 \times 10^{-3}$(*) | - | 0.084 | - | - | f,g |

Source: DOE 1990g

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

a. Releases due to SRB fragments, module impacts on steel, and fueled clad impacts on steel, concrete, and sand.
b. Releases due to SRB fragments, and fueled clad impacts on concrete and sand.
c. Releases due to SRB fragments, and fueled clad impacts on sand
d. Releases due to SRB fragments.
e. Releases due to module impacts on rock following sub-orbital reentry.
f. Reported as expectation values given land impact.
g. Releases due to module impacts on rock following orbital reentry.

Phase 1 Expectation is the probability-weighted mean value calculated thus

For the Fireball

$$\frac{(63.4 \times 3.36 \times 10^{-6}) + (0 \times 8.47 \times 10^{-7}) + (0 \times 4.37 \times 10^{-7}) + (0. \times 4.58 \times 10^{-7}) + (0 \times 2.27 \times 10^{-6})}{(3.36 \times 10^{-6} + 8.47 \times 10^{-7} + 4.37 \times 10^{-7} + 4.58 \times 10^{-7} + 2.27 \times 10^{-6})} = 28.9 \text{ Ci}$$

## TABLE 4-4. SUMMARY OF RADIOLOGICAL CONSEQUENCES: MEAN VALUES

| Mission Phase | Mission Subphase (sec.) | Total Probability[b] of Release (Phase 1)/ Land Impact (Phases 2-4) | Probability of Mean Health Effect[a] | Collective Dose (Person-Rem) | Health[c] Effect w/o de minimis | Maximum Individual Dose (Rem) | Land Area ($km^2$) with Deposition Exceeding 25 mrem/yr | 10 mrem/yr | 0.2 $\mu Ci/m^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0- 10 | $3.36 \times 10^{-6}$ | $6.0 \times 10^{-8}$ | 77.8 | .0369 | $3.84 \times 10^{-3}$ | $2.16 \times 10^{-3}$ | $2.35 \times 10^{-2}$ | 4.65 |
| | 11- 20 | $8.47 \times 10^{-7}$ | $3.0 \times 10^{-8}$ | 12.4 | .00935 | $1.64 \times 10^{-3}$ | $1.38 \times 10^{-3}$ | $1.50 \times 10^{-2}$ | $5.24 \times 10^{-1}$ |
| | 21- 70 | $4.37 \times 10^{-7}$ | $1.1 \times 10^{-8}$ | 2.15 | .00114 | $1.93 \times 10^{-4}$ | $2.24 \times 10^{-3}$ | $2.44 \times 10^{-2}$ | $8.51 \times 10^{-1}$ |
| | 71-105 | $4.58 \times 10^{-7}$ | $3.3 \times 10^{-8}$ | 193 | .0639 | $5.86 \times 10^{-8}$ | - | - | - |
| | 106-120 | $2.27 \times 10^{-6}$ | $3.0 \times 10^{-7}$ | 2,270 | .861 | $6.92 \times 10^{-7}$ | - | - | - |
| Phase 1 | Expectation | $7.37 \times 10^{-6}$ | $4.34 \times 10^{-7}$ | N/A | .605 | - | - | - | - |
| 2 | - | $6.16 \times 10^{-5}$(*) | $2.0 \times 10^{-6}$ | .0368 | $1.56 \times 10^{-5}$ | $4.67 \times 10^{-3}$ | - | - | - |
| 3 | - | $1.55 \times 10^{-4}$(*) | $5.6 \times 10^{-6}$ | .192 | $7.54 \times 10^{-5}$ | $1.31 \times 10^{-2}$ | - | - | - |
| 4 | - | $1.66 \times 10^{-3}$(*) | $6.0 \times 10^{-5}$ | .192 | $7.54 \times 10^{-5}$ | $1.31 \times 10^{-2}$ | - | - | - |

Source: See Appendix G, DOE 1990g

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

a. The probability an accident will lead to health effects numerically equal to the mean value or more.

b. Total Probabilities for Phases 2, 3, and 4 are for land impact. Associated source terms are expectation values given a land impact.

c. Conditional incremental cancer fatalities.

## TABLE 4-5. SUMMARY OF RADIOLOGICAL CONSEQUENCES: 99TH PERCENTILE VALUES

| Mission Phase / Subphase | Total[2] Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | Probability[1] of 99th Percentile Values | Collective Dose (person-rem) | Health Effects Without De Minimis | Maximum Individual Dose (rem) | Land Area ($km^2$) with Deposition Exceeding | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | 25 mrem/yr | 10 mrem/yr | 0.2 $\mu Ci/m^2$ |
| 1 0-10 sec | $3.36 \times 10^{-6}$ | $3.36 \times 10^{-8}$ | $4.57 \times 10^{2}$ | .118 | $2.26 \times 10^{-2}$ | $3.42 \times 10^{-3}$ | $6.28 \times 10^{-2}$ | $1.11 \times 10^{2}$ |
| 11-20 sec | $8.47 \times 10^{-7}$ | $8.47 \times 10^{-9}$ | $1.57 \times 10^{2}$ | .0625 | $2.08 \times 10^{-2}$ | $1.11 \times 10^{-2}$ | $2.04 \times 10^{-1}$ | 9.0 |
| 21-70 sec | $4.37 \times 10^{-7}$ | $4.37 \times 10^{-9}$ | $2.90 \times 10^{1}$ | 0.00852 | $2.60 \times 10^{-3}$ | $2.81 \times 10^{-2}$ | $5.17 \times 10^{-1}$ | $2.28 \times 10^{1}$ |
| 71-105 sec | $4.58 \times 10^{-7}$ | $4.58 \times 10^{-9}$ | $2.97 \times 10^{3}$ | 1.03 | $9.01 \times 10^{-7}$ | - | - | - |
| 106-120 sec | $2.27 \times 10^{-6}$ | $2.27 \times 10^{-8}$ | $4.16 \times 10^{4}$ | 14.5 | $1.27 \times 10^{-5}$ | - | - | - |
| Phase 1 Expectation | $7.37 \times 10^{-6}$ | $7.37 \times 10^{-8}$ | | 4.86 | | | | |
| 2 | $6.16 \times 10^{-5}$(*) | $6.15 \times 10^{-7}$ | .577 | $2.36 \times 10^{-4}$ | $7.32 \times 10^{-2}$ | - | - | - |
| 3 | $1.55 \times 10^{-4}$(*) | $1.55 \times 10^{-6}$ | 2.88 | $1.03 \times 10^{-3}$ | $1.97 \times 10^{-1}$ | - | - | - |
| 4 | $1.66 \times 10^{-3}$(*) | $1.66 \times 10^{-5}$ | 2.88 | $1.03 \times 10^{-3}$ | $1.97 \times 10^{-1}$ | - | - | - |

Source: See Appendix C of this FEIS, DOE 1990g

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

[1] Probability of 99th percentile health effect or more.

[2] For Phases 2, 3, and 4, values are probability of land impact.

NOTE: For ease of presentation, Phase 1 Expectation values are presented only for health effects because other parameters (e.g., Maximum Individual Dose) have different probability functions.

In Tables 4-4 and 4-5, column three lists the total probability of a release for the subphases of Mission Phase 1. For Phase 2, 3, and 4, column three lists the probability of modules hitting land. There is a further conditional probability of one or more modules hitting rock and one or more clads having a release; the value is 0.102 for Phase 2, and 0.129 for Phases 3 and 4. Now there is a further conditional probability that there will be a consequence of a certain extent, given that the release has occurred. Column 4 lists the total probability of the health effect (column 6) dependent upon the accident and the release occurring.

In Table 4-4, columns 5 and 6 list Collective Dose and Health Effects, respectively. As the released material is dispersed, it becomes more dilute and has a lower dose potential, but a larger population is exposed. The collective dose counts each person exposed and the level of their exposure. By Health Effect is meant the number of conditional incremental cancer fatalities, over and above the normal value, that could occur in the population as a result of the accidental release of plutonium from this mission.

Health effects are calculated on the basis of the collective or population dose multiplied by a health effects factor (number of cancer fatalities per rem of exposure). The health effects factor utilized by DOE in the FSAR was developed as follows.

Since plutonium-238 is an alpha emitter, the guidance provided by BIER IV (Nat. Res. Coun. 1988) was considered appropriate in deriving a health effects estimator for use in the Ulysses risk analysis. It should be noted that the recently released BEIR V Report (Nat. Res. Coun. 1990) deals primarily with the effects of gamma radiation, not the alpha radiation that is emitted by the plutonium dioxide RTG fuel. BEIR V incorporates, without change, the recommendations of BIER IV with respect to alpha radiation. In deriving a health effects factor, consideration was given to the method of calculating internal doses based on ICRP-30 (ICRP 1978), which uses organ weighing factors based on low-LET radiation. When this is done in conjunction with the central estimates for health effects due to internally deposited alpha emitters based on BEIR IV, an appropriate health effects estimator can be derived as described in the FSAR (DOE 1990g). The result of this calculation, specific for plutonium dioxide and reflecting all particle sizes and ingestion pathways, can range from $3.2 \times 10^{-4}$ to $3.5 \times 10^{-4}$ excess cancer fatalities per person-rem. For the purposes of calculating health effects for the base cases, a value of $3.5 \times 10^{-4}$ has been used.

Column 7 of Tables 4-4 and 4-5 list Maximum Individual Dose. Calculations of both collective dose and maximum individual dose both use a 50-year dose commitment, as explained in Appendix C. The whole dose is, however, taken to be delivered in the first year. By assuming the dose is delivered in the first year, a conservative comparison can be made to Table 4-6 which lists radiation exposures routinely encountered by the general public.

Columns 8 and 9 in Table 4-4 list the areas of deposition in which the dose levels during the first year after plume passage would be greater than 25 and 10 mrem, respectively. For the purposes of this analysis, based on

TABLE 4-6. AVERAGE ANNUAL EFFECTIVE DOSE EQUIVALENT OF IONIZING RADIATIONS TO A MEMBER OF THE U.S. POPULATION

| Source | Dose Equivalent[a] mrem | Effective Dose Equivalent mrem | Effective Dose Equivalent % of Total |
|---|---|---|---|
| Natural | | | |
| Radon[b] | 2,400 | 200 | 55 |
| Cosmic | 27 | 27 | 8.0 |
| Terrestrial | 28 | 28 | 8.0 |
| Internal | 39 | 39 | 11 |
| Subtotal--Natural | -- | 300 | 82 |
| Human-Made | | | |
| Medical | | | |
| X-ray diagnosis | 39 | 39 | 11 |
| Nuclear medicine | 14 | 14 | 4.0 |
| Consumer Products | 10 | 10 | 3.0 |
| Other | | | |
| Occupational | 0.9 | <1 | <0.3 |
| Nuclear fuel cycle | <1.0 | <1 | <0.03 |
| Fallout | <1.0 | <1 | <0.03 |
| Miscellaneous[c] | <1.0 | <1 | <0.03 |
| Subtotal--Human-Made | -- | 63 | 18 |
| Total Natural and Human-Made | -- | 360 | 100 |

Source: adapted from Nat. Res. Coun. 1990

[a] To soft tissues.

[b] Dose equivalent to bronchi from radon daughter products. The assumed weighting factor for the effective dose equivalent relative to whole-body exposure is 0.08.

[c] Department of Energy facilities, smelters, transportation, etc.

interim EPA and DOE guidance (DOE 1990g), if the annual dose rate exceeds 100 mrem/yr, cleanup is indicated to ensure that administrative controls on land use (to limit individual risk) are not required for extended periods of time. The level of 25 mrem/yr is used solely for illustrative purposes in order to estimate an order of magnitude for cleanup costs since no areas exceeded 100 mrem/yr; however, some limited areas would exceed the U.S. Environmental Protection Agency (EPA) screening level indicating that monitoring would be required to determine the actual concentrations, as noted in Column 10.

Column 10 of Tables 4-4 and 4-5 list the land areas estimated to receive deposition at or above an EPA suggested screening level of 0.2 $\mu Ci/m^2$ at which monitoring is recommended (EPA 1977). (See Section 4.2.1 and Appendix C for more detail.)

Tables 4-4 and 4-5 can be compared as follows: Table 4-4 lists the mean value results and Table 4-5 lists the 99th percentile value results from the FSAR's integrated risk assessment. As explained in greater detail in Appendix C and in the FSAR, Volume III, Book 1, Section 4, the analysis first presented radiological consequences in terms of base cases. That is, the consequences were the mean values resulting from dispersion calculations using average source terms, calculated for all 40 meteorological conditions, with the set of pathway parameters and assumptions representing central estimates. The integrated risk assessment then characterized variations about the base case taking account of the entire distribution of source terms from LASEP, the entire range of meteorological conditions, and ranges of variation in parameter values and differing analytical assumptions affecting radiological consequences. This approach was implemented through use of the SPASM Code, a general purpose Monte Carlo simulation program designed to propagate variabilities through a system model. The result is a distribution of magnitude of consequence in terms of probability of occurrence. The result is probabilistic because the parameters are combined in a way that reflects their frequency of occurrence. Large source terms are infrequent and extreme weather is infrequent, so the combination has a low probability.

We define the expectation value of a consequence as the <u>risk</u> of that consequence. The data can also be used to estimate a mean value of the consequence, as well as, say, the 99th percentile consequence, as indication of values near the tail of the distribution.

Considering Table 4-4, results indicate that the probability of a plutonium dioxide release is small, and even in the rare event of a release, the consequences will be small. The most probable release is in Phase 4 with a total probability of land impact of about $1.66 \times 10^{-3}$ (or 1 in 602) and no health effects would be expected as a result of a subsequent release. It should be noted that the conditional probability of one or more clads having a release (given land impact) is 0.129.

The analysis indicates that a release near the end of first stage ascent could lead to a small collective dose (2,270 person rem) to a very large affected population (5 billion people). In the absence of the <u>de minimis</u>

principle (a health effect dose threshold of 1 mrem/yr) there could be one incremental cancer fatality, worldwide, over a 50-year dose commitment period.

The largest mean value of maximum individual dose (13.1 mrem) relates to a release due to Earth orbital reentry. This level is small compared to average background radiation levels of about 150 mrem/yr (not including radon).

Considering the 99th percentile results, the consequences are greater but at much reduced levels of probability. The most probable release (Phase 4) would still have no health effects. Releases in the latter two phases of first stage ascent could lead to very small collective doses to large populations. On the basis of the linear hypothesis, without de minimis (see Appendix Section C.5), at a probability of $2.3 \times 10^{-8}$ (1 in 43.5 million) there could be as many as 15 cancer fatalities in a population of 5 billion people over a 50-year period.

The largest launch area value of maximum individual dose is also small, less than 23 mrem. The health risk would be about the same as one medical x-ray over a lifetime.

Now addressing the results for land deposition: Columns 8 and 9 of Tables 4-4 and 4-5 indicate the land area where dose levels due to deposition would exceed 25 mrem/yr and 10 mrem/yr, respectively. Column 10 lists the area where deposition would exceed the EPA screening guideline of 0.2 $\mu Ci/m^2$. At lower levels of deposition, long-term monitoring would not be indicated.

Based upon DOE guidelines, cleanup is indicated where dose levels exceed 100 mrem/yr. There were no areas where such dose levels are anticipated, either for mean values or the 99th percentile end of the distribution. Other dose levels are associated with small areas. The EPA screening level is exceeded in a 4.65 $km^2$ region for the case of an early first stage release in the mean value. The 99th percentile value is estimated as 111 $km^2$.

It should be noted that in case of a real accident, mitigation activities would be based on thorough monitoring and evaluation at that time. This analysis was only intended to be indicative of the situation that might pertain.

In order to compare the health risks of the Ulysses mission to risks encountered elsewhere, one may calculate an average individual risk as is shown in Table 4-7. The Ulysses FSAR (Volume III, Book 1) defines the total risk associated with each mission phase or subphase as the product of the total probability of release and the mean value of the health effect for that phase or subphase. For instance, in Phase 1, 106-120 seconds, the mean health effect is 0.861 and the total probability of release is $2.27 \times 10^{-6}$. So the subphase risk is $1.95 \times 10^{-6}$ health effect. Without the de minimis assumption (see Appendix C.5), the collective dose is associated with an affected population of five billion people, because the release takes place high in the stratosphere which will lead to global dispersal. There would be a small dose to a large population. The risk per individual, or average individual risk,

## TABLE 4-7. MISSION RISK SUMMARY: MEAN VALUES

| Mission Phase | Mission Subphase (sec.) | Total Probability[d] of Release (Phase 1)/ Land Impact (Phases 2-4) | Probability of Mean Health Effect[a] | Collective Dose w/o *de minimis* (Person-Rem) | Health Effects[b] | Reference Population | Average Individual Risk[c] |
|---|---|---|---|---|---|---|---|
| 1 | 0- 10 | $3.36 \times 10^{-6}$ | $6.0 \times 10^{-8}$ | 77.8 | .0369 | $1 \times 10^{5}$ | $1.2 \times 10^{-12}$ |
| | 11- 20 | $8.47 \times 10^{-7}$ | $3.0 \times 10^{-8}$ | 12.4 | .00935 | $1 \times 10^{5}$ | $7.9 \times 10^{-14}$ |
| | 21- 70 | $4.37 \times 10^{-7}$ | $1.1 \times 10^{-8}$ | 2.15 | .00114 | $1 \times 10^{5}$ | $5.0 \times 10^{-15}$ |
| | 71-105 | $4.58 \times 10^{-7}$ | $3.3 \times 10^{-8}$ | 193 | .0639 | $5 \times 10^{9}$ | $5.9 \times 10^{-18}$ |
| | 106-120 | $2.27 \times 10^{-6}$ | $3.0 \times 10^{-7}$ | 2,270 | .861 | $5 \times 10^{9}$ | $3.9 \times 10^{-16}$ |
| Phase 1 Expectation | | $7.37 \times 10^{-6}$ | $4.3 \times 10^{-7}$ | | .605 | N/A | $1.2 \times 10^{-12}$ |
| 2 | - | $6.16 \times 10^{-5}$(*) | $2.0 \times 10^{-6}$ | .0368 | $1.56 \times 10^{-5}$ | $1 \times 10^{3}$ | $9.6 \times 10^{-13}$ |
| 3 | - | $1.55 \times 10^{-4}$(*) | $5.6 \times 10^{-6}$ | .192 | $7.76 \times 10^{-5}$ | $5 \times 10^{3}$ | $2.4 \times 10^{-12}$ |
| 4 | - | $1.66 \times 10^{-3}$(*) | $6.0 \times 10^{-5}$ | .192 | $7.76 \times 10^{-5}$ | $5 \times 10^{3}$ | $2.6 \times 10^{-11}$ |

Source: Appendix G, DOE 1990g

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

a. Probability of having a health effect numerically equal to the mean value or more.

b. Conditional incremental cancer fatalities.

c. Average Individual Risk = $\frac{\text{(Total Probability of Release) x (Health Effect)}}{\text{Reference Population}} = \frac{\text{(Col. 4) x (Col. 6)}}{\text{(Col. 7)}}$

d. Total Probabilities for Phases 2, 3, and 4 are for land impact. Associated source terms are expectation values given a land impact. The conditional probabilities of release are 0.102 for Phase 2, and 0.129 for Phases 3 and 4.

is then the quotient of the risk divided by the affected population. For 106-120 seconds, the value is $3.9 \times 10^{-16}$. This number is very small compared to the risks data listed in Table 4-8. The mission can be taken as the sum of the phase values.

Appendix C summarizes the DOE Final Safety Analysis Report for the Ulysses mission and describes the work of the DOE to characterize the distribution of consequences in a mathematically rigorous way.

## 4.2 ENVIRONMENTAL ASSESSMENT METHODOLOGIES

Accidental releases can occur in the Kennedy Space Center vicinity only during the ascent phase and at unspecified areas worldwide during later launch phases. Section 3 presented a description of the environments that could be affected by radioactive deposition. Two different impact assessment methodologies were developed to analyze these releases. One is for the Kennedy Space Center vicinity during the early first stage ascent phase. The other is global for later phases. The methodology for estimating potential economic costs resulting from the accidents is also provided.

As a measure, solely for illustrative purposes in this EIS, a cleanup level of 25 mrem/yr is used to estimate cleanup costs. That is, the land area contaminated to a level greater than 25 mrem/yr would be cleaned up to a level as low as reasonably achievable (ALARA). The Galileo EIS used a level of 25 mrem/yr as an estimate of ALARA based upon Federal agency experience and draft guidance. Since this item was a subject of some discussion, and since the estimates are purely illustrative, this Ulysses EIS has adopted a somewhat more conservative approach. It should be emphasized that in the event of an accident, post-accident mitigation would be based upon detailed monitoring and assessment conducted at that time. Actual cleanup levels will depend upon a number of factors, such as the location and use of the specific area contaminated, potential threat to the public, evaluation of the specific exposure pathways, and the specific particle size distribution of the contamination.

Not withstanding this estimate, actual mitigation activities and cleanup levels will be based upon a separate specific environmental analysis.

### 4.2.1 Kennedy Space Center and Vicinity

The method used to assess impacts from accidents in the early first stage ascent phase (up to about 70 seconds after launch) proceeds as follows. The first step is the identification of areas where there could be deposition above a specified level (0.2 $\mu Ci/m^2$) by mission phase (Table 4-4). For the purposes of this EIS, the level chosen is based on EPA guidance (EPA 1977) for contamination of soil by unspecified transuranic elements, including $PuO_2$, and is expressed in microcuries per square meter ($\mu Ci/m^2$). This EPA screening level is 0.2 $\mu Ci/m^2$. EPA suggests that areas contaminated above the 0.2 $\mu Ci/m^2$ level should be evaluated for possible mitigation actions. The recommended screening level was selected on the basis of limiting the additional annual individual risk of a radiation induced cancer death to less

TABLE 4-8. CALCULATED INDIVIDUAL RISK OF FATALITY BY VARIOUS CAUSES[a]

| Accident Type | Number of Fatalities for 1987 | Approximate Individual Risk Per Year[c] |
|---|---|---|
| Motor Vehicle | 48,290 | $2 \times 10^{-4}$ |
| Falls | 11,733 | $5 \times 10^{-5}$ |
| Drowning | 4,360 | $2 \times 10^{-5}$ |
| Fires and Flames | 4,710 | $2 \times 10^{-5}$ |
| Poison | 5,315 | $2 \times 10^{-5}$ |
| Water Transport | 949 | $4 \times 10^{-6}$ |
| Air Travel | 1,263 | $5 \times 10^{-6}$ |
| Manufacturing[d] | 1,200 | $5 \times 10^{-6}$ |
| Railway | 624 | $2.5 \times 10^{-6}$ |
| Electrocution | 760 | $3 \times 10^{-6}$ |
| Lightning | 99 | $4 \times 10^{-7}$ |
| Tornadoes[b] | 114[b] | $5 \times 10^{-7}$ |
| Hurricanes[b] | 46[b] | $2 \times 10^{-7}$ |
| Suicide | 30,796 | $1.2 \times 10^{-4}$ |
| Homicide and Legal Intervention (Executions) | 21,103 | $9 \times 10^{-5}$ |
| Guns, Firearms, and Explosives | 1,656 | $7 \times 10^{-6}$ |
| Suffocation | 3,688 | $1.5 \times 10^{-5}$ |
| All Accidents | 95,020 | $4 \times 10^{-4}$ |
| Diseases | 1,993,381 | $8 \times 10^{-3}$ |
| ALL CAUSES | 2,123,323 | $9 \times 10^{-3}$ |

[a] USDHHS 1989.
[b] 1946 to 1984 average.
[c] Fatalities/Total Population. (USBC 1988).
[d] Source USBC 1986.

than one chance in one million. Given that humans are generally considered the species most sensitive to radiation effects, contamination below the screening level is conservatively judged to have minimal impacts on other plant and animal species. Thus, for EIS purposes, areas that do not exceed the 0.2 $\mu Ci/m^2$ screening level are considered to have negligible potential for significant environmental impact and are not analyzed.

The last step in environmental assessment methodology is the identification of the nature and magnitude of the impacts in the areas affected. A brief discussion of how $PuO_2$ moves through the ecosystem and how it could affect plant and animal species is presented in Section 4.3. Potential exposure effects are determined through a survey of $PuO_2$ research literature. In addition to effects caused by exposure to $PuO_2$ in the environment, decontamination and mitigation activities employed to reduce $PuO_2$ exposure could also affect natural habitats and human land uses. Potential decontamination and mitigation methods are also presented in 4.3, along with an analysis of the impacts resulting from mitigation activities.

Because $PuO_2$ deposition is partially dependent upon the distribution of $PuO_2$ particles released during an accident, two fundamental assumptions were made. The first is that particles of released $PuO_2$ will be distributed such that the majority of large particles are deposited closer to the accident/impact site, with the size of particles decreasing with distance. The second assumption is that the highest concentrations of released curies are closer to the release point, and that concentrations will tend to decrease with distance.

### 4.2.2 Global Assessment

Beyond 70 seconds of the first stage ascent, about 99 percent of any potential release would be deposited in the ocean. The remainder consists of small particles (less than 10 microns in size) which would be subject to long-term residence time and transport in the upper atmosphere before settling to Earth.

In the latter stages of Phase 1 and for Phases 2, 3, and 4, release may occur due to reentry, RTG breakup, and ground impact of heat source modules. The environmental impacts are estimated based upon global average population data and general environmental conditions.

### 4.2.3 Economic Impact

Due to the uncertainty in defining the exact magnitude of economic costs associated with the radiological impacts, a range of mitigation costs were estimated in order to bound the costs which could result from ascent phase accidents. The minimum economic impact is based on the estimated cost of a radiological monitoring program. This estimate represents the costs of equipment and personnel needed to develop and implement a comprehensive long-term monitoring program. The maximum economic impact is defined as comprehensive mitigation actions undertaken on all areas contaminated above a 25 mrem/yr dose level (see Appendix C for details). The economic costs

following a potential accident could be reasonably expected to fall within this range. Only economic impacts associated with the effects of radioactive deposition are estimated in this analysis.

The post-accident monitoring program builds on the initial monitoring effort in place at the time of the launch. Before launch, monitoring teams and equipment from DOE, EPA, NASA, and the State of Florida will be in place and commence monitoring. In the event of an accident, these teams would continue monitoring for at least 30 days, after which EPA assumes responsibility for long-term monitoring. A large percentage of the costs associated with this program occur in the first year or two when a program plan must be developed, equipment must be purchased, and personnel must be hired and trained. After the program has been initiated and a shakedown period has been completed, costs decrease to a maintenance level necessary to run the program in the succeeding years. The minimum cost estimates are presented in Table 4-9.

A number of factors can affect the cost of radiological decontamination and mitigation activities, including:

- Location - The location can affect the ease of access to the deposition (e.g., a steep hillslope could be more expensive to cleanup than a level field), as can access to the site location and necessary decontamination resources, such as heavy equipment, water, clean soil, etc.

- Land Cover Type - The characteristics of some kinds of land covers make them more difficult and therefore more expensive to decontaminate (e.g., plowing and restoration of a natural vegetation area could be more costly than using the same technique in an agricultural area).

- Initial Contamination Level - Higher levels of initial contamination can require more sophisticated and more costly decontamination techniques to meet a particular cleanup standard than a lower level of initial contamination.

- Decontamination Method - More sophisticated decontamination methods, such as wetland restoration, are much more expensive than simple actions, such as water rinses.

- Disposal of Contaminated Materials - Disposal of contaminated vegetation and soils onsite could be much more cost effective than transportation and disposal of these same materials to a distant repository.

- Cleanup standard.

In setting the level at which specific mitigation efforts will be taken, the characteristics of the material deposited must be taken into account. Plutonium dioxide has extremely low solubility in water and has a low bioaccumulation rate within the food chain; its alpha emissions are short range, and the primary concern is inhalation of respirable fines.

TABLE 4-9. MONITORING PROGRAM COST ESTIMATES

| Period | Activity | Cost |
|---|---|---|
| Year one | Transition from launch monitoring activity, plan development, supplemental equipment purchases, hiring of personnel. | $1,000,000 |
| Year two | Testing and shakedown of program methods and monitoring network, monitoring of mitigation actions. | $ 500,000 |
| Year three | Transition to long-term monitoring of impacts and mitigation actions. | $ 250,000 |
| Year four and each succeeding year | Program maintenance. | $ 100,000 |

Source: NASA 1989a

In the event of an accident, the ground monitoring program will be based upon:

- Measurement of ground concentrations to characterize the nature and extent of contamination
- Airborne measurements of the amount and characteristics of the release
- Atmospheric model estimates of the amount and location of material deposited, using recent climatological data.

The need for cleanup, however, would be based upon actual conditions, as characterized by the monitoring program initiated following an accident. While the actual cost of cleanup associated with a potential Phase 1 accident can not be predicted with great precision because the number of factors involved (see above), an approximation can be developed from data provided in an EPA report (EPA 1977). That report indicated that in 1977, cleanup costs could range from approximately $250,000 to $2,500,000 per square kilometer ($1,000 to $10,000 per acre) if removal and disposal of contamination is not required. Removal and disposal of contaminated soil at a near-surface facility could cost from approximately $36,000,000 to $47,500,000 per square kilometer ($145,000 to $190,000 per acre). In terms of 1990 dollars, these costs should be approximately doubled. (It is estimated that cleanup without removal and disposal would range from $500,000 to $5,000,000; and with disposal could range from $72,000,000 to $95,000,000.)

In addition, there are significant secondary costs associated with the decontamination and mitigation activities, such as:

- Temporary or longer term relocation of residents
- Temporary or longer term loss of employment
- Destruction or quarantine of agricultural products, including citrus crops
- Restriction or bans on commercial fishing
- Land use restrictions (which could effect real estate values and tourism activity)
- Public health effects and medical care.

To gain an appreciation for the potential magnitude of these secondary costs, results from a nuclear reactor risk assessment model were used. A U.S. Nuclear Regulatory Commission (NRC) document (NRC 1975) presents results from a probabilistic risk assessment and an economic cost distribution for accidents at commercial nuclear power plants. Although the kinds of radioactive contamination resulting from a potential nuclear reactor accident are quite different from the contamination resulting from an RTG accident, the

treatment of secondary costs for decontamination and mitigation activities is employed here as a useful guide. The cost distribution study found that decontamination costs account for approximately 20 percent of the total economic cost of an accident. In other words, the total cost of a radioactive contamination accident could be as much as five times the direct decontamination costs. This multiplier of 5, however, applies only to those types of areas that would incur secondary costs, such as the urban and agricultural land.

The potential range of cleanup methods that could be utilized is listed in Table 4-10. Cleanup costs estimated in this EIS are solely for illustrative purposes. Actual post-accident mitigation activities would result from detailed monitoring and assessments at that time. The cost estimates discussed in Section 4.3.2.3 are based on draft guidance discussed in the FSAR (Volume III) and presume cleanup of areas where contamination could lead to dose levels exceeding 25 mrem/yr during the first year following plume passage.

## 4.3 ENVIRONMENTAL CONSEQUENCES OF ACCIDENTS RELEASING RTG FUEL

This section presents the environmental consequences of an accident in which plutonium dioxide is released to the environment. A brief discussion of how $PuO_2$ behaves in the environment precedes the impact analysis. The description of the affected environment is found in Section 3.

It should be emphasized that the following discussions are provided for illustrative purposes and are not intended to reflect a definitive statement regarding specific areas that would be contaminated in the event of an accident involving a release of plutonium dioxide fuel. In the unlikely event such an accident occurred, the amount of contamination and the specific affected areas would be determined and appropriate actions taken. This would include evaluation of alternatives in accordance with the National Contingency Plan and development of appropriate cleanup levels for contaminated sites.

### 4.3.1 Plutonium Dioxide in the Environment

The extent and magnitude of potential environmental impacts caused by $PuO_2$ releases resulting from STS/IUS/PAM-S accidents are dependent on the mobility and availability of $PuO_2$ in the environment. The mobility and availability of $PuO_2$ in turn, is directly controlled by a number of physical and chemical parameters, including: particle size, potential for suspension and resuspension, solubility, and oxidation state of any dissolved $PuO_2$. It is these factors, in conjunction with the three potential exposure pathways (i.e., surface contact, ingestion, and inhalation), that determine the impacts on marine, aquatic, and terrestrial ecosystems.

The size of $PuO_2$ particles is an important factor in assessing impacts to environmental resources resulting from an accidental release. Particle size can affect the rate of dissolution of $PuO_2$ in water and the initial suspension and subsequent resuspension of particles in air and water. The dissolution

## TABLE 4-10. RANGE OF DECONTAMINATION METHODS FOR VARIOUS LAND COVER TYPES FOR POTENTIAL RTG ACCIDENTS

| Land Cover Type | Low-Range Cost Decontamination/Mitigation Methods | High-Range Cost Decontamination/Mitigation Methods |
|---|---|---|
| Natural Vegetation | - Removal of large particles<br>- Water rinses of vegetation<br>- Recreational and other use restrictions | - Removal of large particles<br>- Removal and disposal of all vegetation<br>- Removal and disposal of topsoil<br>- Relocation of animals<br>- Habitat restoration |
| Urban | - Removal of large particles<br>- Rinsing of building exteriors and hard surfaces<br>- Rinsing of ornamental vegetation<br>- Deep irrigation of lawns | - Removal of large particles<br>- Removal and disposal of all vegetation<br>- Land use restrictions<br>- Demolition of some or all structures<br>- Permanent relocation of affected population |
| Agriculture | - Removal of large particles<br>- Deep irrigation of cropland<br>- Destruction of first year crop, including citrus crops<br>- Rinsing of citrus and other growing stocks<br>- Shallow plowing of pasture and grain crop areas | - Removal of large particles<br>- Destruction of citrus and other perennial growing stocks<br>- Banning of future agricultural land uses |
| Wetland | - Removal of large particles<br>- Rinsing of emergent vegetation<br>- Recreational and other use restrictions | - Removal of large particles<br>- Removal of disposal of all vegetation<br>- Dredging and disposal of sediments<br>- Habitat restoration |
| Inland Water | - Removal of large particles<br>- Boating and recreational restrictions | - Removal of large particles<br>- Dredging and disposal of contaminated sediment<br>- Commercial and recreational fishing restrictions |
| Ocean | - Removal of large particles<br>- Shoreline use restrictions | - Removal of large particles<br>- Dredging and disposal of contaminated sediment<br>- Commercial and recreational fishing restrictions |

and the suspension/resuspension potential ultimately control the mobility and availability of $PuO_2$ to plant and animal species. Generally speaking, larger particles have less potential for suspension and resuspension; as particle size decreases, particles are more easily kept in suspension.

Chemically, plutonium oxide is extremely resistant to dissolution, especially in lung or digestive fluids of the human body. Since uptake of ingested plutonium oxide (e.g., in water or food) is extremely low (on the order of one part per million), such plutonium is normally excreted in the feces. The major risk to humans is from accidental inhalation of respirable particles (about 10 micrometers or less in size), since natural removal from the pulmonary parts of the lung takes many years.

Particle sizes have been predicted for the first stage ascent phase accident in which accident released plutonium dioxide can be incorporated into the resulting fireball. Plutonium dioxide particle size is inversely related to deposition range. For a fireball accident representative of SRB case failure accidents in the period 0 to 10 seconds of the first stage ascent phase, approximately 92.8 percent of the released curies will be deposited as particles greater than 44 microns, and the greatest number of these particles will fall in an area from 0 to 10 km from the accident. Approximately 2.5 percent of the released curies will be deposited as particles in the range of 30 to 44 microns, and the greatest number of these particles will fall in an area from 10 to 20 km from the accident. Approximately 3.4 percent of the released curies will be deposited as 10 to 30 micron particles, and the majority will fall within the range of 20 to 50 km from the accident. The smallest particles, those less than 10 microns, account for approximately 1.3 percent of released curies, and the majority will travel greater than 50 km. The greater the distance over which a release will be transported, the more dilute will be the ground level deposition. These finer particles could also be more easily resuspended by subsequent wind action and human disturbance. However, resuspended material available for inhalation is on the order of $1 \times 10^{-6}$ (one-millionth) of the ground deposition, thus high levels of ground concentration would be required to constitute a risk to animals through this route. Given the deposition levels estimated in the safety analysis (see Appendix C), this risk is not likely to be significant.

In marine and aquatic systems, larger particles will quickly settle to the bottom sediments, while smaller, silt-size particles may remain in suspension within the water column indefinitely. Smaller particles may not even break the water surface due to surface tension, instead forming a thin layer on the water surface and subsequently transported to the shoreline. Resuspension of smaller particles from the bottom can occur due to physical disturbance of the sediments by wave action, recreational use of the water bodies (e.g., swimming, boating, and fishing), as well as by the feeding activity of various marine and aquatic species. Plutonium dioxide particles, as a component of the bottom sediments, may also be transported toward and along the shoreline by wave action and currents in near-shore environments.

The prevailing southerly winds during the launch period (autumn - October/November) as noted in Section 3.2.3.5, would tend to keep the fine

material which is suspended in the water column confined to the inshore area. Heavier particles settling to the bottom would also tend to remain in that area. During those autumn periods when episodic wind reversal occurs (i.e. northerly winds), suspended fines would tend to move offshore, with the heavier bottom material tending to move inshore. A 3-year study of inshore sediment transport due to coastal currents near Cape Canaveral using tracers (dyed sand) injected at 3 and 6 m depths, indicated that particles persisted in the area for at least the 3-year study period (INSRP 1989). Particles injected at depth of 6 m or less moved rapidly on to the beach over the study period, and moved at least 4 km north and south of the test site.

A number of factors can affect the solubility of $PuO_2$ in water. Physiochemical parameters most important to the solubility of plutonium dioxide are the reactive surface area and oxidation state of $PuO_2$ and the water chemistry including pH, reduction/oxidation potential, and temperature. Mass to surface area ratios of particles affect reactivity and solubility, with solubility being inversely related to particle size. The dissolution rate of the plutonium dioxide fuel in the RTG is very small, ranging from 1.2 to 90 $\mu Ci/m^2/sec$ in sea water and fresh water, respectively, based upon the dissolution rate per unit surface area of the fuel.

Plutonium dioxide entering into a water/sediment system would be preferentially taken out of solution and bound in saturated sediments in amounts 10 to 100,000 times greater than the amounts that would remain in the associated water column.

Plutonium dioxide may be carried into the soil by a number of routes, including percolation of rainfall and subsequent leaching of particles into the soil, animal burrowing activity, and plowing or other disturbance of the soil by humans. Migration of the $PuO_2$ particles into the soil column is of concern, primarily because of the potential for $PuO_2$ to reach ground-water aquifers used as drinking water supplies. The opportunity would most likely occur where surface contamination is deposited on primary aquifer recharge zones. Once deposited on soil, plutonium dioxide appears to be extremely stable. Soil profile studies have shown that generally more than 95 percent of the plutonium dioxide from fallout remained in the top 5 cm of surface soil after 10 to 20 years of residence time in undisturbed areas (DOE 1987).

Direct contamination of an aquifer where it reaches the surface is remote but possible. It would be expected that clays, organics, and other anionic constituents would bind most of the $PuO_2$. The binding of $PuO_2$ would occur in the first few meters of sediment, therefore greatly reducing the concentration of this constituent with depth. This natural filtering of $PuO_2$ would probably reduce concentrations to levels that would be below the Primary Drinking Water Standard of 4 mrem for exposure due to drinking water.

It is also possible that surface water run-off containing $PuO_2$ could directly contaminate drinking water supplies from surface water bodies since this type of contamination is greatest due to suspended $PuO_2$ and not from dissolved $PuO_2$. Filtering of the surface water before chemical treatment would reduce the concentration of total plutonium to very low exposure levels.

The availability of $PuO_2$ to biota in marine, aquatic, and terrestrial environments depends on the route of $PuO_2$ exposure to the biota and the physical and chemical interaction of $PuO_2$ with the water and soil of the affected area. These interactions determine whether $PuO_2$ is available for root uptake by plants and for ingestion and/or inhalation by marine, aquatic, and terrestrial fauna. The route of $PuO_2$ exposure differs between the two basic categories of biota-flora and fauna. Flora, in marine, aquatic, and terrestrial environments, can be exposed to $PuO_2$ contamination via surface contamination, root uptake, and leaf absorption. Fauna can be exposed via skin contact, ingestion, and inhalation of $PuO_2$ particles.

Surface contamination and skin contact does not pose a significant danger to the biota. The alpha radiation emitted by plutonium has very little penetration power (Hobbs and McClellan 1980). Therefore, little penetration can occur through the skin of fauna. In addition, several studies on root uptake and leaf absorption of $PuO_2$ indicate that very little, if any, $PuO_2$ is absorbed by plants when $PuO_2$ is in an insoluble form (Cataldo et al. 1976, Schultz et al. 1976).

The significance of ingesting $PuO_2$ can vary between terrestrial, and marine and aquatic fauna. Studies of animals indicate that the digestive tract tends to discriminate against transuranic elements (Cataldo et al. 1976, Schultz et al. 1976). However, ingestion may be significant for small fauna in terms of total exposure, especially for those that burrow, ingesting soil along with food material. If the soil is contaminated, ingestion of $PuO_2$ could result. Although the transfer factor from the intestinal tract to the blood and other organs is small, total activity passing through the tract could be large relative to total body size.

Summary

The impact of ingesting $PuO_2$ by marine and aquatic fauna can be significant depending on $PuO_2$ availability. For example, studies have found that bioaccumulation of $PuO_2$ does occur in benthic organisms that ingest sediments contaminated with $PuO_2$ (Thompson and Wachholz 1980). However, most of these studies also indicate that the bioaccumulation of $PuO_2$ is not critical to the upper trophic levels, including humans.

Inhalation is considered to be the most critical exposure route for terrestrial fauna (Wicker 1980). However, inhalation impact depends on several factors, including the frequency of resuspension of $PuO_2$, the concentration and size of resuspended particles, and the amount actually inhaled (Schmel 1980, Pinder et al. undated). Smaller particles have a greater chance than larger particles for being resuspended and inhaled. Although many of the particles may be subsequently exhaled, the smallest particles have the greatest likelihood of being retained deep in the lung (Hobbs and McClellan 1980, Thompson and Wachholz 1980). However, resuspended material available for inhalation is on the order of $1 \times 10^{-6}$ (one-millionth) of the ground deposition, thus high levels of ground concentration would be required to constitute a risk to animals through this route. Given the

deposition levels estimated in the analysis, this risk is not likely to be significant.

No definitive research has been conducted that defines the specific effects of $PuO_2$ on plant and animal species, particularly at the relatively low contamination levels resulting from potential STS/IUS/PAM-S accidents. Generally speaking, however, radiation can cause three main types of physical effects on organisms: 1) somatic injury, that is damage to the normal morphology and functioning of the exposed organism; 2) carcinogenic injury, that is an increase in the incidence of cancers; and 3) genetic injury, affecting reproductive cells and causing deleterious genetic changes in an organism's offspring. Any of these three physical effects could cause increased mortality to exposed organisms. Overall ecosystem structure is not expected to change, and therefore no significant ecological consequences are anticipated. At the low levels of deposition determined in the safety analysis (see Appendix G), the effects are not likely to be significant.

### 4.3.2 Assessment of Impacts to Kennedy Space Center and Vicinity

#### 4.3.2.1 Surface Areas Contaminated by Representative Accidents

In the unlikely event that an accident severe enough to cause a release of RTG fuel occurs, the areas potentially contaminated by the release are noted in Tables 4-4 and 4-5.

Accidents occurring within the first 70 seconds of the first stage ascent phase would result primarily in deposition on the controlled land areas of KSC. Beyond 70 seconds into the first stage ascent phase, the Shuttle has gained enough altitude and down range distance from KSC that about 99 percent of an accident release would result in ocean deposition, with the remaining 1 percent (small particles less than 10 microns in size) subject to long-term residence time and transport in the upper atmosphere before settling to Earth.

#### 4.3.2.2 Exposure Effects

Deposition of $PuO_2$ from ascent phase accident releases will have little direct effect on land cover. The material will not physically alter land cover unless a particle provides enough heat to start a fire. Although $PuO_2$ can affect the human use of these land covers, there is no initial impact on soil chemistry, and most of the $PuO_2$ contamination deposited on the water bodies is not expected to react chemically with the water column. No significant consequences to flora and fauna are expected from surface contamination and skin contact with the $PuO_2$, except where particle concentration and/or size is great enough to overheat the contaminated surface.

Plutonium dioxide deposition would not have any direct effects on historical or archaeological resources. It will not physically alter nor chemically degrade historical or archaeological resources.

4.3.2.3 Long-Term and Mitigation Effects

Natural Vegetation and Wetlands

Plutonium dioxide deposited on the soil will interact with inorganic and organic ligands to form primarily insoluble compounds. It is expected that over 95 percent of the plutonium dioxide will remain in the top 5 cm (2 in) of surface soil for at least 10 to 20 years. No mitigation is necessary because of long-term impacts to soil. Mitigation required for other reasons may result in significant soil impacts.

As discussed in Section 4.3.1, surface contamination and skin contact do not pose significant dangers to biota. No significant consequences to flora are expected from root uptake and leaf absorption. Ingestion by terrestrial fauna is negligible except for small fauna due to ingestion of contaminated soil. This could result in a large total activity passing through the general intestine track. Inhalation due to resuspended material is small [$1 \times 10^{-6}$ percent (one-millionth of one percent) of ground deposition]. No significant impacts to biota would be expected in any of the areas receiving surface contamination. Areas of highest concentration are the result of deposition of larger particles or chunks, which are noninhalable.

The particulate $PuO_2$ on the surface of the water bodies is not likely to be readily available for consumption by pelagic aquatic fauna. The amount of $PuO_2$ to be suspended or dissolved in the water column is predicted to be slightly higher than $1 \times 10^{-5}$ (i.e., .00001) times the concentration of $PuO_2$ deposited in the bottom sediment (i.e., the amount dissolved or suspended in the water column is 100,000 times less than the amount in the sediment). Thus, for example, even if a wetland area were contaminated by 2.0 $\mu Ci/m^2$ of $PuO_2$, only about $2 \times 10^{-5}$ $\mu Ci/m^2$ of $PuO_2$ would be dissolved or suspended in the water column. This small amount of $PuO_2$ available in the water column is not considered to have significant impacts to the aquatic fauna that may ingest the dissolved or suspended $PuO_2$. In addition, studies have indicated that higher trophic level organisms, such as fish, that are likely to live within the water column have a low accumulation factor (DOE 1987, DOE 1990c).

Overall, the major potential impacts to the natural vegetation and wetland biotic resources of the KSC and vicinity resulting from early first stage ascent phase releases accidents include bioaccumulation of $PuO_2$ by benthic organisms and bioaccumulation of $PuO_2$ by the aquatic vegetation. Because of the potential for bioaccumulation to occur in aquatic vegetation and benthic organisms, there is a potential for the $PuO_2$ to travel up both the terrestrial and aquatic food chains. However, bioaccumulation of plutonium decreases with higher trophic levels, thus impacts to the biological diversity are not expected to occur. Redistribution of $PuO_2$ is a possible occurrence, especially when contaminated terrestrial fauna, including birds, move from one place to another. However, it is unlikely that they will create any additional impacts that have not already been described. Recycling of $PuO_2$ will predominantly occur with vegetation and fauna having short-life spans. The bacteria that decomposes the organic matter may accumulate $PuO_2$. However, most of the $PuO_2$ should return to the sediments. In the aquatic environment

this may promote the continuance of bioaccumulation of $PuO_2$ by the benthic organisms and aquatic vegetation.

Mitigation of the impacts to flora and fauna in natural vegetation and wetland areas could be accomplished through a combination of monitoring and remedial action based on monitoring. The amount of $PuO_2$ resuspended in the air in natural areas determines if $PuO_2$ concentrations may pose inhalation health hazards to humans. If levels are determined to pose inhalation health hazards, then access to the area could be restricted until monitoring indicates that $PuO_2$ concentrations will no longer pose a potential health hazard. The impacts of wetland mitigation activities (see Table 4-10) could range from temporary disturbance of wetland soils and vegetation associated with low range decontamination/mitigation methods, to complete removal of vegetation and sediments/soils from localized areas of contamination followed by longer-term recovery of the affected areas with habitat restoration.

Agricultural Land

Citrus groves on the Kennedy Space Center could be contaminated with $PuO_2$ at or above 0.2 $\mu Ci/m^2$ from an early first stage ascent phase accident resulting in a release. A study on citrus groves contaminated with $PuO_2$ indicated that the plutonium dioxide on the fruit surfaces was not readily washable with water. The $PuO_2$ could enter the human food chain through transfer to internal tissues during peeling or in reconstituted juices, flavorings, or other products made from orange skins. Approximately 1 percent of the $PuO_2$ deposited on the orange groves would be retained on fruit harvested in the year following deposition. Almost all would be from fruit surface contamination. In contrast with the fruit, plutonium was readily washed away from leaf surfaces (Pinder et al. undated). Thus, if the leaf surfaces were washed, recontamination of the fruit should not occur. Resuspension of plutonium from the soil via splash up was also studied. Very little, if any, reached the fruit or leaf surfaces. This was thought to occur because splash up generally does not reach a height greater than 1 m (3 ft) above the ground. Most orange tree leaves are over 1 m (3 ft) above the ground.

Mitigation of contaminated citrus fruit could include collection and disposal of the contaminated fruit according to Federal and State regulations. To prevent future contamination of citrus crops and protect the safety of workers, the trees could be washed down to remove $PuO_2$ from the leaves, and the soil around the trees could be covered with new soil to reduce resuspension. Future citrus crops could be monitored for $PuO_2$ contamination before sold on the market.

Other crops grown in areas off the Kennedy Space Center site may be contaminated by surface deposition. These crops would be examined and washed to ensure no contamination. Those crops that can not be decontaminated may be destroyed. The land on which the crops have been grown would be monitored and scraping implemented if the monitoring shows significant $PuO_2$ concentrations.

Urban Areas

Areas of land cover for human activities (e.g., buildings, roads, ornamental vegetation, and grass areas) contaminated above the 0.2 $\mu Ci/m^2$ level would be monitored to determine if decontamination or mitigation actions might be necessary. The results of the accident consequences analyses show up to 2.240 $m^2$ of dry land areas could be contaminated at 25 mrem/yr. It is likely that only small areas of cleanup would be necessary. If mitigation actions were necessary, temporary relocation of the population from their homes and workplaces may be required. Cleanup actions could last from several days to several months. Rainfall could wash paved surfaces and exteriors of buildings and move $PuO_2$ into the surface soil and surface waters.

There are several archaeological sites on the Kennedy Space Center site and vicinity that may receive deposition by first stage ascent phase accidents. In addition, Kennedy Space Center facilities that have historical significance and are not damaged in the blast, could also have $PuO_2$ deposited on them. Presently, unknown archaeological sites could be within the area of deposition. While the present analyses indicate that cleanup actions would not be necessary (Table 4-10), should monitoring indicate otherwise, these sites could be affected.

Deposition could also have a long-term effect on future investigations at any archaeological site. Archaeological digs, by their very nature, disturb the soil surface with digging and sifting operations, which could expose workers and others to the $PuO_2$. Radiological safety measures would need to be taken to prevent potential health effects to the workers and could greatly increase the cost of investigating these sites. If investigation of archaeological sites that have $PuO_2$ deposited on them is proposed, a safety analysis would be completed and approval given to proceed from appropriate Federal and/or state authorities.

Inland Water and Ocean

The waters surrounding Merritt Island are classified by the State of Florida as Class II and Class III waters, with radionuclide contamination threshold limits of 15 pCi/l. Most of the $PuO_2$ deposition is not expected to be dissolved in the water column; therefore, this threshold level is not expected to be exceeded.

Some of the waters surrounding Merritt Island are considered Outstanding Florida Waters. These waters are designated to receive protection which supersedes any other water classifications and standards, and as such prohibits any activity which reduces water quality parameters below existing ambient water quality conditions. An ascent phase accident leading to a release could deposit sufficient amounts of $PuO_2$ to result in violation of this protection standard. The recently designated manatee refuge (Banana River north of State Road 528) could possibly be affected by deposition from an early Phase 1 accident.

Although shellfish harvesting is prohibited or unapproved in some waters surrounding Merritt Island, deposition above 0.2 $\mu Ci/m^2$ could impact an area of conditionally approved shellfish harvesting. Again, the screening level is used here only as an indicator. The EPA suggested screening level applies only to land areas.

Mitigation of $PuO_2$ impacts to inland water bodies may include any of the following.

- All ditches and borrow pits with shallow depths and in close proximity to human activity receiving surface concentrations of 0.2 $\mu Ci/m^2$ or greater may need to be monitored. If the monitoring results provide evidence of contamination, the ditches and borrow pits may need to be drained and any contaminated sediment removed and disposed of within Federal and State requirements. Larger areas of ponded water in close proximity to human activity can also be monitored. Mitigation could include skimming to remove the surficial film of $PuO_2$. Monitoring after skimming will determine the need for water and/or sediment removal. Measures should be employed to reduce surficial runoff and sediment from entering water bodies used by humans.

- Recreational water activities (e.g., swimming, boating), as well as sport and commercial fishing, may need to be restricted in larger water bodies until monitoring results indicate that it is safe for them to be resumed.

Monitoring the amount of $PuO_2$ suspended and/or dissolved in the water columns of impacted water bodies will determine if $PuO_2$ has been deposited in the sediments. Benthic organisms, such as clams, scallops, and crabs, should be monitored for bioaccumulation of $PuO_2$. If bioaccumulation of $PuO_2$ in benthic organisms is significant, then it should be determined if consumption of such organisms would pose a human health hazard. If it is determined that consumption of such organisms will pose a human health hazard, harvesting of such organisms should be banned until concentration levels within the organisms no longer pose a threat.

If it is determined that $PuO_2$ concentrations are significant in either the water or sediment of impacted water bodies, then $PuO_2$ bioaccumulation in aquatic vegetation should be monitored. If bioaccumulation of $PuO_2$ in aquatic vegetation is found to be significant, then organisms that feed off of these aquatic plants should also be monitored for $PuO_2$ bioaccumulation and the levels of bioaccumulation determined that could pose a human health threat if such organisms are consumed.

Surface contamination levels may also impact the recharge areas of the surficial aquifer. The surficial aquifer serves as the potable water source for the cities of Titusville, Mims, and Palm Bay. In addition, many wells on private land in the area use the surficial aquifer as a source of water. Plutonium dioxide may have the potential to contaminate this aquifer, but since $PuO_2$ is essentially insoluble, it is unlikely for any contamination to reach the wellheads of municipal water supplies. It is also highly unlikely

that any contamination on the Kennedy Space Center will reach offsite wells, including municipal water supply wells. Transport through the underlying aquatard to the lower Floridan aquifer is considered very unlikely.

Mitigation could include assessment of the amount of contamination in the different soil horizons in aquifer recharge areas to determine if the plutonium dioxide is migrating to the water table. If the potential for migration of $PuO_2$ to the aquifer is high, these areas could be scraped to below the contamination depth and the spoil disposed of properly. Private wells in the area of contamination could be monitored and alternative water supplies would need to be developed if contamination occurs.

A rough order of magnitude of possible cleanup costs can be estimated as follows. Guidance under consideration calls for cleanup where dose levels due to deposition exceed 100 millirems per year. This analysis indicated no such areas. The same guidance indicates monitoring, but not cleanup, at dose levels below 10 millirem per year. This analysis indicates that, in the mean value case for 0-10 seconds, during the first year following plume passage, an area of $2.16 \times 10^{-3}$ $km^2$ exceeded 25 mrem/yr at a probability of $3.36 \times 10^{-6}$. Using the cost estimate of $25 million per square kilometer yields an expectation value of cleanup cost which is a small fraction of the total investment in this mission. Even using the figure of $475 million per square kilometer still yields an expectation value of cleanup cost which is small compared to the investment in the mission.

#### 4.3.2.4 Assessment of Global Impacts

This section presents the environmental consequences of the last three mission phases. The contamination from a release during any of these later phases will result from accidents in which GPHS modules or fueled clads impact a hard surface. Each of the GPHS modules or fueled clads involved in the accident release would release $PuO_2$ at a different location separated by a few kilometers to hundreds or thousands of kilometers. Each release point is independent of the other.

The radiological consequence analysis indicated that deposition from an accident in any of the last three mission phases did not exceed the cleanup level of 25 mrem/yr (or even 10 mrem/yr) as noted in Tables 4-4 and 4-5.

Should an accident occur during the mission, resulting in deposition outside the United States, the Federal government will respond with the technical assistance and support needed to clean up and remediate affected areas, and to recover the plutonium fuel.

In summary, due to its low solubility in water and its limited uptake in the food chain, in the unlikely event of an accident, the plutonium dioxide RTG fuel released is expected to have very limited health or environmental effects through these pathways, given the accident and risk analyses.

### 4.3.3 Emergency Response Planning

In the event of an accident involving the Ulysses spacecraft and its RTG, NASA and the DOE (the RTG supplier), have developed a comprehensive contingency plan to ensure that any accident, whether it involves a radiological release or not, can be met with a well-developed and tested response. The plan encompasses every phase of the Ulysses mission. It has been coordinated with the Federal, State, and County organizations involved in the launch, and has been exercised to assure the various organizations are prepared to support the launch. The contingency plan entails the following steps:

- Determine whether there has been a release of radioactive material
- Assess and characterize the extent of any release
- Predict the propagation and dispersion of the released material
- Formulate/recommend protective and mitigating actions to safeguard people and property from the consequences of the release
- Minimize the effects of a release through control of the contaminated areas and containment of radioactive materials
- Recover and dispose of the radioactive material
- Decontaminate and recover affected areas, facilities, equipment, and properties.

A specially equipped Radiation Control Center located at KSC would direct any emergency actions required during prelaunch countdown or early ascent. These emergency actions would involve ground and aerial radiation monitoring by prepositioned teams, and possibly precautionary sheltering or relocating personnel. From a nearby offsite location, DOE, EPA, and the State of Florida would conduct radiological monitoring and assess the accumulated data. In the event of even the smallest release, or in support of preplanned precautionary measures, the State of Florida and local governments would decide upon an appropriate course of action. As more detailed radiological measurements became available, decisions on the addition or rescission of precautions would be made by State and local authorities. Long-term monitoring and recovery measures would be the responsibility of the EPA and the State of Florida.

## 4.4 INCOMPLETE OR UNAVAILABLE INFORMATION

The magnitude of the environmental impact for normal launches has been determined from extensive data gathered over the past nine years. For the assessment of possible accidents that could result in a release from the RTG, data has been derived from models, simulations, and analyses based on the extensive test and verification program as discussed in Section 4.1.4.3 and Appendix C.

This Environmental Impact Statement uses the safety analysis conducted by DOE for the Ulysses mission (see Appendix C and G) as its primary data source for the risk assessment of accidents releasing nuclear material. The analysis of the Ulysses mission builds upon the analysis of the Galileo mission, which also used the Shuttle/IUS launch configuration. Even though Ulysses has an additional third (PAM-S) stage, the third stage operates far from Earth and is not expected to contribute to accident environments. The basic launch vehicle configuration has therefore been through two comprehensive safety analyses, including major external peer evaluations.

Regarding the conditional probability of release and the consequence analysis, in addition to the analyses of RTG response to accidents (FSAR, Volume II), and the dispersion and deposition analysis (FSAR, Volume III), there has been an integrated (i.e., overall) risk assessment which used Monte Carlo techniques to combine all of the source terms from the LASEP analysis (FSAR, Volume II, Book 1) with the ranges of possible dispersion, deposition, and exposure pathway characteristics (FSAR, Volume III, Book 1). This resulted in tables of possible consequences, Table 4-3 to 4-5. Even within LASEP, the analysis sampled across ranges for release thresholds and ranges for material properties where there were data and experience to support such a range. These techniques were intended to allow for uncertainties in material properties and for differences in the interpretation of test data. Through use of these techniques, the results are judged to be representative of the range of eventualities which may pertain to an accident situation. For instance, if a launch area accident were to occur, winds could be blowing from sea to shore or shore to sea. The risk assessment takes into account the range and frequency of the climatological situations.

For the purposes of this analysis, <u>risk</u> is defined as the product of the consequences and probability of that consequence. In the risk assessment, source terms, dispersions, deposition, and dose parameters ranged over one or more orders or magnitude in the Monte Carlo (SPASM Code) combinations. For the mission as a whole, the largest 99th percentile consequence is for late in Mission Phase 1 (106-120 seconds) and is 14.5 health effects at a probability of $2.27 \times 10^{-8}$. Allowing for even an additional order of magnitude uncertainty, the <u>risk</u> would be $3.3 \times 10^{-6}$ health effects. Dividing by the affected population, the average individual risk would still be several orders of magnitude below any of the tabulated risks routinely faced by the public.

In view of the extensive analyses of the Shuttle/IUS launch configuration together with the comprehensive analysis of significant parameters (and their variabilities) which affect risk, sufficient information exists to enable a decision among the alternatives in this EIS.

## 4.5 NO-ACTION ALTERNATIVE

There are no environmental impacts associated with the no-action alternative; however, there are major economic, programmatic, and geopolitical consequences of such a cancellation. Through FY 1990 (i.e., through September 30, 1989), NASA will have expended approximately $150 million on the

Ulysses program. Cancellation would mean the abandonment of that investment and a loss of the anticipated scientific gains identified in Section 1.2.

Currently, the United States has a clear lead in the exploration of the solar system. Programmatically, there are currently no backup missions that could achieve Ulysses' scientific goals within this century. Thus, the United States would forego detailed scientific knowledge from the Ulysses mission.

## 4.6 SUMMARY OF ENVIRONMENTAL CONSEQUENCES

The proposed action is the completion of preparations and operation of the Ulysses mission, including its launch on the STS/IUS PAM-S in October 1990 or November 1991 as the backup contingency opportunity. The alternative to the proposed action is no-action; that is, to terminate further commitment of resources to the mission. The only expected environmental consequences are associated with a normal launch. These impacts have been treated elsewhere in NASA National Environmental Policy Act (NEPA) documentation. Even in the statistically rare event of an accident leading to a release of plutonium, the estimated consequences are quite limited, and the risks are small.

## 4.7 ADVERSE ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED

During the normal launch, hydrogen chloride will be produced by the SRBs. This will likely produce short-term acidification of shallow surface waters near the launch pad and deposition on nearby vegetation. The airborne concentrations of aluminum oxide particulates within the launch cloud will exceed air quality standards (see Section 4.1.2.1) for a short period, but should not affect the overall ambient air quality of areas outside the launch cloud. The deposition of HCl from the Shuttle exhaust will probably result in some vegetation damage near the launch pad and possible fish kills in onsite ponds near the launch pad. Launch of the Ulysses mission will contribute to long-term changes in species richness in the near-field environment that will be experienced with the resumption of STS launches at Launch Complex 39. Launch of the Ulysses mission will also introduce ozone-degrading hydrogen chloride into the stratosphere. This will have limited, temporary effect on global ozone levels.

In the event of an accident near KSC, it is possible that some areas could be contaminated by plutonium dioxide. The probability of this occurring is predicted to be less than 1 in 215 thousand (first three subphases of first stage ascent total probability of release). If such an accident did occur, decontamination of land, vegetation, and buildings could be required, and costs would be incurred.

## 4.8 RELATIONSHIP BETWEEN SHORT-TERM USES OF THE HUMAN ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

### 4.8.1 Short-Term Uses

The affected environment, for the short term, includes the KSC and surrounding areas. The short-term uses of the area include NASA operations, a

fish and wildlife refuge, citrus groves, residential communities, and recreational areas. The proposed action will be conducted in accordance with past and ongoing NASA procedures for operations at the launch site.

### 4.8.2 Long-Term Productivity

The KSC region will continue to support citrus groves and wildlife habitat, as well as human activities. The proposed action should have no long-term effect on such uses. Successful completion of the project, however, may have an impact on the future of the space program and the continued economic stability of Merritt Island and the surrounding areas. Both the human and biotic ecosystems are expected to maintain their harmonious productivity.

A potentially large benefit to be gained from successful completion of this project is a better understanding of Earth through exploration and study of the Sun. Included among the benefits are better understanding of the Earth's climate, the Earth/space environment, and the Earth/space interface.

## 4.9 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

### 4.9.1 Iridium

A total of 109.5 troy ounces of iridium are contained in the Ulysses RTG. This amount represents less than 0.0001 percent of the discovered reserves of this metal in the world. Based on a cost of $315 per troy ounce, the December 1989 market price of iridium (DOI 1989), approximately $34,461 worth of iridium would be irreversibly committed to the Ulysses mission.

Essentially all platinum-group metals, including iridium, are recycled in domestic use, resulting in a small percentage loss. Consequently, the total supply available does not appreciably decrease with time, as is the case with less precious materials that are not aggressively recycled. The United States maintains a strategic stockpile of iridium and, in 1988, had an inventory of approximately 29,500 troy ounces (DOD 1989). Although the amount of iridium lost in the successful implementation of the missions would represent about 0.46 percent of the current U.S. stockpile, this amount could easily be replaced from the world supply through current sources.

### 4.9.2 Plutonium-238

The RTG contains approximately 23.7 pounds of plutonium dioxide. Therefore, successful implementation of the Ulysses mission therefore would result in the loss of this much plutonium-238.

### 4.9.3 Other Materials

The total quantities of other materials in the payloads that would be irreversibly and irretrievably committed to the Ulysses mission are relatively minor. These materials consist primarily of steel, aluminum, titanium, iron, molybdenum, plastic, glass, nickel, chromium, lead, zinc, and copper, as well as small quantities of silver, mercury, gold, and platinum.

# 5. CONTRIBUTORS TO THE EIS

This Environmental Impact Statement (EIS) was prepared by Code SL of the Office of Space Science and Applications of the National Aeronautics and Space Administration (NASA). The organizations and individuals listed below contributed inputs for use by NASA Code SL in the preparation of this document. Table 5-1 summarizes, for each contributor, the sections of the EIS for which inputs were prepared.

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# TABLE 5-1. CONTRIBUTORS TO THE EIS

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TABLE 5-1. CONTRIBUTORS TO THE EIS (Continued)

| Responsible Person | Summary | Chapter 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Appendix A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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# 6. AGENCIES AND INDIVIDUALS CONSULTED

This Final Environmental Impact Statement (FEIS) was preceeded by a Draft EIS which was made available for review and comment by Federal, state, and local agencies and the public, as applicable, for a 45-day comment period. All information received was considered during the preparation of the Final EIS.

In preparing this EIS, NASA has actively solicited input from a wide group of interested parties. In addition to the publication in the Federal Register of a Notice of Intent (54 FR 48168) and a Notice of Availability (55 FR 6326) for the DEIS, NASA mailed copies of the DEIS directly to agencies and organizations which may have interest in environmental impacts and alternatives associated with the Ulysses mission.

Comments on the DEIS were solicited or received from the following:

Federal Agencies:

Council on Environmental Quality
Federal Emergency Management Agency
Nuclear Regulatory Commission
Office of Management and Budget
U.S. Department of the Air Force
U.S. Department of Commerce
U.S. Department of Defense
U.S. Department of Energy
U.S. Department of Health and Human Services-Centers for Disease Control
U.S. Department of the Interior
U.S. Department of State
U.S. Department of Transportation
U.S. Environmental Protection Agency

State Agencies:

Florida Department of Environmental Regulation
East Central Florida Regional Planning Council
State of California--Office of the Governor
State of Florida, Office of the Governor
State of New Mexico

Local Agencies:

Brevard County: Board of Commissioners
Comprehensive Planning Division
Economic Development Council
Planning and Zoning Department
Canaveral Port Authority
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Titusville, City of

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Air Pollution Control Association
American Society of Mechanical Engineers
Brevardians for Peace and Justice
Center for Law and Social Policy
Christic Institute
Citizens for Peace in Space
Citizens to Stop Plutonium in Space
Committee for Risk Analysis and Regulation
Common Cause
Concern, Inc.
Environmental Defense Fund
Environmental Policy Institute
Federation of American Scientists
Florida Coalition for Peace and Justice
Florida Defenders of the Environment
Foundation on Economic Trends
Friends of the Earth
National Academy of Sciences
National Audubon Society
National Council on Radiation Protection and Measurements
National Mobilization for Survival
National Space Society
National Wildlife Federation
Natural Resources Defense Council
Physicians for Social Responsibility
Project Censored
Radioactive Waste Campaign
SANE/FREEZE
Sandia National Laboratory
Sierra Club
Sierra Club, Committee on Military Impacts on the Environment
Sierra Club, Florida Chapter
Southern California Federation of Scientists
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# 8. INDEX


-A-

Abbreviations, A-1
Abort
    landing sites, 2-22
    launch, 2-22
    types of, 2-22
Accident
    Challenger, 4-9
    cleanup costs, 4-22
    decontamination, 4-22, 4-25
    general, 4-5
    global impacts, 4-21, 4-35
    impact of, 4-21
    launch, 4-5, 4-9
    mitigation, 4-31
    monitoring, 4-22, 4-24
    RTGs, 2-30, 4-7
    scenarios, 4-7, 4-9
    shuttle, 4-5
Acronyms, A-1
Advanced Photovoltaic Solar Array, 2-5
Advanced Solar Dynamic, 2-5
Aeroshell, 2-8
Agencies and Individuals Consulted, 6-1
Alkali Metal Thermoelectric Converter, 2-3, 2-5
Alternative
    to launch vehicle, 2-5, 2-23
    to proposed action, 2-1, 2-23
    to the RTG power source, 2-5, 2-6
Apollo, 2-13, 2-14
Apollo Lunar Surface Experiment Packages, 2-13

-B-

Battery, 2-3, 2-5
Benefits of launch, 1-1

-C-

Cape Canaveral Air Force Station, 3-1, 3-13
Centaur, 2-5
Challenger, 4-7
Charging effects, 2-20
Clean Water Act, 3-22
Cleanup of Contaminated Areas: EPA Guidance for, 4-17

Collective Dose, 4-14
Consequence
    of accident, 4-1, 4-8
    environmental, iv, 4-1, 4-9, 4-27
Consultations with Agencies and Individuals, 6-1
Contributors to the EIS, 5-1

-D-

Deep Space Network, iii, 2-24, 2-31
De minimus, v, 4-16, C-11
Department of Defense, i, ii, 3-42, 4-9
Department of Energy, 2-8, 2-13, 3-42, 4-7, 4-9, 4-16, 4-20, 4-22, 4-36, 5-2

-E-

East Central Florida Planning Regional Council, 3-1
Eastern Space and Missile Center, 2-22
Eastern Test Range, 2-20, 2-31
Edwards Air Force Base, 2-23
EMERGE model, C-9
Emergency response planning, 4-36
Environmental Consequences, 4-1
Environmental Protection Agency, v, 4-16, 4-20, 4-22, 4-36
European Space Agency, ii, iii, 1-1, 2-1, 2-5, 4-40
External Tank, 2-14, 4-7, 4-8, 4-10

-F-

Fault trees, B-2
Federal Emergency Response Plan, 4-36
Final Safety Analysis Report, 4-7, 4-14, 4-16, 4-20
Fine weave, pierced fabric, 2-13
U.S. Fish and Wildlife Service, 3-9
Florida Department of Natural Resources, 3-27
Formerly Utilized Site Remedial Action Plan (FUSRAP), 4-16
Fuel Cell, 2-3, 2-5, 2-8
Fueled Clad, 2-8, 2-11, 4-9

-G-

Galileo Mission, ii, iii, iv, 2-8, 3-1, 4-7
General Purpose Heat Source (GPHS), 2-8, 2-9, 2-10, 2-12, 4-7, 4-9
Graphite impact shell, 2-8, 2-10, 2-12, 4-9

-H-

HIPAR model, C-9
Hydrazine monopropellant, 2-15, 4-5

-I-

Inertial Upper Stage, i, iii, 1-1, 2-1, 2-15, 2-17, 2-23, 4-7, 4-25, 4-30
Integrated risk analysis elements, C-14
International Solar Terrestrial Program, 1-6
Iridium, 2-8, 2-13, 4-39

-J-

Jet Propulsion Laboratory (JPL), 5-1
Johnson Space Center, 4-3
Jupiter, 1-1, 1-2, 2-2, 2-5

-K-

Kennedy Space Center, ii, 2-22, 2-29, 3-1, 3-13, 4-1, 4-20, 4-30, 5-1

-L-

LASEP models, 4-9, 4-16, C-1, C-7
Launch Commit Criteria, 2-20
Launch Vehicle
    external tank (ET), 2-18, 4-6, 4-9
    inertial upper stage, i, 1-1, 2-1, 2-15, 2-17, 2-23, 4-7, 4-25, 4-30
    solid rocket booster (SRB), 2-18, 4-6, 4-9
Lightning, 2-19
LOPAR model, C-7

-M-

Maximum Individual Dose, 4-14
Mission Objectives, 1-1, 2-19
Mission Phases, 4-11, 4-12, 4-13
Monomethyl hydrazine, 2-15, 4-5

-N-

National Council on Radiation Protection and Measurements, 4-20
National Environmental Policy Act, i, 2-29, 4-10, 4-38
National Park Service, 3-13
Nimbus, 2-15

Nuclear
plutonium, ii, iv, 2-8, 2-11, 2-13, 2-29, 2-30, 4-7, 4-9, 4-14, 4-27
radiological consequences of accident, 4-1, 4-9, 4-14, 4-27
Nuclear Regulatory Commission, v, 4-24

-O-

Orbital Maneuvering System, 2-18

-P-

PAM-S, i, iii, 1-1, 2-1, 2-15, 2-17, 2-23, 4-7, 4-25, 4-30
Patrick Air Force Base, 2-2, 2-18
Photovoltaic, 2-3, 2-5, 2-6
Pioneer Spacecraft, 1-3, 2-8, 2-13, 2-24, 2-31
Plutonium, ii, iv, v, 2-8, 2-11, 2-12, 4-9, 4-14, 4-27
bioaccumulation, 4-33
effects on citrus groves, 4-32
effects on marine and aquatic fauna, 4-27
effects on soil, 4-28
effects on water, 4-28
worldwide levels, 3-46
Power System Criteria, 2-3
Proposed action
alternatives to, 2-1, 2-24, 2-25
description of, iii, 1-1, 2-1,
environmental consequences of, 4-1

-R-

Radioisotope Thermoelectric Generator (RTG), iv, 2-3, 2-8, 2-12, 2-32, 4-5, 4-31
RTG safety design goals, 2-12
Range Safety Officer, 2-18
References, 7-1

-S-

Safety
abort landing sites, 2-22
RTG evaluation, 2-8
range, 2-18
Safety Status Report, 4-7
Science Applications International Corporation, 5-1
SNAP 19B2, 2-15
SNAP 27, 2-15
Solar activity cycles, 1-5

Solar array, 2-5
    Advanced Photovoltaic, 2-5
Solar Physics Program, iii, 1-1
Solar System Exploration Program, iii, 1-1
Solar Wind, 1-3
Solid rocket booster, 2-12, 2-16, 2-19, 4-2, 4-6, 4-9
Sonic boom, 4-2
Space Shuttle
    Challenger, 4-7
    Major elements, B-1
    Transportation System, i, iii, 1-1, 2-22
Spacecraft Propulsion Subsystem, 2-15
SPASM Computer Code, 4-37, C-17
Sun, 1-2

-T-

Titan IV, i, iii, 2-23
Trajectory, 1-2, 2-1, 2-2, 2-5
Turbine Energy Conversion, 2-3, 2-5, 2-7

-U-

Ulysses Mission, i, ii, iii, 1-1, 2-1, 2-3, 2-5
Upper Atmosphere Program, 4-4
Use of Mission Findings, 1-2

-V-

Vertical Assembly Building, 3-41
Viking Spacecraft, 2-8, 2-13, 2-24
Voyager Spacecraft, 1-3, 2-8, 2-13, 2-24, 2-31

# APPENDICES

# APPENDIX A

# GLOSSARY OF ABBREVIATIONS AND ACRONYMS

# APPENDIX A
## GLOSSARY OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AFO | Abort-From-Orbit |
| AOA | Abort-Once-Around |
| ALARA | As Low As Reasonably Achievable |
| ALSEP | Apollo Lunar Surface Experiment Package |
| AMTEC | Alkali Metal Thermoelectric Converter |
| APSA | Advanced Photovoltaic Solar Array |
| ASD | Advanced Solar Dynamic |
| ATO | Abort-To-Orbit |
| AU | Astronomical Units |
| BEIR | Biological Effects of Ionizing Radiation |
| BRC | Below Regulatory Control |
| CAA | Clean Air Act |
| CBCF | Carbon Bonded Carbon Fiber |
| CCAFS | Cape Canaveral Air Force Station |
| CEQ | Council on Environmental Quality |
| Ci | Curie |
| cm | centimeter |
| CO | Carbon Monoxide |
| DEIS | Draft Environmental Impact Statement |
| DOC | Dissolved Organic Carbon |
| DOD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| DOI | U.S. Department of Interior |
| DREF | Dose Reduction Effectiveness Factor |
| DSN | Deep Space Network |
| ECFRPC | East Central Florida Regional Planning Council |
| EDE | Effective Dose Equivalent |
| EIS | Environmental Impact Statement |
| EMC | Electromagnetic Compatibility |
| EMI | Electromagnetic Interference |
| EMISM | Electromagnetic Interference Safety Margins |

| | |
|---|---|
| EPA | U.S. Environmental Protection Agency |
| ESA | European Space Agency |
| ESD | Electrostatic Discharge |
| ESMC | Eastern Space and Missile Center |
| ET | External Tank |
| ETR | Eastern Test Range |
| FAST | Failure/Abort Sequence Tree |
| FC | Fueled clad |
| FEIS | Final Environmental Impact Statement |
| FDER | Florida Department of Environmental Regulations |
| FDNR | Florida Department of Natural Resources |
| FGFWFC | Florida Game and Fresh Water Fish Commission |
| FRERP | Federal Radiological Emergency Response Plan |
| f/s | feet per second |
| FSAR | Final Safety Analysis Report |
| FTS | Flight Termination System |
| FUSRAP | Formerly Utilized Site Remedial Action Program |
| FWPF | fine weave, pierced fabric |
| FY | Fiscal Year |
| g | gram |
| GIS | Graphite impact shell |
| GPHS | General Purpose Heat Source |
| HERF | Hazards of Electromagnetic Radiation to Fuels |
| HERO | Hazards of Electromagnetic Radiation to Ordnance |
| ICE-E | International Cometary Explorer-E |
| ISEE-3 | International Solar Earth Explorer |
| ICRP | International Commission on Radiological Protection |
| IMP-8 | International Monitoring Platform-8 |
| INSRP | Interagency Nuclear Safety Review Panel |
| ISEE-3 | International Solar Earth Explorer |
| IUS | Inertial Upper Stage |
| JPL | Jet Propulsion Laboratory |
| JSC | Johnson Space Center |
| Kd | Distribution Coefficient |

| | |
|---|---|
| kg | kilograms |
| KSC | Kennedy Space Center |
| km/s | kilometers per second |
| $km^2$ | square kilometers |
| LASEP | Launch Accident Scenario Evaluation Program |
| LES 8/9 | Lincoln Experimental Satellite 8 and 9 |
| LET | Low Energy Transfer |
| lbs | pounds |
| MECO | Main Engine Cut Off |
| MET | Mission elapsed time |
| MMH | Monomethyl hydrazine |
| mm | millimeter |
| m/s | meters per second |
| MSA | Metropolitan Statistical Area |
| NAS | National Academy of Sciences |
| NASA | National Aeronautics and Space Administration |
| NCRP | National Council on Radiation Protection and Measurements |
| NESHAP | National Emissions Standards for Hazardous Air Pollutants |
| NEPA | National Environmental Policy Act |
| NIH | National Institutes of Health |
| NOAA | National Oceanic and Atmospheric Administration |
| NOI | Notice of Intent |
| $NO_x$ | Nitrogen Oxides |
| $NO_2$ | Nitrogen Dioxide |
| NRC | Nuclear Regulatory Commission |
| NSTS | National Space Transportation System |
| OFW | Outstanding Florida Waters |
| OMS | Orbital Maneuvering System |
| PAMS | Permanent Air Monitoring Station |
| PAM-S | Payload Assist Module-Special |
| ppm | parts per million |
| PSAR | Preliminary Safety Analysis Report |
| psi | pounds per square inch |
| Pu | Plutonium |

| | |
|---|---|
| $PuO_2$ | Plutonium dioxide |
| RCE | Reaction Control Equipment |
| RCRA | Resource Conservation and Recovery Act |
| RDA | RDA Logicon, Inc. |
| RDT&E | Research, Development, Test and Evaluation |
| ROD | Record of Decision |
| RSO | Range Safety Officer |
| RSS | Range Safety System |
| RTG | Radioisotope Thermoelectric Generator |
| RTLS | Return to Launch Site (abort) |
| SAR | Safety Analysis Report |
| SER | Safety Evaluation Report |
| SNAP | Space Nuclear Auxiliary Power |
| $SO_2$ | Sulfur Dioxide |
| SPP | Space Physics Program |
| SRB | Solid Rocket Booster |
| SRM | Solid Rocket Motor |
| SSEP | Solar System Exploration Program |
| SSME | Space Shuttle Main Engine |
| STS | Space Transportation System |
| TAL | Transoceanic Abort Landing |
| TEC | Turbine Energy Converter |
| TOPEX | Ocean Topography Experiment |
| $\mu Ci$ | micro Curies |
| $\mu g/m^3$ | micrograms per cubic meter |
| UNSCEAR | United Nations Scientific Committee on the Effects of Atomic Radiation |
| USAEC | United States Atomic Energy Commission |
| USAF | United States Air Force |
| USFWS | U.S. Fish and Wildlife Service |
| VAB | Vertical Assembly Building |
| VAFB | Vandenberg Air Force Base |
| W | Watt |
| WIND | Weather Information Network Display |

# APPENDIX B

# DEVELOPMENT OF ACCIDENT SCENARIOS AND PROBABILITIES

# APPENDIX B

# DEVELOPMENT OF ACCIDENT SCENARIOS AND PROBABILITIES

## B.1 INTRODUCTION

### B.1.1 RTG Response to Accidents: Source Term Derivation

This appendix describes the methodology of the analyses of FSAR Volume II, the Accident Model Document (AMD) (DOE 1990f) which principally presents the response of the RTG to various accident environments. That is, if there is a source term, then the analysis describes its magnitude, location (air, ground, fireball), and conditional probability of source term occurrence given that the initiating accident occurred.

### B.1.2 Accident Probabilities: Updated Values

A key input to the overall analysis is the probability of the initiating accidents. Based on its operational experience and knowledge of the launch system, NASA provides accident scenario probabilities to the DOE for use in the safety analysis. In July 1988, NASA provided data to DOE for use in both the Galileo and Ulysses safety analyses. In April 1990, as part of its continuing oversight of Shuttle operations, NASA completed a reassessment of Shuttle accident scenario probabilities and provided those updated values to DOE. The data could not be incorporated in the FSAR. NASA did, however, ask the DOE to use the updated data to update the Ulysses safety analysis for incorporation in the FEIS. The basic methodology of the RTG response analysis and of the nuclear risk assessment remained unchanged. The only change was in the values for the initiating accident probabilities. The updated probability values are generally higher (by a factor of about three) than the earlier values, so their use is an added measure of conservatism. To avoid confusion, Appendix C presents only the tabular and graphical results of the updated analysis.

## B.2 ACCIDENT SCENARIO DEFINITION APPROACH

The National Aeronautic and Space Administration (NASA) approach to defining potential accident scenarios and probabilities involved several steps. First, potential failures were identified that could occur in each of the seven major elements of the Shuttle Space Transportation System (STS):

- Launch Support Equipment
- Payload
- Orbiter
- External Tank (ET)
- Solid Rocket Boosters (SRBs)
- Space Shuttle Main Engines (SSMEs)
- Range Safety Destruct System.

The failure modes of concern are those that generally cause a loss of the vehicle and may produce an accident environment which is a potential threat to the Radioisotope Thermoelectric Generator (RTG). These are generally single point failures in systems and subsystems which cannot be mitigated by astronaut intervention or other pre-planned system overrides. These failure modes represent exceptions to the program requirement of single-failure tolerance. They have been accepted by NASA technical and program management and by the contractor, after extensive review indicating that they were impractical or impossible to eliminate.

The next step involved dividing the mission into five phases, with each of the phases subdivided further, as necessary. Fault trees were developed for each of these mission phases. Each fault tree encompassed, as appropriate, all relevant failures that could occur in the seven major Shuttle systems. Finally, because many of the accident scenarios represented by the fault trees looked similar, representative accident scenarios were developed for each of the mission phases.

After the Johnson Space Center developed the mapping of system failures into scenarios, NASA provided estimates of failure probabilities for each of the systems as a function of time (see Appendix G). These estimates were generated based on reviews of system characteristics, historical failure rate data from similar systems, and previous safety analyses. Because of the wide uncertainty in applying historical data, NASA provided estimates with an order of magnitude range for each system. The U.S. Department of Energy (DOE), with NASA concurrence, then used the geometric means of each range in performing its safety analysis. The representative accident scenarios and accident probabilities are presented in Tables B-1 and B-2, respectively. The accidents listed represent only failures that can potentially lead to RTG damage and possible fuel release.

## B.3 ACCIDENT SCENARIOS

This section summarizes information contained in the Accident Model Document of the DOE Final Safety Analysis Report for the Ulysses mission (DOE 1990f).

Accident scenarios and environments by mission phase (from NASA 1988, and as described in DOE 1990f) are summarized in Table B-1. The applicable intact abort modes for each phase are also indicated in Table B-1. The intact abort modes are: Return to Launch Site (RTLS), Transoceanic Abort Landing (TAL), Abort-Once-Around (AOA), Abort-To-Orbit (ATO), and Abort-From-Orbit (AFO). The first four are generally caused by premature shutdown of one of the SSMEs. AFO would be a result of ATO or a problem with the Inertial Upper Stage (IUS) or spacecraft which prevented deployment on orbit. If two or more SSMEs shut down during parts of the ascent to orbit, a contingency abort mode leading to crew bailout and ocean ditch of the Shuttle would occur. Finally, there is a very small probability of multiple Shuttle system failures leading to a crash during the landing phase. Both types of crash accidents were evaluated in the Final Safety Analysis Report (DOE 1990d, DOE 1990e, DOE 1990f, DOE 1990g).

TABLE B-1. ACCIDENT SCENARIOS BY MISSION PHASE, STS

| Phase | Description | Accident Scenario |
|---|---|---|
| 0 | Prelaunch to Launch (T-8 hrs. to T = 0 sec.) | Inadvertent Range Safety System (RSS) destruct<br>Pad Fire/explosion |
| 1 | First Stage Ascent (T + 0 sec. to 128 sec.) | **Solid Rocket Booster failure***<br>Case Rupture<br>Tower Impact<br>Loss of Thrust<br>No Ignition<br>**Range Safety System destruct***<br>Aft compartment explosion<br>Vehicle breakup<br>Orbiter Failure<br>External Tank Failure<br>Payload Failure<br>Crash landing<br>Ocean ditch<br>Intact Abort Scenario - RTLS, TAL |
| 2 | Second Stage (SSME) Ascent (T + 128 sec. to 532 sec.) | **Vehicle Breakup***<br>Orbiter failure<br>External Tank failure<br>Space Shuttle main engine failure<br>Payload failure<br>Range Safety System destruct<br>Crash landing<br>Ocean ditch<br>Intact Abort Scenario - TAL, ATO |
| 3 | On-Orbit (T+532 sec. to 6 hrs.40m.) | **Orbiter failure and reentry***<br>Intact Abort Scenario - AFO |
| 4 | Payload Deploy (T + 6 hr 40m. to Spacecraft Escape) | Solid Rocket Motor Case burst/ burnthrough (IUS)<br>**Other IUS Failures/Reentry***<br>Solid Rocket Motor no ignition, Low impulse<br>Tumbling from separation or recontact<br>Misaligned burns due to guidance failure<br>Erratic burns |

* Indicates scenario potentially resulting in release of RTG fuel.

TABLE B-2. ULYSSES MISSION ACCIDENT PROBABILITIES

| | Mean Accident Probabilities | |
|---|---|---|
| | FSAR[1] | Updated[2] |
| Phase 0 | | |
| Pad Fire/Explosion | $1.79 \times 10^{-4}$ | $2.91 \times 10^{-3}$ |
| Phase 1 | | |
| Tower Impact | $2.06 \times 10^{-4}$ | $1.89 \times 10^{-4}$ |
| SRB Loss of Thrust | $2.49 \times 10^{-3}$ | $2.17 \times 10^{-3}$ |
| SRB No Ignition | $7.59 \times 10^{-5}$ | $8.65 \times 10^{-5}$ |
| SRB Case Burst | $1.02 \times 10^{-3}$ | $2.92 \times 10^{-3}$ |
| Range Destruct | $1.51 \times 10^{-6}$ | $1.70 \times 10^{-6}$ |
| Aft. Compartment Explosion | $3.95 \times 10^{-4}$ | $3.54 \times 10^{-3}$ |
| Vehicle Breakup | $8.98 \times 10^{-5}$ | $2.20 \times 10^{-4}$ |
| Crash Landing | $3.79 \times 10^{-6}$ | $3.79 \times 10^{-6}$ |
| Ocean Ditch | $7.21 \times 10^{-5}$ | $7.21 \times 10^{-5}$ |
| Phase 2 | | |
| Vehicle Breakup | $1.51 \times 10^{-3}$ | $5.65 \times 10^{-3}$ |
| Crash Landing | $8.85 \times 10^{-6}$ | $8.0 \times 10^{-6}$ |
| Ocean Ditch | $1.68 \times 10^{-4}$ | $1.59 \times 10^{-4}$ |
| Phase 3 | | |
| On Orbit Failure | $1.58 \times 10^{-4}$ | $5.75 \times 10^{-4}$ |
| Phase 4 | | |
| Reentry | $6.16 \times 10^{-3}$ | $6.16 \times 10^{-3}$ |

Source: See Appendix G

[1] Geometric mean of a decade range

[2] Arithmetic mean of distribution

The primary accidents for each phase are generally caused by the most active portion of the system during that phase. For the propulsive phases, it is generally that system providing the propulsive thrust, the structure supporting the thrust and being acted on by external loads, and/or the guidance system. Multiple redundancies in the Shuttle guidance tend to decrease the likelihood of guidance failures for the Shuttle.

Environments created by the accidents generally depend on the source of the accident and the time that it occurs. Time is important because it may affect the character of the source or the resulting secondary environments. For example, the Shuttle SRB fragments will achieve higher velocity if an SRB case failure occurs near the end of the burn when less propellant is available to be accelerated along with the case wall. Liquid propellant explosions are more severe near the ground where the ground promotes mixing. Early failures can result in ground impacts, while failures above the upper atmosphere can result in reentry heating and subsequent ground or water impact.

Phase 0 Accident Scenarios (Pre-Launch)

Phase 0 accidents of concern are those associated with propellant loading. A pad fire or a pad explosion are the primary accidents of concern. The causes for either accident are the same, being linked to failures in launch support equipment, vehicle structural failures, propellant contamination, and inadvertent Range Safety System destruct activation. The latter accident could occur only after destruct arming in the last 20 seconds before launch.

Phase 1 Accident Scenarios (SRB Burn)

Phase 1 commences with launch at T-0 seconds and ends with separation of the SRBs at T+128 seconds. Phase 1 accident scenarios (Table B-1) represent the period in which the SRBs are the primary failure threat, and the external environments which may be seen by the RTG can be affected by ground surface interactions. A failure of the left SRB in the first 2 seconds can cause vehicle impact with the launch tower. Between 0 and 10 seconds, a release of ET propellants caused by either a Shuttle main engine failure or a rupture of the ET initiated by a SRB case rupture can cause a ground surface pool explosion, which is explained in Section B.3. After about 17 seconds, the trajectory of the launch vehicle, if thrust were stopped, would lead to water impact rather than land impact.

An aft-compartment explosion causing the large bipropellant feed lines to rupture and propellant flow onto the launch pad can result from a Shuttle main engine failure. In this accident, the Shuttle continues its ascent until the blast wave, from explosion of the propellants pooled on the launch pad, reaches the vehicle and causes it to break up. The SRBs continue their ascent until Range Safety System (RSS) destruct occurs.

In-flight vehicle breakup occurring between T+10 seconds and the end of Phase 1 can occur with a catastrophic structural failure of the ET. Between T+10 to T+30 seconds, the massive dump of liquid propellants can lead to an

explosion with breakup of the Shuttle and subsequent ground impact. Between T+30 seconds and the end of Phase 1, a trailing fire and small local explosions would ensue with vehicle breakup and impact in the ocean.

In addition to vehicle breakup by instantaneous failures of the SRBs or SSMEs, RSS destruct is an intentional abort action by the Range Safety Officer in the event the Shuttle vehicle trajectory could result in endangering populated land areas.

Automatic shutdown of one of the SSMEs during Phase 1 can lead to a RTLS intact abort mode. After SRB separation, the vehicle reverses the direction of flight till such a time when main engine cutoff (MECO) point is reached, which allows acceptable Orbiter/ET separation conditions, acceptable ET impact location, and an acceptable range for the Shuttle to glide back to the Kennedy Space Center (KSC). A Shuttle failure on touchdown can result in a crash landing.

If a combination of failures occurs which does not allow the Shuttle to safely return to KSC, the contingency abort plan of crew bailout will occur, leading to ocean ditch.

Phase 2 Accident Scenarios (Start of 1st Orbital Maneuvering System Burn)

This phase of the flight starts when the SRBs separate from the vehicle at T+128 seconds and extends until start of 1st Orbital Maneuvering System burn at T+532 seconds. The primary vehicle catastrophic accidents during this period (Table B-1) result in vehicle breakup or in failure to achieve orbit, leading to uncontrolled reentry. Given a normal mission trajectory, accidents in this phase would occur at altitudes in excess of 150,000 feet with the vehicle a minimum of 40 miles down range from KSC.

At altitudes exceeding 150,000 feet, explosions and fragment environments are no longer a threat to the RTG. The SRBs are no longer attached and formation of explosive mixtures of liquid oxygen and liquid hydrogen from the ET cannot result in explosion overpressures, considering the rarefied atmosphere at the altitudes during which this phase takes place. Ballistic reentry of the spacecraft will result in breakup and release of the RTG. There are only 5.5 sec of MET (out of 404 sec of Phase 2 total MET) during which the RTG can reenter and have modules land on Africa.

Non-catastrophic shutdown of one or more SSMEs during this phase can lead to a variety of intact or contingency abort modes.

Phase 3 Accident Scenarios [1st Orbital Maneuvering System Burn to IUS/Payload Assist Module-Special Deployment]

Phase 3 commences with initiation of the 1st Orbital Maneuvering System burn at T+532 seconds and ends with deployment of the Ulysses/IUS/Payload Assist Module-Special (PAM-S) at about T+6 hours 40 minutes. Accidents in this phase would occur after vehicle orbit has been achieved but prior to deployment of the Ulysses/IUS/PAM-S. The accidents of primary concern

deployment of the Ulysses/IUS/PAM-S. The accidents of primary concern (Table B-1) are those associated with Shuttle failures that would result in orbital decay and eventual uncontrolled reentry. The entry angle would be very shallow at a velocity of less than 26,000 feet per second. Should a reentering General Purpose Heat Source (GPHS) module impact rock or a similar hard surface, small amounts of fuel could be released.

If problems are found with either orbital parameters, the Ulysses spacecraft, or the IUS/PAM-S, that clearly indicate deployment from the Shuttle would not result in a successful Earth escape trajectory insertion, then two options exist. If safe return of the Shuttle is threatened,the cargo will be jettisoned in low Earth orbit. However, if it is determined no threat exists to a safe landing, the Shuttle will return with the cargo. The primary and alternate landing sites noted previously for the AOA may be employed in this abort mode.

Although abort landing accidents are theoretically possible from AFO, the probability was considered to be very small compared to RTLS, TAL, or AOA related accidents because the SSME does not affect AFO, and time pressures are much reduced. Because of these considerations and since the consequences would be no different, a separate treatment was not included in the Phase 3 analyses.

Phase 4 Accident Scenarios (Ulysses/IUS/PAM-S Deployment to Earth Escape)

Phase 4 commences with deployment of the spacecraft/IUS/PAM-S at T+6 hours 40 minutes and ends with firing of the IUS and insertion of the spacecraft on its trajectory to Jupiter. Accidents in this phase would occur between Ulysses/IUS/PAM-S separation from the Shuttle and trajectory insertion. The accidents of primary concern (Table B-1) are IUS propulsion or guidance failures which could result in vehicle breakup and/or in reentry from orbit. The IUS motor case burst accidents could lead to large chunks of the solid propellant interacting with the RTG. Reentry conditions can range from speeds of 6,900 to 36,400 ft/sec at angles of -0.5 to -89.0 degrees. Should the GPHS module impact rock or a similar hard surface, a small amount of fuel could be released.

## B.4 ACCIDENT ENVIRONMENTS

The following paragraphs summarize the key accident environments which were addressed in the Final Safety Analysis Report for the Ulysses mission (DOE 1990f).

SRB Fragment Environment

During operation of a SRB, fragments will be produced upon rupture of the steel pressure-containment motor case either by random failure or by range destruct action. These substantial fragments may damage an RTG or propel it into another structure. The size, velocity, and directional distributions of SRB fragments are based in part upon analysis of films and recovered debris of the destructed SRBs from the Challenger (STS 51-L) and the Titan 34D-9

accidents. To supplement these empirical data and to fill gaps not represented by the two accidents, analytical modeling was performed and calculations were made using a computer code capable of predicting the very fast structural breakup of the rocket motor case and the ensuing fragment motion away from the centerline of the motor.

The characteristic mechanism for fragment formation is a rapid release of the operating motor pressure through a fracture in the case causing further extensive breakup of the case and rapid acceleration of the pieces to velocities of hundreds of feet per second. The peak velocity of case wall fragments depends on motor pressure and volume. The mass of propellant remaining attached to a case wall fragment is also a major determinant of the final fragment velocity. In addition to velocity, the fragment also rotates or spins as it travels. Since all these parameters vary with mission elapsed time, the spectrum of SRB fragment characteristics is highly dependent upon mission elapsed time (MET) at the time of initial case fracture.

In the range destruct scenario, the two SRBs are destroyed simultaneously. The two fragment fields thus created could result in sequential hits on the RTG. Tests in which GPHS modules and intact RTGs were subjected to impact by SRB motor case fragments have indicated that a fuel release will not occur when the intact RTG is struck by the face of SRB fragments (face-on) at velocities up to 695 feet-per-second (fps). (Note that fragment velocities will not be in this range until near the end of Phase 1; i.e., between 105 and 120 seconds after launch. During this period, a minimum of 95 percent of the SRB fragment impacts would be in a face-on orientation.) When struck by fragments in the edge-on orientation at velocities of 312 f/s or greater, the leading fueled clads impacted can be breached with gram quantities of fuel released. The probability of the range destruct scenarios is much smaller than the probability of SRB random failure (see Table B-2).

Pre- and Early-Flight Ground Pool Explosions

A significant explosion source for the Shuttle is possible should a massive spill of the liquid oxygen and hydrogen ET propellants occur. Spills of these propellants, as a result of ET structural breakup, Shuttle impact with the launch tower, early range destruct, SRB case rupture, or Orbiter aft-compartment explosions could lead to collection, mixing, and ignition of significant portions of the propellants on launch pad surfaces while the Shuttle is still essentially at the pad. The resulting blast wave subsequently sweeps past the Orbiter, acting on the exterior surfaces in a manner to implode or crush the structure into the RTG within the Orbiter. It is also possible that, as the blast wave causes the structure to fail, the RTG will be directly exposed to the blast environment. Thus, not only Orbiter fragmentation but also blast loading (acceleration) hazards are presented to the RTG.

There have been no pad accidents involving the spillage of ET propellants from which to base estimates of potential explosion environments, therefore, environments are based on results from a hydrodynamic computer code capable of predicting the blast loading parameters of a fast moving planar blast pulse as

it travels through the air above the pad. The behavior of the explosion energy release itself (source characteristic) is varied over a wide range to include the range of uncertainty in the initial collection, mixing, and ignition of the propellants. Since the explosion source characteristic controls the blast pulse loading parameters, a probabilistic computational treatment of the source characteristic yields a probabilistic estimate of blast loading parameters at specified heights above the pad. Application of these loading parameters to an analytical fragment acceleration model for the Orbiter cargo bay door yields a probabilistic estimate of fragment velocity for this closest component to the RTG.

An explosion of ET propellants on or near the launch pad would cause the walls of the Shuttle payload bay to implode around the Ulysses spacecraft and the RTG. Because ensuing distortion of fueled clads within the RTG is estimated at 10 percent or less, fuel would not be released. The distortion threshold for breach is 25 percent as determined in bare clad impact tests conducted for the safety verification and test program.

In-Flight Explosions

A second explosion source involving the ET propellants is possible for a short time after the Shuttle has cleared the tower. Aerodynamic conditions through the next 20 seconds (up to a MET of 30 seconds) are such that failures of the ET structure can lead quickly to its breakup and the consequent airborne dump of liquid hydrogen and oxygen propellants. The hydrogen quickly vaporizes and mixes with air to form a vapor cloud. The burning SRBs provide an ignition source to ignite the mixture at some distance from the Shuttle depending upon velocity of the vehicle. A hydrodynamic computer code is used to compute the blast loading parameters of a fast-moving, spherically-expanding, blast pulse.

As the ET breaks up, propellant dump and mixing require an elapsed time on the order of a second. As Phase 1 proceeds, the increasing speed of the Shuttle over elapsed time allows an increased distance to develop between the Orbiter and the center of explosion for the later occurring breakup. Hence, the potential blast environment for airborne explosions rapidly diminishes. Beyond MET 30 seconds, changing atmospheric and aerodynamic conditions will preclude significant airborne explosions. No source terms are predicted for this accident scenario.

An IUS solid-fuel rocket was in the Shuttle bay during the Challenger accident as the booster to propel a data relay satellite into its prescribed orbit. Detailed examination of photographic records, telemetry data, and fragments recovered from the Challenger accident have shown that 1) no major explosion occurred, rather a rupture of the external propellant tank, initiated by the effects of the Shuttle booster joint failure, was followed by release and rapid burn of some of the liquid propellants; 2) the Shuttle Orbiter subsequently broke up under flight dynamic and aerodynamic forces; and 3) the IUS booster came out of the cargo bay relatively intact, broke up under aerodynamic forces, and fell 50,000 feet to the ocean surface without violent solid propellant ignition. Uncertain photographic evidence and an incomplete

recovery of the Tracking and Data Relay Satellite did not permit an assessment of its response sequence.

The interagency study group formed to evaluate both the Challenger and Titan 34 D-9 explosions (NASA et al. 1989) concluded that, had an RTG been on board, both it and its cladded heat sources would have survived the Challenger accident with no release of plutonium fuel. This study did not consider solid rocket motor fragments since these were not a factor in the case of the Challenger accident.

Fireball Environment From ET Propellants

The updrafts and high temperatures within the fireball produced by a large liquid propellant ground fire are important if the exposed RTG fuel clads have been breached earlier by severe mechanical impact loads. The released fuel fines in this case can be vaporized and dispersed into the atmosphere by the fireball environment. It should be noted that bare fueled clads, that is those unprotected by any of the graphitics (aeroshell or graphite impact shield, or the RTG case), have been demonstrated to survive temperatures (see Section 2.2.4.3) greater than expected in the peak fireball (2,163°C or 3,925°F), without a loss of fuel. The fireball will, however, modify the particle size distribution or location of fuel released from clads damaged by SRB fragments. Fires and the fireball above, cannot cause a release of fuel.

Abort Crash Environments

During the latter aerodynamic flight portion of a return from a mission abort, the Orbiter flies without engine thrust and exhibits the same general flight characteristics as a conventional heavy aircraft during a final landing approach. Assuming that the orbiter has entered this final phase of the abort return under normal control, a crash could ensue due to control error or mechanical failures of the flight control system or landing gear.

Examination of the Orbiter flight profile and flying characteristics leads to a set of four abort crash accidents that are deemed credible: two landing scenarios and two ocean ditch scenarios. In each case, crashes with and without the final landing flare are considered in estimating the resulting relative-impact velocity of the RTG with the surrounding Orbiter structure. The estimated upper and lower bounds of these impact velocities are shown in Table B-3. The environments experienced by the RTG during a landing crash or ocean ditch are relatively mild compared with other accident environments. The GPHS modules are capable of surviving impacts on steel and concrete up to 172 f/s and the bare fueled clads survive impact on concrete up to 213 f/s, much more severe than the impacts experienced inside the Shuttle while crushing up during an accident. For this reason, landing and ocean ditch crash accidents are not considered to be threatening accident environments for the RTG.

TABLE B-3. RTG IMPACT VELOCITIES DUE TO ABORT CRASH: STS/IUS/PAM-S

| Crash Scenario | RTG Impact Velocity (fps) |
|---|---|
| Ditch No Flare | 65-115 |
| Ditch With Flare | 50-100 |
| Landing Pre-Flare | 60-115 |
| Landing Post-Flare | 50-60 |
| Flat Spin | 60-200 |

Environments For Uncontrolled Orbiter Reentry

Aerodynamic and heat transfer analysis of the uncontrolled, accidental reentry of the Shuttle prior to the deployment of the upper stage and payload shows that the RTG condition just prior to earth surface impact varies with the time of launch failure. For the time interval of interest between SRB separation (MET = 128 seconds) and the achievement of the parking orbit (MET = 510 seconds), the predictions are:

1) The Orbiter and IUS will always break up during reentry and will not reach the surface intact.

2) For MET between 128 and 210 seconds, the RTG will reach the surface intact without case melting and attached to the spacecraft.

3) For MET between 210 and 238 seconds, the RTG can either reach the surface without case melting, or if the case melts, the GPHS modules may be released prior to reaching the surface.

4) For MET greater than 238 seconds, the GPHS modules are released prior to surface impact.

5) For all MET less than 495 seconds, the RTG or GPHS modules reach the surface over the Atlantic Ocean.

6) Between MET 495-501 seconds, the GPHS modules will impact on the African continent along the ground track of the Shuttle.

Inertial Upper Stage and Payload Environments

The IUS/PAM-S does not significantly add to any of the accident environments produced by the main launch vehicle. The solid propellant is not detonable under accident conditions of concern for the Ulysses mission. Although solid propellant impacting the ground as ejecta from other events may react vigorously as an explosion, these events produce only localized blast effects. In addition, the propellant does not contribute significantly to fireball environments, since the burn is relatively slow and occurs at ambient pressure.

Some IUS failures after the deployment of Ulysses/IUS/PAM-S from the Orbiter result in errant reentry within the design capability of the RTG. Earth impact conditions are similar to those for reentry from orbit.

The only IUS failure that can cause a direct threat to the RTG is a motor case rupture during the second firing of the IUS. The dominant threat from this failure is the production of fragments of solid propellant estimated to be traveling at velocities in the range of 92 to 728 feet per second and weighing from 2 to 8 pounds per fragment.

With a successful second-stage (IUS) burn, the spacecraft will be on its trajectory toward Venus and will have escaped Earth's gravitational influence. Thus, a failure in the PAM-S at this point in the mission will not result in a threat that the spacecraft will reenter into the Earth's atmosphere and have a potential of release of any RTG fuel into the Earth's environment.

The Ulysses spacecraft also does not significantly add to any of the accident environments produced by the launch vehicle accident scenarios. GPHS modules released by orbiter reentry or upper stage/payload accident environments may release small amounts of fuel upon impact with land if rock or other hard surfaces are hit.

# APPENDIX C

# SUMMARY OF DOE ULYSSES MISSION UPDATED ACCIDENT PROBABILITIES AND RISK ANALYSIS

# APPENDIX C

## SUMMARY OF THE DOE ULYSSES MISSION UPDATED ACCIDENT PROBABILITIES AND RISK ANALYSIS

## C.1 INTRODUCTION

### C.1.1 Source Term Consequence Analysis and Risk Assessment

This appendix describes the methodology of the analyses of the Final Safety Analysis Report (FSAR) Volume III, the Nuclear Risk Assessment Document (NRAD) (DOE 1990g). This volume principally presents the consequence, if any, of the released material. That is, if there is a source term, then the analysis describes how the atmosphere disperses and deposits the material, and calculates the health and environmental consequences of the dispersed material.

### C.1.2 Accident Probabilities: Updated Values

A key input to the overall analysis is the probability of the initiating accidents. Based on its operational experience and knowledge of the launch system, NASA provides accident scenario probabilities to the DOE for use in the safety analysis. In July 1988, NASA provided data to DOE for use in both the Galileo and Ulysses safety analyses. In April 1990, as part of its continuing oversight of Shuttle operations, NASA completed a reassessment of Shuttle accident scenario probabilities and provided those updated values to DOE. The data could not be incorporated in the FSAR. NASA did, however, ask the DOE to use the updated data to update the Ulysses safety analysis for incorporation in the FEIS. The basic methodology of the RTG response analysis and of the nuclear risk assessment remained unchanged. The only change was in the values for the initiating accident probabilities. The updated values are generally higher (by a factor of about three) than the earlier values, so their use is an added measure of conservatism. To avoid confusion, Appendix C presents the tabular and graphical results of the updated analysis as provided in Appendix G.

## C.2 PROCEDURE FOR ANALYSIS OF RADIOLOGICAL ACCIDENTS AND CONSEQUENCES

The U.S. Department of Energy (DOE) conducts a detailed analysis of the safety of the Radioisotope Thermoelectric Generator (RTG) systems used on space missions. This analysis is included in the FSAR. The elements of the analysis and the information flow are summarized in Figure C-1. For the Ulysses mission, the DOE has prepared a Final Safety Analysis Report (DOE 1990d, DOE 1990e, DOE 1990f, DOE 1990g) to provide the basic safety data used in this Final (Tier 2) Environmental Impact Statement (FEIS). Research, development, test, and evaluation (RDT&E) of RTGs has been an ongoing activity within the DOE for over 3 decades and continues at the present time. Specifically, RDT&E work on the Galileo/Ulysses RTGs has been underway since the late 1970s. For instance, even after publication of the FSAR for the Galileo mission (DOE 1988a, DOE 1988b, DOE 1989a), additional test and

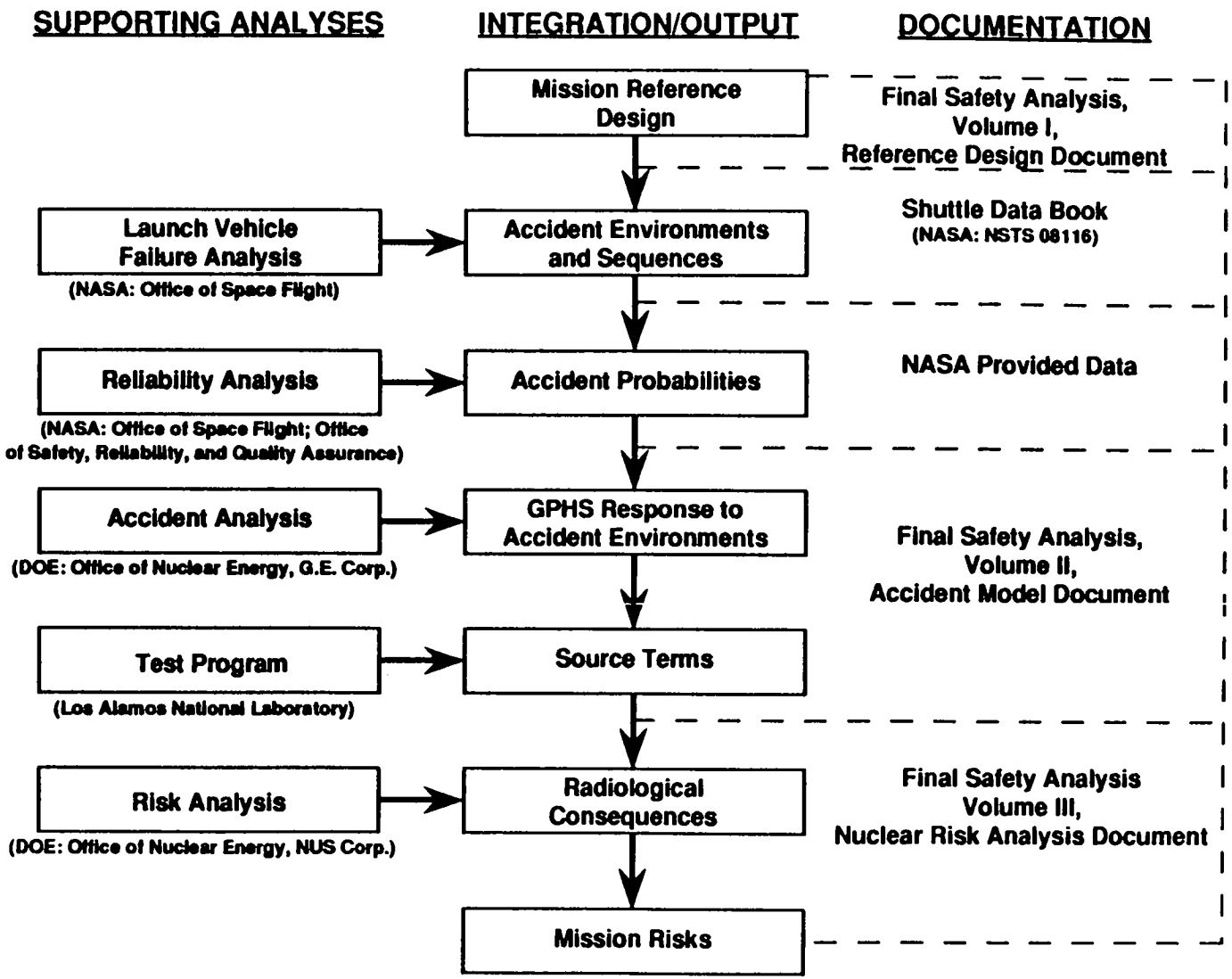


FIGURE C-1. FINAL SAFETY ANALYSIS REPORT DEVELOPMENT PROCESS

analysis results were documented in a supplement (DOE 1989b). The Ulysses safety analysis utilizes the data base, techniques, and experience developed over the years. This appendix summarizes key information found in two documents of the DOE Final Safety Analysis Report (DOE 1990f, DOE 1990g), which forms the basis for the evaluation of radiological consequences found in Chapter 4 of the Ulysses FEIS.

The accident scenarios and environments were reviewed in Appendix B. Not all accident scenarios were found to pose a threat to the RTG in terms of fuel release. This appendix deals only with the accident scenarios potentially leading to a release of fuel.

## C.3 SOURCE TERMS

A source term consists of the quantity of fuel released (expressed in Curies of plutonium dioxide), the location of the release, the particle size distribution of the released $PuO_2$, and the probability of release. The methods for developing the source terms are described in the Accident Model Document of the FSAR (DOE 1990f) and are summarized below.

Shuttle-related accident source terms for Phase 0 and Phase 1 were calculated using the Launch Accident Scenario Evaluation Program (LASEP 3). LASEP 3 uses a Monte Carlo approach to simulate RTG response to a given accident environment. This is done using 100,000 trials (20,000 trials for the explosion case) for each scenario or subscenario considered, representing variations on accident environment severity and RTG component responses determined by probability distributions of conditions based on the accident environments, hydrocode modeling, and component test results. The LASEP 3 calculations arrive ultimately at fueled clad distortion and amount of fuel release, if it is found to occur. LASEP 3 was developed specifically for the Ulysses safety analysis, utilizing the LASEP 2 program developed for the Galileo analysis (DOE 1988a, DOE 1988b, DOE 1989a) as a foundation. The following subsection discusses some key revisions and modifications incorporated into the LASEP program for use as LASEP 3 in the Ulysses safety analysis.

A number of revisions were made to LASEP utilizing updated environments from the Shuttle Data Book (NASA 1988b) and more recent results obtained from the GPHS Safety Test and Development Program conducted by DOE on the RTG and its components. These revisions and others were incorporated into LASEP 3, as discussed in the Ulysses Final Safety Analysis Report (DOE 1990d, DOE 1990e, DOE 1990f, DOE 1990g).

Changes were also made to LASEP 3 for Ulysses to accommodate the addition of the Payload Assist Module-Special (PAM-S) to the Inertial Upper Stage (IUS) and the positioning of the Ulysses RTG in the Orbiter bay. The long axis of the Ulysses RTG is oriented perpendicular to the long axis of the Shuttle, whereas the Galileo RTGs were along the sides of the spacecraft.

The Monte Carlo calculational technique incorporated in LASEP 3 samples values from the range of variables and conditions applicable to each failure mode and accident scenario or subscenario. For example, in a given LASEP 3 trial (i.e., one of the 100,000 individual trials in a run) for a Solid Rocket Booster (SRB) case rupture accident analysis, LASEP 3 randomly samples (within the bounds set in the Shuttle Data Book) variables and conditions such as SRB fragment size, fragment velocities, spin rates of the fragments, the direction and angle at which the fragment leaves the disintegrating SRB case, and the point along the mission trajectory (Mission Elapsed Time) at which the accident occurs. LASEP 3 then determines if the RTG is hit by a fragment, and utilizing the data base of RTG response to accident environments developed through component tests and hydrocode modeling, determines the scenario of the RTG damage as a result of the hit. If the damage is sufficient, LASEP 3 then calculates the amount of fuel released in the air. LASEP 3 then continues to analyze the trajectory of the RTG or RTG component (e.g., GPHS module, fueled clad) to determine its Earth impact location (e.g., steel, concrete, sand) and associated release if any. For Phase 1 accidents, LASEP 3 also determines whether or not the release occurs within the confines of the fireball and whether impact would occur on steel or concrete surfaces at the launch pad or on the surrounding sandy areas, or in the ocean. Each release or source term is further described by a particle size distribution.

The releases or source terms resulting from the Phase 1 LASEP 3 runs are reported in the Accident Model document of the Final Safety Analysis Report (DOE 1990f) as the average for the given accident scenario or subscenario. (The output from LASEP 3 are in the form of a distribution of source terms by quantity of release.) The average source term is simply the average of the source terms from those trials which result in a release (i.e., the average is not based upon the 100,000 trials in a run, only those that have a release). Average source terms are reported for each release location (fireball, ground level, in-air), (see Section 2 of DOE, 1990f).

Source terms for Phases 2, 3, and 4 accidents were developed utilizing prior analyses of the response of the General Purpose Heat Source (GPHS) modules to various types of reentry conditions. Among the tests providing results pertinent to these analyses were the Safety Verification Test series, the Design Iteration Test series, and the Reentry Testing program [details of these programs are provided in the Accident Model Document of the Final Safety Analysis Report (DOE 1990f)].

Results of the accident analyses for all of the accident scenarios within each mission phase show that only the accident scenarios listed below have any potential for a release or source term.

- Phase 0 - None
- Phase 1 - SRB Case Rupture and Range Safety System (RSS) Destruct
- Phase 2 - Vehicle Breakup

- Phase 3 - Uncontrolled Reentry of the Orbiter (Shuttle) and Payload
- Phase 4 - IUS/PAM-S Failure and Reentry with Breakup of the Spacecraft.

C.3.1 Phase 0 Source Terms

None of the Phase 0 (Prelaunch) accident scenarios resulted in a release of RTG fuel. The inadvertent RSS destruct scenario will not generate any case or propellant fragments because the SRBs have not been ignited in this phase, thus there is no chamber pressure in the SRBs with which to generate fragments. (SRB fragments are the principal threat to the RTG during Phase 1 of the mission.) The pad fire/explosion scenario also does not result in a release of RTG fuel. Implosion of the payload bay doors will not cause the doors to strike the RTG in an edge-on manner because there is not enough room in the bay for the doors to orient in this fashion before striking the RTG. Initial distortions of the fueled clads would be less than 10 percent, well below that needed to breach the clads (25 percent). Subsequent impacts of modules or bare clads on the steel and concrete surfaces of the launch pad or on the surrounding land (sand) have been demonstrated in the Bare Clad Impact tests and the Safety Verification Tests to be insufficient to cause fuel release. Thus, Phase 0 was not considered further in the evaluation of potential radiological consequences of accidents.

C.3.2 Phase 1 Source Terms

The Monte Carlo runs for the Phase 1 SRB case rupture scenario were treated differently from the other accident scenarios. The National Aeronautics and Space Administration (NASA)-supplied failure probabilities (NASA 1988b) indicated that the probability of a random SRB failure varied over five different periods in Phase 1: 0-10 seconds, 11-20 seconds, 21-70 seconds, 71-105 seconds, and 106-120 seconds.

The SRBs have essentially completed their burn by 119 seconds and can no longer rupture because the SRB chamber pressure drops rapidly to zero by 120 seconds into the flight.

Within Phase 1, the source terms for the SRB case rupture scenario were developed by 100,000 Monte Carlo runs for each of the five remaining time intervals. In addition, given the revisions to LASEP (i.e., LASEP 3) for the Ulysses safety analysis which enable LASEP 3 to track the affected RTG components, type of ground impact (e.g., steel, concrete, sand), and whether or not a release would occur within a fireball, the individual source terms were reported by location of release (i.e., fireball, ground-level, or in air) and the altitude of the release.

Releases into the fireball are an important consideration because of the potential for the fireball to vaporize and/or modify the particle sizes and dispersion of the released plutonium dioxide (see Appendix B). Particle sizes in the range of 10 microns or less can be inhaled by humans and remain in lung

tissue. Such particles are the principal source of human health consequences, through the inhalation pathway.

The particle size distributions associated with these releases are based on aeroshell module and fueled clad impact tests conducted at Los Alamos National Laboratory (DOE 1990c). Based on the fueled clad crack sizes calculated by LASEP 3, the particle size distributions were cut off at a particle size equal to one-half the maximum crack size and then renormalized.

A more detailed discussion of the particle size considerations is presented in Appendices D and H of the Accident Model Document (DOE 1990f) and Appendix D to the Nuclear Risk Analysis Document of the Final Safety Analysis Report (DOE 1990g). The results of these analyses show that:

1. Stratification of the particles in an explosion plume is very rapid, usually occurring within the first kilometer (.6 mi) of plume movement after an explosion.

2. The vaporized $PuO_2$ is a significant component of dose (86 percent of the short-term dose and 69 percent of the long-term dose).

3. The primary contributor to surface contamination above the U.S. Environmental Protection Agency (EPA) suggested 0.2 $\mu Ci/m^2$ screening level (EPA 1977) are particles in the 10 to 20 micron range.

C.3.3 Phases 2, 3, and 4 Source Terms

The source terms for Phases 2, 3, and 4 were derived by factoring the probability of one or more of the GPHS modules impacting rock on the Earth's surface into the analyses. In Phase 2 (T+128 seconds to T+532 seconds), an accident leading to breakup of the Shuttle and payload during the period T+128 seconds to T+210 seconds will result in the RTG reaching the Earth's surface intact. After T+210 seconds, the GPHS modules will be released from the RTG by thermal failure of the RTG case prior to impact. During Phase 2, there are only 5.5 seconds out of a total 404 seconds when the reentering RTG or its modules can impact on the African Continent.

A Phase 3 accident causing breakup of the Shuttle and payload due to an uncontrolled reentry results in thermal failure of the RTG case, with release of the 18 GPHS modules. The modules will survive reentry to impact on either land or ocean. The Phase 3 source term was developed utilizing the distributions of ocean and land within the North-South latitude band where impact could occur, and within the land category the distribution of soil/water versus rock. Ocean and soil/water land impacts will not result in a release of RTG fuel; however, a rock impact may.

In Phase 4, an IUS failure with subsequent reentry and breakup of the spacecraft will cause release of the GPHS modules from the RTG due to thermal failure of the RTG case. The footprint of the 18 GPHS modules is assumed to be small compared with the major oceans and land masses, and large compared

with the average rock area. Therefore, it is assumed that all the modules either impact on water or on land, but that for land impact each module has an independent probability of striking rock. Based upon the reentry analysis performed for the Ulysses Final Safety Analysis Report (see DOE 1990f, Appendix I), the GPHS modules will survive reentry intact to impact either ocean or land. An ocean impact will not result in a source term; whereas, a land impact on rock may result in fueled clad failure with a release of RTG fuel. The resulting source term is the same as in Phase 3.

The numerical values of the source terms for Phases 2, 3, and 4 were calculated as the expectation value of one or more modules hitting rock and one or more clads releasing fuel, given land impact. Specifically in Phases 2, 3, and 4, the total probabilities of land impact are $6.16 \times 10^{-5}$, $1.55 \times 10^{-4}$, and $1.66 \times 10^{-3}$, respectively. The subsequent expectation values for the conditional probability of fuel release are 0.102 in Phase 2 and 0.129 in Phases 3 and 4.

Review of the data from the SVT test series indicates a basis for the released material being contained within the graphite aeroshell and thus not available for atmospheric transport. Nevertheless, both the FSAR and this EIS adopt the conservative position that the releases in Phases 2, 3, and 4, although small, are available for atmospheric transport.

## C.4 RADIOLOGICAL CONSEQUENCES METHODOLOGY

The evaluation of the radiological consequences of fuel releases from postulated accidents include the following steps:

1. Identification of the postulated accident, fuel release probability, and release location.

2. Source term characterization in terms of quantity, particle size distribution, and volume distribution.

3. Analysis of the dispersion of the released fuel in the environment to determine concentrations in environmental media (i.e., air, soil, and water) as functions of time and space.

4. Analysis of the interaction of environmental radioactive concentrations with people through inhalation, ingestion, and external exposure pathways.

5. Evaluation of resulting radiological consequences in terms of maximum individual and population doses and contaminated environmental media.

The average source terms derived from the accident modeling analyses and used in the nuclear risk analysis of the FSAR are found in Table C-1.

It should be noted that the Phase 1 RSS destruct scenario analyses yielded release probabilities on the order of $10^{-9}$ to $10^{-11}$ (1 in 1 trillion or less) or about 1,000 or more times less probable than the SRB case rupture

## TABLE C-1. AVERAGE SOURCE TERMS FOR RADIOLOGICAL CONSEQUENCES ANALYSES

| PHASE | Time Period(Sec) | Probability | | | Average Source Term(Ci) | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | Initiating | Conditional | Total - Release (Phase 1)/ Land Impact (Phases 2-4) | Fireball | Ground Level | Altitude | At Altitude(m) | |
| 1 (SRB Case Rupture) | 0- 10 | $1.46 \times 10^{-3}$ | $2.30 \times 10^{-3}$ | $3.36 \times 10^{-6}$ | 63.4 | 2.15 | - | - | a |
| | 11- 20 | $3.65 \times 10^{-4}$ | $2.32 \times 10^{-3}$ | $8.47 \times 10^{-7}$ | - | 4.90 | 7.08 | 576 | b |
| | 21- 70 | $6.62 \times 10^{-4}$ | $6.60 \times 10^{-4}$ | $4.37 \times 10^{-7}$ | - | 0.006 | 3.74 | 6,523 | c |
| | 71-105 | $2.60 \times 10^{-4}$ | $1.76 \times 10^{-3}$ | $4.58 \times 10^{-7}$ | - | - | 12.2 | 25,725 | d |
| | 106-120 | $1.71 \times 10^{-4}$ | $1.33 \times 10^{-2}$ | $2.27 \times 10^{-6}$ | - | - | 251 | 38,100 | d |
| 2 | - | $5.65 \times 10^{-3}$ | $1.09 \times 10^{-2}$ | $6.16 \times 10^{-5}$(*) | - | 0.063 | - | - | e,f |
| 3 | - | $5.75 \times 10^{-4}$ | $2.69 \times 10^{-1}$ | $1.55 \times 10^{-4}$(*) | - | 0.084 | - | - | f,g |
| 4 | - | $6.17 \times 10^{-3}$ | $2.69 \times 10^{-1}$ | $1.66 \times 10^{-3}$(*) | - | 0.084 | - | - | f,g |

Source: See Appendix C, DOE 1990g

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

a Releases due to SRB fragments, module impacts on steel, and fueled clad impacts on steel, concrete, and sand
b Releases due to SRB fragments, and fueled clad impacts on concrete and sand
c Releases due to SRB fragments, and fueled clad impacts on sand
d Releases due to SRB fragments
e Releases due to module impacts on rock following sub-orbital reentry
f Reported as expectation values given land impact
g Releases due to module impacts on rock following orbital reentry

accident. In addition, the releases or source terms were of the same order of magnitude. Thus, the RSS destruct scenario contributes only a small fraction of the risk attributable to Phase 1 SRB failures and was not carried into the risk analyses for the Ulysses mission.

The radiological consequences for the first stage ascent phase were calculated using the EMERGE, LOPAR, and HIPAR computer models. Releases in the troposphere (up to about 6.2 miles in altitude; i.e., reached at a Mission Elapsed Time of about 60 seconds) are treated using EMERGE, and higher altitude releases are treated using LOPAR for small particles (less than 10 microns in diameter) and HIPAR for large particles (greater than 10 microns in diameter). EMERGE is a three dimensional Gaussian puff-trajectory model that treats meteorology which varies in time and space (vertically) and accounts for vertical plume configuration; particle-size-dependent transport, deposition, and plume depletion; and sea-breeze recirculation in the vicinity of KSC. HIPAR is a particle trajectory model which accounts for atmospheric properties which affect the velocity of particle fall, specifically, altitudinal variation in atmospheric conditions and the rotation of the Earth. HIPAR utilizes a wind field that is a function of latitude, longitude, and altitude. LOPAR is an empirical model derived from weapons testing data, and accounts for worldwide circulation patterns and delayed fallout as a function of latitude band. Both HIPAR and LOPAR interface with a worldwide demographic data base to facilitate the estimation of radiological consequences. The consequences for the remaining three mission phases were estimated using average population densities from the worldwide demographic data base for the affected area, and time-independent median meteorological conditions utilizing the EMERGE model.

Key features and assumptions of the analysis are summarized below. Details of the methodology are presented in the Nuclear Risk Analysis Document of the Final Safety Analysis Report (DOE 1990g).

The average source terms with their particle size distributions are given an initial spatial distribution appropriate to the conditions for release. Releases in the launch area from surface impacts outside a fireball are given an initial cloud diameter of 33 ft (10 m) at a height of 16 ft (5 m).

The fireball would have a diameter of about 1,000 ft and a mean duration of 30 seconds. The fireball sphere would lift off the ground after about 7 seconds, with the trailing stem lifting off the ground after about 10 seconds. Material released into a fireball starting out at ground level is given a distribution in which 80 percent of the material is in an elevated cloud and 20 percent is in a vertical stem reaching toward ground. (See Appendix B for additional discussion of the fireball environment.)

The plume configuration resulting from liquid propellant explosions and fire has been estimated based on results of high explosive field tests involving both liquid and solid high explosives. The center release height and the diameter of the stabilized cloud resulting from the explosion fireball are correlated to the TNT equivalent yield of the explosion.

Of the thermal energy associated with the complete combustion of liquid propellants, it is estimated that 50 percent contributes to the thermal buoyancy of the initial fireball. The resulting center release height and diameter of the cloud were assumed to be representative of the base case for launch pad accidents during the first 10 seconds (0-10 sec.) of Phase 1.

Launch area ground-level source terms result when fueled clads impact hard surfaces at speeds above their failure thresholds or when previously breached fueled clads impact any surface outside of the initial fireball. Impact points would be distributed around the launch pad. All of these distributed releases have been assumed to be at the launch pad with an initial height of 16 ft (5 m) and an initial 33 ft (10 m) cloud diameter. Collective (population) doses should not be significantly affected.

Due to the forward velocity of the vehicle beyond T+10 seconds, the release is distributed in a "puff," the diameter of which is equal to the distance travelled by the vehicle in 1 second, determined by the velocity of the vehicle at the release altitude.

The atmospheric dispersion of the source term material with the initial cloud specifications determined, as described in the preceding paragraphs, is then calculated, using models described below.

Meteorology for the launch period (October 5 - 23) reflects the complex coastal meteorology of the KSC launch area. Historical meteorological data were examined to provide 40 sets of actual sequential data representative of the launch window. Each set consisted of 15-minute averages of surface wind speeds and direction, temperature lapse rate, and wind variability over the 12-hour period of T-2 hours to T+10 hours. The radiological consequences were the mean values resulting from dispersion calculations using average source terms, calculated for all 40 meteorological conditions, with the set of pathway parameters and assumptions representing central estimates, to define the Base Case consequences for Phase 1. For Phases 2, 3, and 4, the calculations used an average source term and time independent meteorology representative of the average condition for the Base Case.

Radiation doses to populations are calculated based on environmental concentrations. The dose conversion factors have been derived using a model published by the International Commission on Radiological Protection in ICRP-30 (ICRP 1978).

The features of the analyses significant to the magnitude of the results reported here are:

1. The fuel remains in the insoluble $PuO_2$ form in the environment.

2. Particle size distributions are unchanged following the accident except for the effects of vaporization in fireballs.

3. The initial plume configuration (cloud size, height) of ground-level and elevated releases is important to the results.

4. Long-term doses contain a component due to food ingestion. In other words, no credit was taken for dose reduction measures, such as sheltering, cleanup operations, or food restrictions.

## C.5 RADIOLOGICAL CONSEQUENCE RESULTS

The results of the radiological consequence analysis for the Base Case are summarized in Table C-2.

The types of radiological consequences include:

1. The "short-term" radiation dose resulting from the initial exposure and dose from continuing exposure to materials in the environment over an extended period following release. Long-term doses include those to KSC workers and to offsite KSC and worldwide populations due to inhalation of resuspended material and ingestion of contaminated food over a 50-year period. The doses are 50-year dose commitments resulting from the extended retention of material in the body.

2. Estimates of land- and water-surface areas contaminated by deposition of radioactivity above certain levels. It should be noted that the estimates presented here are for illustrative purposes. In the event of an accident, real-time estimates of wind transport and deposition would use meteorological conditions current at that time.

This information is presented in the following terms:

1. Maximum Individual Dose. The maximum individual dose commitment which an individual could receive. For launch area accidents (mission phase 1), this estimate takes account of the location of launch site visitors and workers and local demographics. For succeeding phases, average population distributions are used. Table C-3 provides a list of radiological doses commonly received in everyday life.

2. Collective (or Population) Dose (i.e., the sum of all doses to exposed individuals). This accounts for the fact that as the released material is transported by the atmosphere, in general its concentration decreases but the area of deposition and exposed population increases. The collective dose thus accounts for the number of people exposed and their level of exposure and is reported in terms of person-rems.

   The term "de minimis" refers to a dose level below which values could be excluded from assessments of collective dose as they contribute negligible individual risk. In this EIS, collective doses are calculated without reference to a de minimis value.

   (It should be noted that the Maximum Individual Dose and the Total Collective Dose are committed effective dose equivalents. Specifically, "committed" means that the dose from uptake from the

## TABLE C-2. BASE CASE RADIOLOGICAL CONSEQUENCES

| Phase | Time Period(Sec) | Total Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | Maximum Individual Dose(rem) | Collective Dose (Person-rem) Total | Above De Minimis | Dry Land Area Within Which Dose Level Exceeded [$km^2$($mi^2$)] 100 mrem/yr | 25 mrem/yr | 10 mrem/yr | Dry Land Area Exceeding 0.2 $\mu Ci/m^2$ [area in $km^2$($mi^2$)] |
|---|---|---|---|---|---|---|---|---|---|
| 1 (SRB Case Rupture) | 0- 10 | $3.36 \times 10^{-6}$ | $6.96 \times 10^{-4}$ | $1.41 \times 10^{1}$ | - | - | - | - | 3.91 (1.51) |
| | 11- 20 | $8.47 \times 10^{-7}$ | $4.95 \times 10^{-4}$ | $3.74 \times 10^{0}$ | - | - | - | - | 0.448 (0.17) |
| | 21- 70 | $4.37 \times 10^{-7}$ | $3.97 \times 10^{-5}$ | $4.43 \times 10^{-1}$ | - | - | - | - | 0.665 (0.26) |
| | 71-105 | $4.58 \times 10^{-7}$ | $5.37 \times 10^{-9}$ | $1.77 \times 10^{1}$ | - | - | - | - | - |
| | 106-120 | $2.27 \times 10^{-6}$ | $6.46 \times 10^{-8}$ | $2.12 \times 10^{2}$ | - | - | - | - | - |
| 2[a] | - | $6.16 \times 10^{-5}$(*) | $1.51 \times 10^{-3}$ | $1.19 \times 10^{-2}$ | - | - | - | - | - |
| 3[a] | - | $1.55 \times 10^{-4}$(*) | $6.37 \times 10^{-3}$ | $9.32 \times 10^{-2}$ | - | - | - | - | - |
| 4[a] | - | $1.66 \times 10^{-3}$(*) | $6.37 \times 10^{-3}$ | $9.32 \times 10^{-2}$ | - | - | - | - | - |

Source: See Appendix G, DOE 1990g

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

[a] Total probabilities for Phases 2, 3, and 4 are for land impact. Associated source terms are expectation values given a land impact.

TABLE C-3. AVERAGE ANNUAL EFFECTIVE DOSE EQUIVALENT OF IONIZING RADIATIONS TO A MEMBER OF THE U.S. POPULATION

| Source | Dose Equivalent[a] mrem | Effective Dose Equivalent mrem | Effective Dose Equivalent % of Total |
|---|---|---|---|
| Natural | | | |
| Radon[b] | 2,400 | 200 | 55 |
| Cosmic | 27 | 27 | 8.0 |
| Terrestrial | 28 | 28 | 8.0 |
| Internal | 39 | 39 | 11 |
| Subtotal--Natural | -- | 300 | 82 |
| Man-Made | | | |
| Medical | | | |
| X-ray diagnosis | 39 | 39 | 11 |
| Nuclear medicine | 14 | 14 | 4.0 |
| Consumer Products | 10 | 10 | 3.0 |
| Other | | | |
| Occupational | 0.9 | <1 | <0.3 |
| Nuclear fuel cycle | <1.0 | <1 | <0.03 |
| Fallout | <1.0 | <1 | <0.03 |
| Miscellaneous[c] | <1.0 | <1 | <0.03 |
| Subtotal--Man-Made | -- | 63 | 18 |
| Total Natural and Man-Made | -- | 360 | 100 |

Source: adapted from Nat. Res. Coun. 1990

[a] To soft tissues.

[b] Dose equivalent to bronchi from radon daughter products. The assumed weighting factor for the effective dose equivalent relative to whole-body exposure is 0.08.

[c] Department of Energy facilities, smelters, transportation, etc.

radioactive material into the body is accounted for over a 50-year residence time in the body. "Dose equivalent" means the dose to (a) specific organ(s). Effective means that the "dose equivalent" to (a) specific organ(s) is then converted to the equivalent of a dose delivered to the whole body.

3. Estimates of the dry land area affected within which the annual dose level would exceed 10, 25, and 100 mrem per year during the first year following plume passage, assuming no cleanup or other remedial activities have taken place.

4. Land areas on which initial deposition would exceed the screening level of 0.2 $\mu Ci/m^2$ suggested by the EPA.

For the purposes of comparing the accident consequences and the release probabilities from a Ulysses mission accident as estimated in the FSAR (DOE 1990e, DOE 1990f, DOE 1990g), a list of common accident causes, numbers of fatalities, and the chances of an individual in the U.S. population succumbing to those causes is provided in Table C-4.

## C-6 INTEGRATED MISSION RISK ANALYSIS

### C.6.1 Approach

The radiological consequences outlined in Table C-2 were based on averages.

Each of the average and best estimate parameter values used to calculate the consequences in Table C-2, was drawn from a group or population of possible parameter values. It follows then, that each of the parameters could vary, and as a result, the radiological consequences could vary depending upon which value (other than the mean or best estimate) is chosen from the various populations of values. For example, the 0-10 second LASEP 3 run resulted in 230 trials that had a release (see Appendix D, Table D-15 of DOE 1990f). The source terms used in the calculation of the 14.1 person-rem collective dose in Table C-2, was the mean over those 230 trials. The source term value that could be used to determine collective dose, however, could be any of the other values found in those 230 trials, ranging from the lowest source term to the highest source term. In other words, the source term value used in the calculation could be any value within that range. The same is true for all the other parameters (meteorological and exposure pathway) used in the calculation of collective dose.

In addition to a range of possible values for each of the parameters used to calculate collective dose, each of those populations of values also has another characteristic--a probability distribution. In other words, each value in the range has a probability of occurring. The LASEP 3 source term population for the 0-10 second subphase, for example, has a probability

TABLE C-4. CALCULATED INDIVIDUAL RISK OF FATALITY BY VARIOUS CAUSES[a]

| Accident Type | Number of Fatalities for 1987 | Approximate Individual Risk Per Year[c] |
|---|---|---|
| Motor Vehicle | 48,290 | $2 \times 10^{-4}$ |
| Falls | 11,733 | $5 \times 10^{-5}$ |
| Drowning | 4,360 | $2 \times 10^{-5}$ |
| Fires and Flames | 4,710 | $2 \times 10^{-5}$ |
| Poison | 5,315 | $2 \times 10^{-5}$ |
| Water Transport | 949 | $4 \times 10^{-6}$ |
| Air Travel | 1,263 | $5 \times 10^{-6}$ |
| Manufacturing[d] | 1,200 | $5 \times 10^{-6}$ |
| Railway | 624 | $2.5 \times 10^{-6}$ |
| Electrocution | 760 | $3 \times 10^{-6}$ |
| Lightning | 99 | $4 \times 10^{-7}$ |
| Tornadoes[b] | 114[b] | $5 \times 10^{-7}$ |
| Hurricanes[b] | 46[b] | $2 \times 10^{-7}$ |
| Suicide | 30,796 | $1.2 \times 10^{-4}$ |
| Homicide and Legal Intervention (Executions) | 21,103 | $9 \times 10^{-5}$ |
| Guns, Firearms, and Explosives | 1,656 | $7 \times 10^{-6}$ |
| Suffocation | 3,688 | $1.5 \times 10^{-5}$ |
| All Accidents | 95,020 | $4 \times 10^{-4}$ |
| Diseases | 1,993,381 | $8 \times 10^{-3}$ |
| ALL CAUSES | 2,123,323 | $9 \times 10^{-3}$ |

[a] USDHHS 1989.
[b] 1946 to 1984 average.
[c] Fatalities/Total Population. (USBC 1988).
[d] Source USBC 1986.

distribution that is directly determined by the LASEP 3 run. Specifically, each possible source term value within the range of values established by that run, has a probability of occurring.

The function of the integrated risk assessment is to evaluate the effects of the variability in each of the parameters used to calculate the Base Case consequences. In other words, what is the possible array of outcomes (i.e, consequences) that could occur if the value of each of the parameters affecting the outcome were something other than the mean or best estimate values used in the Base Case.

The approach to assessing the effects of this variability was performed in a stepwise fashion:

(1) First, the areas where variability exists within each of the three major factors (source terms, meteorology, exposure pathways), and which affect the consequences (i.e. collective dose, health effects, area contaminated), were identified, (see Section 4.0 and Appendix A - Section A.5 of DOE 1990g for details). The areas of variability thus identified were:

- Accident scenario
  - Accident environment
  - Accident probability
- Release characterization
  - Conditional source term probability
  - Source term
  - Source term modifiers
  - Particle size distribution
  - Particle size distribution modifiers
  - Initial cloud dimensions
  - Vertical source term distribution
  - Release location
- Meteorological conditions
  - Atmospheric stability
  - Wind speed and direction
  - Mixing height
  - Sea-breeze recirculation
  - Fumigation
  - Space and time variation

- Exposure pathway parameters

  - Population distribution
  - Resuspension factor
  - Deposition velocity
  - Vegetable ingestion
  - Protective action

- Radiation doses and health effects

  - Internal dose factors
  - Health effects estimator.

(2) Second, a range was established for the variability of each of the parameters affecting radiological consequences, and the probability distribution of the values within the range was determined. The ranges were established either from actual data, as in the case of the Phase 1 LASEP 3 source term results and the results from transport modeling with EMERGE, or from specific sensitivity analyses. Sensitivity analyses were performed on the effect of particle size distribution, particle size modifiers, specifically agglomeration and vaporization, plume drift, internal dose factors, resuspension factor and vegetable dose pathway. Additional details can be found in Appendix A, Section A.5 of Volume III of the FSAR (DOE 1990g). The probability distributions were determined either from actual data (LASEP 3 source terms and EMERGE modeling), from the sensitivity analyses, or in the case of some parameters by applying one of two commonly used probability distributions. If all values with a range are considered equally probable, then what is known as a "flat top" distribution was used for that parameter. If a "best estimate" value was determined, then the range in variability was represented as a $\pm 2\ \sigma$ of a normal or log-normal distribution, with the "best estimate" treated as an arithmetic or geometric mean, respectively.

In applying the results of sensitivity analyses, it was recognized that the sensitivity case represented a small sample of a larger population. Thus the parameter range established for use in the integrated risk analysis was usually larger than that indicated by the sensitivity analysis. The ranges and probability distributions for each area of variability examined in the integrated risk assessment are provided in Tables C-5, C-6, and C-7.

(3) Third, the functional relationships among all of the variable parameters as they affect the radiological consequences, were determined from earlier sensitivity studies.

These relationships are most often additive or multiplicative as determined by sensitivity analyses.

TABLE C-5. AREAS OF VARIABILITY CONSIDERED FOR MISSION PHASE 1
(0 TO 10, 11 TO 20, AND 21 TO 70 SECONDS)

| Area of Variability | Variability Factor Range | Probability Distribution |
|---|---|---|
| • Release characteristics | | |
| - Source term | * | LASEP 3 output distribution |
| - Particle size distribution (based on test data) | 0.5 - 1.5 | Flat-top |
| - Particle size modifiers (agglomeration/vaporization) | 0.5 - 1.5 | Flat-top |
| - Release height and cloud size | 0.5 - 1.5 | Flat-top |
| - Plume drift | 0.75 - 1.25 | Flat-top |
| • Meteorological conditions | - | EMERGE output distribution for 40 data sets |
| • Exposure pathways | | |
| - Direct inhalation | 0.5 - 1.5 | Flat-top |
| - Resuspension | 1.0 - 10.0 | $\pm 1\sigma$ of log-normal |
| - Vegetable | 0.5 - 1.5 | Flat-top |
| - Internal dose factor | 0.5 - 1.5 | Flat-top |
| - Health effects estimator | 0.33 - - 3.0 | $\pm 2\sigma$ of log-normal |

Source: DOE 1990g

* Range was entire LASEP 3 output.

TABLE C-6. AREAS OF VARIABILITY CONSIDERED FOR MISSION PHASE 1
(71 TO 104 AND 105 TO 120 SECONDS)

| Area of Variability | Variability Factor Range | Probability Distribution |
|---|---|---|
| • Release characteristics | | |
| - Source term | * | LASEP 3 output distribution |
| - Particle size distribution (based on test data) | 0.5 - 1.5 | |
| - Particle size modifiers (agglomeration/vaporization) | 0.5 - 1.5 | |
| • Meteorological conditions | | |
| - Effective deposition velocity | 0.1 - 10 | $\pm 2\sigma$ of log-normal |
| • Exposure pathways | | |
| - Direct inhalation | 0.5 - 1.5 | Flat-top |
| - Resuspension | 1.0 - 10.0 | $\pm 1\sigma$ of log-normal |
| - Vegetable | 0.5 - 1.5 | Flat-top |
| - Internal dose factor | 0.5 - 1.5 | Flat-top |
| - Health effects | 0.33 - 3.0 | $\pm 2\sigma$ of log-normal |

Source: DOE 1990g

* Range was entire LASEP 3 output.

TABLE C-7. AREAS OF VARIABILITY CONSIDERED FOR MISSION PHASES 2 THROUGH 4

| Area of Variability | Variability Factor Range | Probability Distribution |
|---|---|---|
| • Source term probability | | |
| - Module impact on rock | 1 - 18 modules | Binomial |
| - Fuel clad failure | 1 - 72 fuel clads | Binomial |
| • Release characteristics | | |
| - Source term | - | SVT test data (see DOE 1990f, Appendix G) |
| - Graphictics retention | 0 - 1.0 | Flat-top |
| - Particle size distribution | 0.5 - 1.5 | Flat-top |
| • Meteorological conditions | 0.1 - 10 | $\pm 2\sigma$ of log-normal |
| • Population | - | Based on DOE, 1990f, Appendix G information |
| • Exposure pathways | | |
| - Direct inhalation | 0.5 - 1.5 | Flat-top |
| - Resuspension | 1.0 - 10.0 | $\pm 1\sigma$ of log-normal |
| - Vegetable | 0.5 - 1.5 | Flat-top |
| - Internal dose factor | 0.5 - 1.5 | Flat-top |
| - Health effects | 0.33 - 3.0 | $\pm 2\sigma$ of log-normal |

Source: DOE 1990g

(4) Lastly, the probability distributions of all the variable parameters were combined using a Monte Carlo approach, to determine the probability distribution of the radiological consequences (i.e., collective dose, health effects, area contaminated and risk). The SPASM Monte Carlo computer code was used for this final step. SPASM is a general use simulation program designed to test the effects of parameter variability on a systems model. A total of 15,000 trials were performed for each phase and/or subphase to develop the overall probability distribution of the consequences reflecting the variabilities determined for the individual parameters.

The variability in accident environments were also accounted for in the accident modeling (DOE 1990f). The accident environments specified in the Shuttle Data Book (NASA 1988b), were presented as distributions of conditions (e.g., explosion overpressure; SRB fragment velocities). The distributions were factored into the accident modeling (DOE 1990f), and are thus reflected in the source term distributions provided for the nuclear risk assessment portion of the FSAR (DOE 1990g).

C.6.2 Results

The SPASM runs worked in essentially the following manner:

(a) The ranges and probability distributions for each of the source term parameters, meteorological conditions and exposure pathways parameters affecting the radiological consequences of a given phase/subphase accident release were inputted to SPASM;

(b) The SPASM code was run for 15,000 trials for that phase/subphase, with each trial randomly selecting a value for each parameter from that parameter's range and probability distribution;

(c) Each trial produced, for example, the collective dose that resulted from using the randomly selected parameter values; a resulting health effect was calculated using the randomly selected health effects factor; and an area of contamination was determined reflecting the randomly selected meteorological parameters.

The 15,000 SPASM trials for each of the accident release scenarios thus produced the range of possible outcomes (radiological consequences) associated with the variability in all of the source term, meteorological and exposure pathway parameters used in the Base Case analysis. In other words, SPASM produced new populations of consequence outcomes, with each population consisting of 15,000 outcomes (i.e., 15,000 possible collective doses; 15,000 possible health effects outcomes; etc.). The results are presented in the cumulative complementary distribution functions and the tabular data that follows.

Table C-8 presents the mission risk, by phase/subphase, calculated on the basis of the phase/subphase SPASM runs. In general, risk of an outcome is defined as the expectation value of that outcome. Here risk is applied to health effects. The phase/subphase risks provided in Table C-8 are based upon the mean of the health effects distribution for each phase/subphase, times the total probability of release for each phase/subphase. The total probabilities of release noted in Table C-8 reflect the updated NASA initiating accident probabilities provided to DOE in April of 1990. The effect of the updated NASA initiating accident probabilities was to increase mission risk by a factor of 3.2 compared with the FSAR (DOE 1990g). This is due primarily to the increase in the SRB case rupture initiating accident probability, (see Appendix B; Table B-2).

The results of the 15,000 SPASM trials for each phase/subphase were then transformed into a Complementary Cumulative Distribution Function (CCDF) of health effects consequences. The results were then plotted as shown in Figures C-2 through C-9. These plots show the total probability that a given level of health effects consequences are equal to or greater than the value indicated on the horizontal or X-axis.

These plots are derived from the SPASM run for each phase/subphase as follows:

(a) When SPASM randomly selects a value for a given parameter from the range of values for that parameter, the value selected also has a probability of occurring associated with it as determined by the probability distribution for the parameter;

(b) SPASM, once it has randomly selected a value for each of the parameters being examined, generates the resulting value of the radiological consequence. The consequence value is generated using the functional relationships (e.g., additive, multiplicative, etc.) by which the consequence is calculated.

(c) SPASM does the same thing for the probability associated with each of the randomly selected parameter values, generating the probability of that consequence by adding, multiplying, etc. the probabilities of each randomly selected parameter value to arrive at what is called the cumulative probability of the consequence.

Thus, each SPASM trial results in two numbers for each consequence type--a numerical value of the consequence, and the associated cumulative probability of that value. The 15,000 data sets thus generated by a SPASM run are used to develop the Complementary Cumulative Distribution Function plots.

TABLE C-8. MISSION RISK BY PHASE OR SUBPHASE AND AREA AFFECTED

| Phase | Subphase (seconds, MET) | Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | Mean Health Effects | Risk | Area Affected |
|---|---|---|---|---|---|
| 1 | 0-10 | $3.36 \times 10^{-6}$ | $3.69 \times 10^{-2}$ | $1.24 \times 10^{-7}$ | Cape Canaveral |
| | 11-20 | $8.47 \times 10^{-7}$ | $9.35 \times 10^{-3}$ | $7.92 \times 10^{-9}$ | Cape Canaveral |
| | 21-70 | $4.37 \times 10^{-7}$ | $1.14 \times 10^{-3}$ | $4.98 \times 10^{-10}$ | Cape Canaveral |
| | 71-105 | $4.58 \times 10^{-7}$ | $6.38 \times 10^{-2}$ | $2.92 \times 10^{-8}$ | World-wide |
| | 106-120 | $2.27 \times 10^{-6}$ | $8.61 \times 10^{-1}$ | $1.95 \times 10^{-6}$ | World-wide |
| | 0-120[a] | $7.37 \times 10^{-6}$ | $2.87 \times 10^{-1}$[a] | $2.10 \times 10^{-6}$ | |
| 2 | - | $6.16 \times 10^{-5}$(*) | $1.56 \times 10^{-5}$ | $9.61 \times 10^{-10}$ | Impact Area (Africa) |
| 3 | - | $1.55 \times 10^{-4}$(*) | $7.54 \times 10^{-5}$ | $1.17 \times 10^{-8}$ | Impact Area (World-wide) |
| 4 | - | $1.66 \times 10^{-3}$(*) | $7.54 \times 10^{-5}$ | $1.25 \times 10^{-7}$ | Impact Area (World-wide) |

Source: DOE 1990g

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

[a] Represents the expectation of all Phase 1 health effects, determined by probability weighting the values for each sub-period. Phase risk is the sum of the sub-phase values.

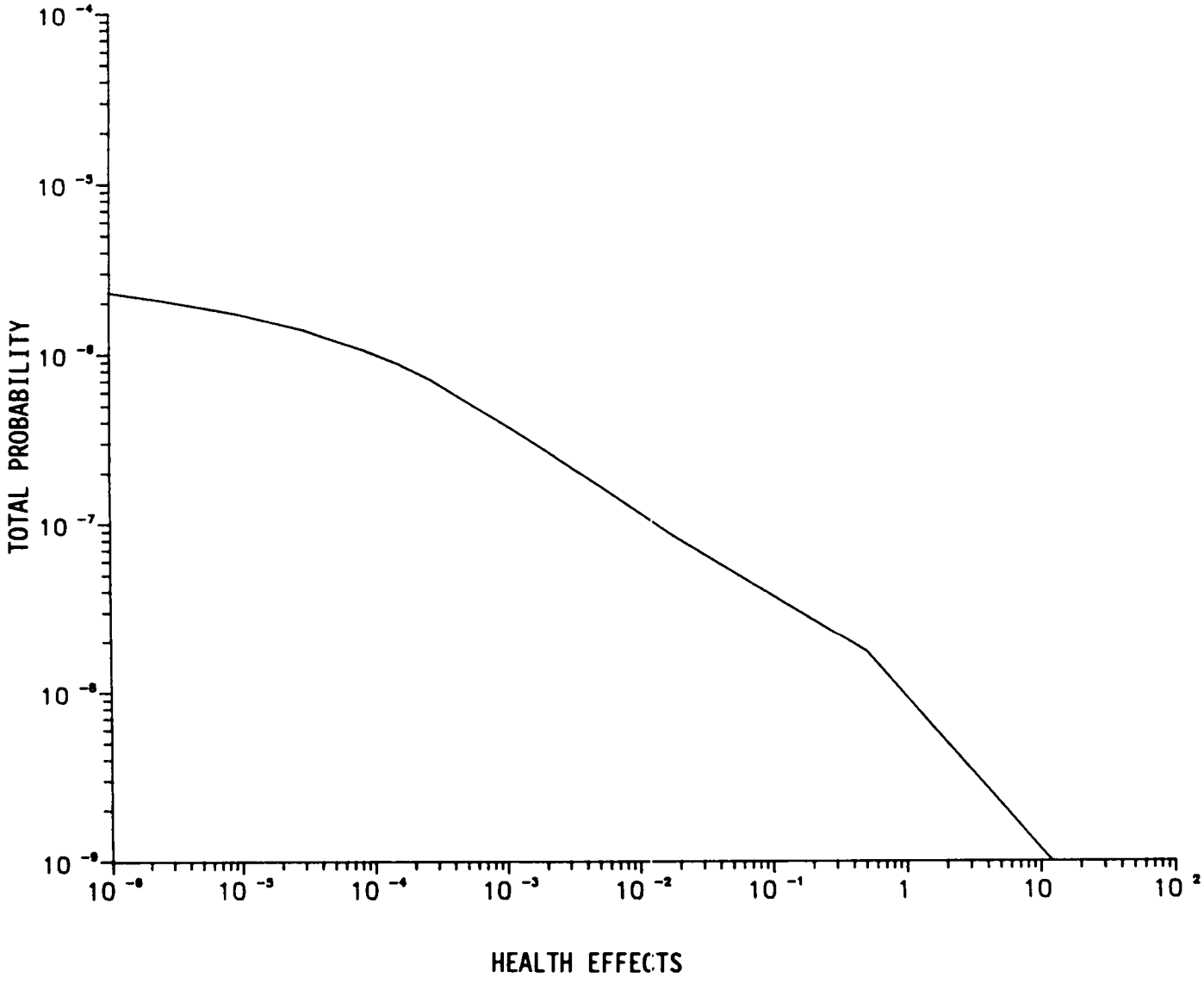


FIGURE C-2. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTIONS OF HEALTH EFFECTS CONSEQUENCE, 0-10 SECONDS

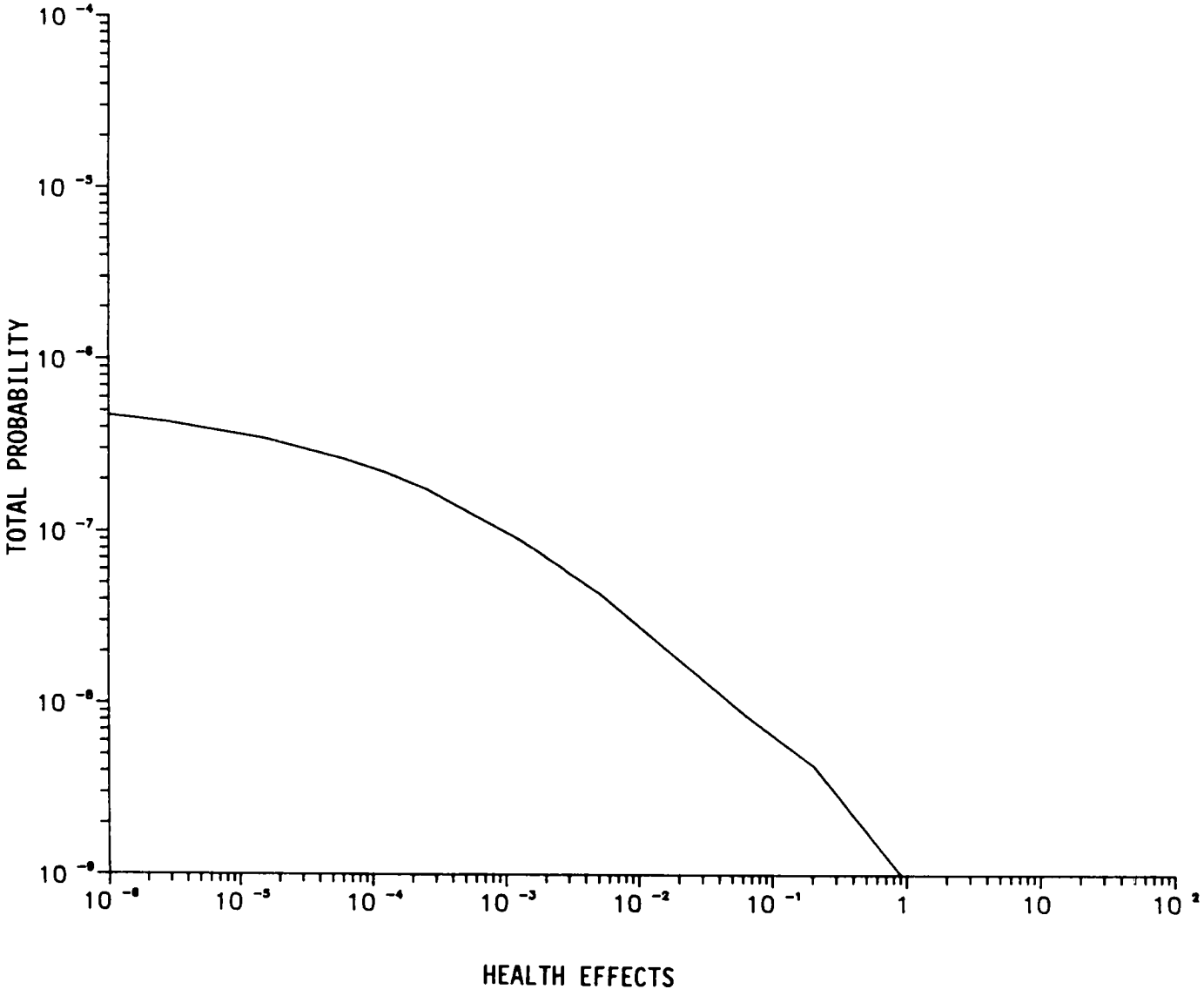


FIGURE C-3. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION OF HEALTH EFFECTS CONSEQUENCE, 11-20 SECONDS

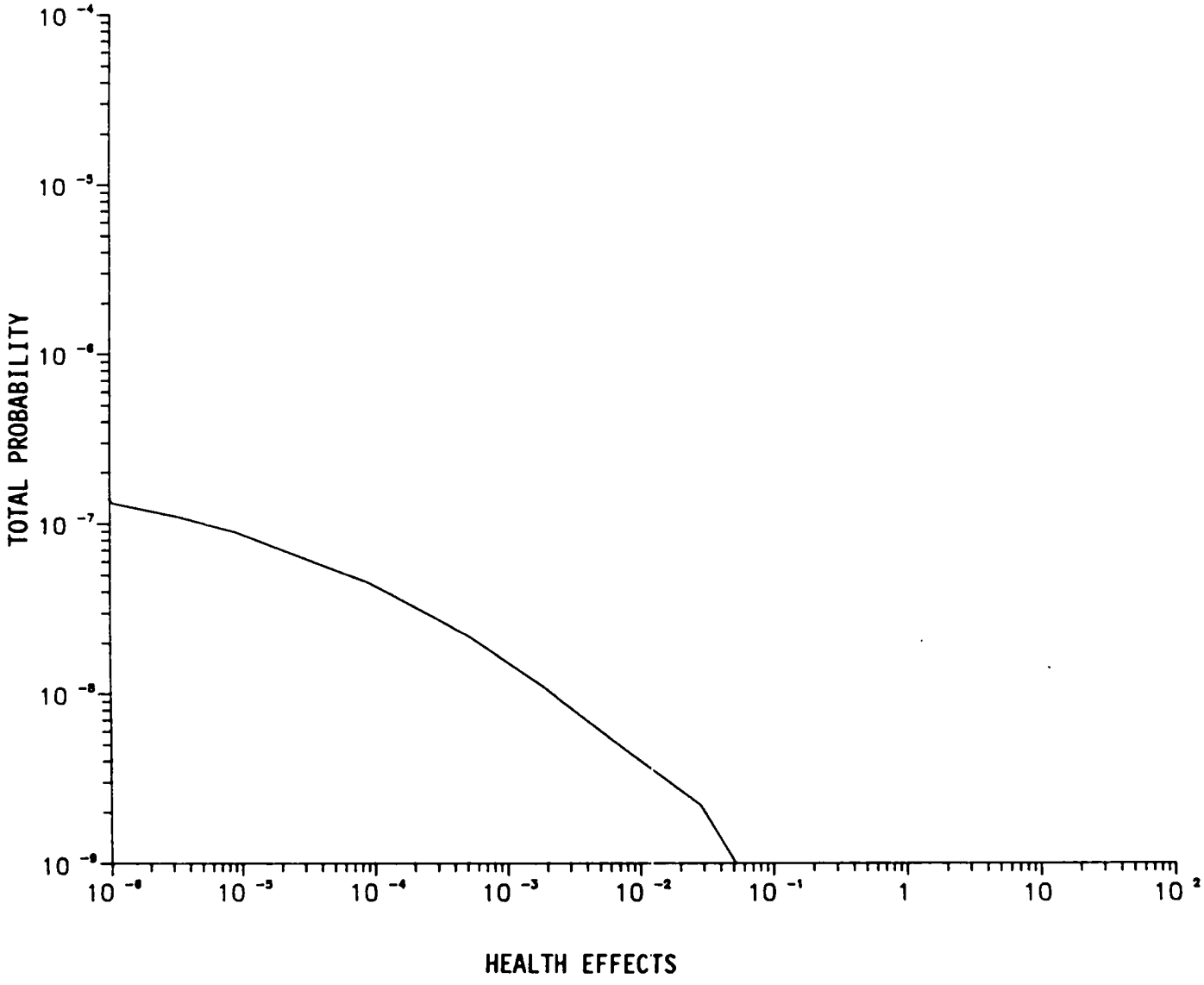


FIGURE C-4. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION OF HEALTH EFFECTS CONSEQUENCE, 21-70 SECONDS

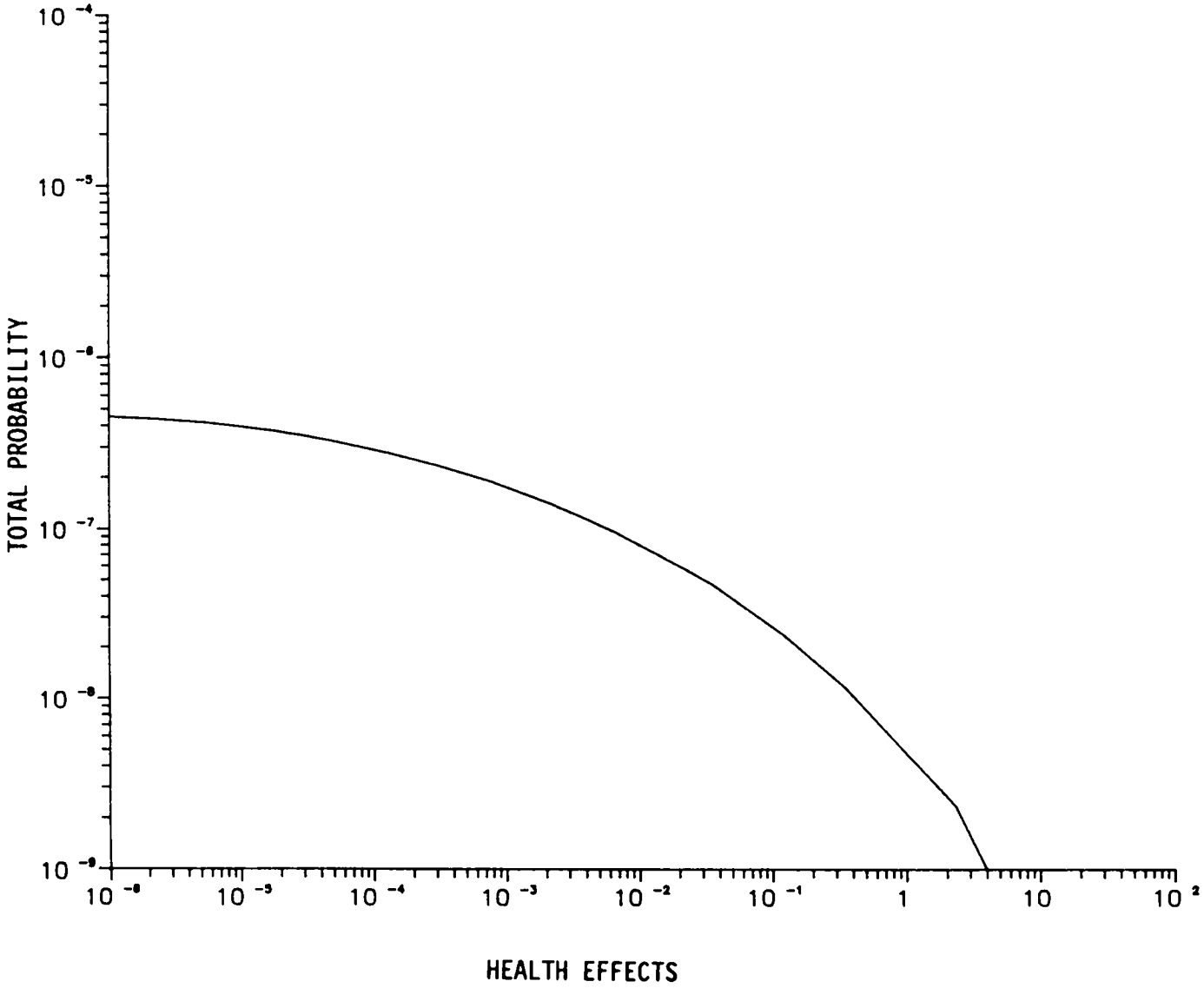


FIGURE C-5. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION OF HEALTH EFFECTS CONSEQUENCE, 71-105 SECONDS

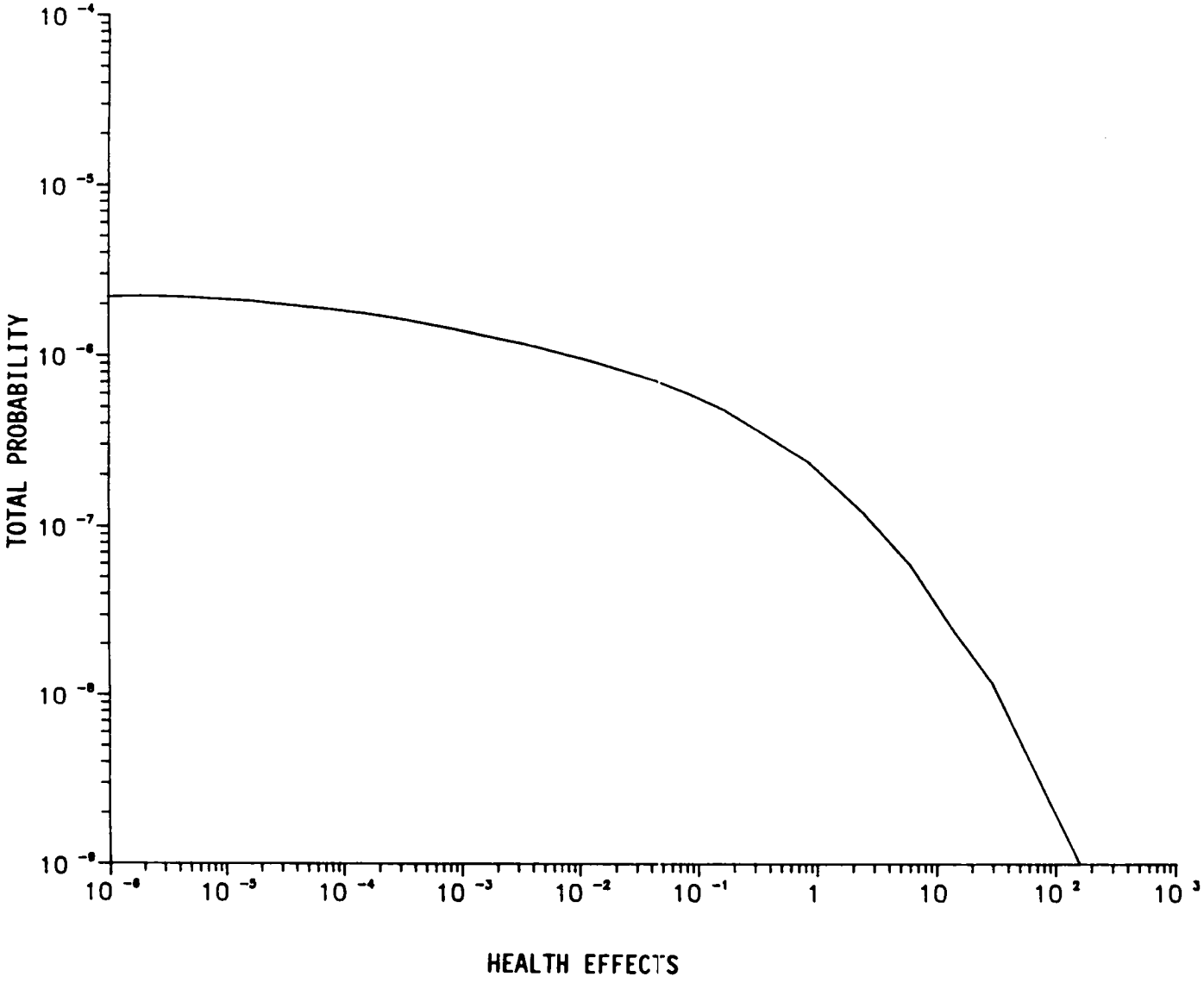


FIGURE C-6. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION OF HEALTH EFFECTS CONSEQUENCE, 106-120 SECONDS

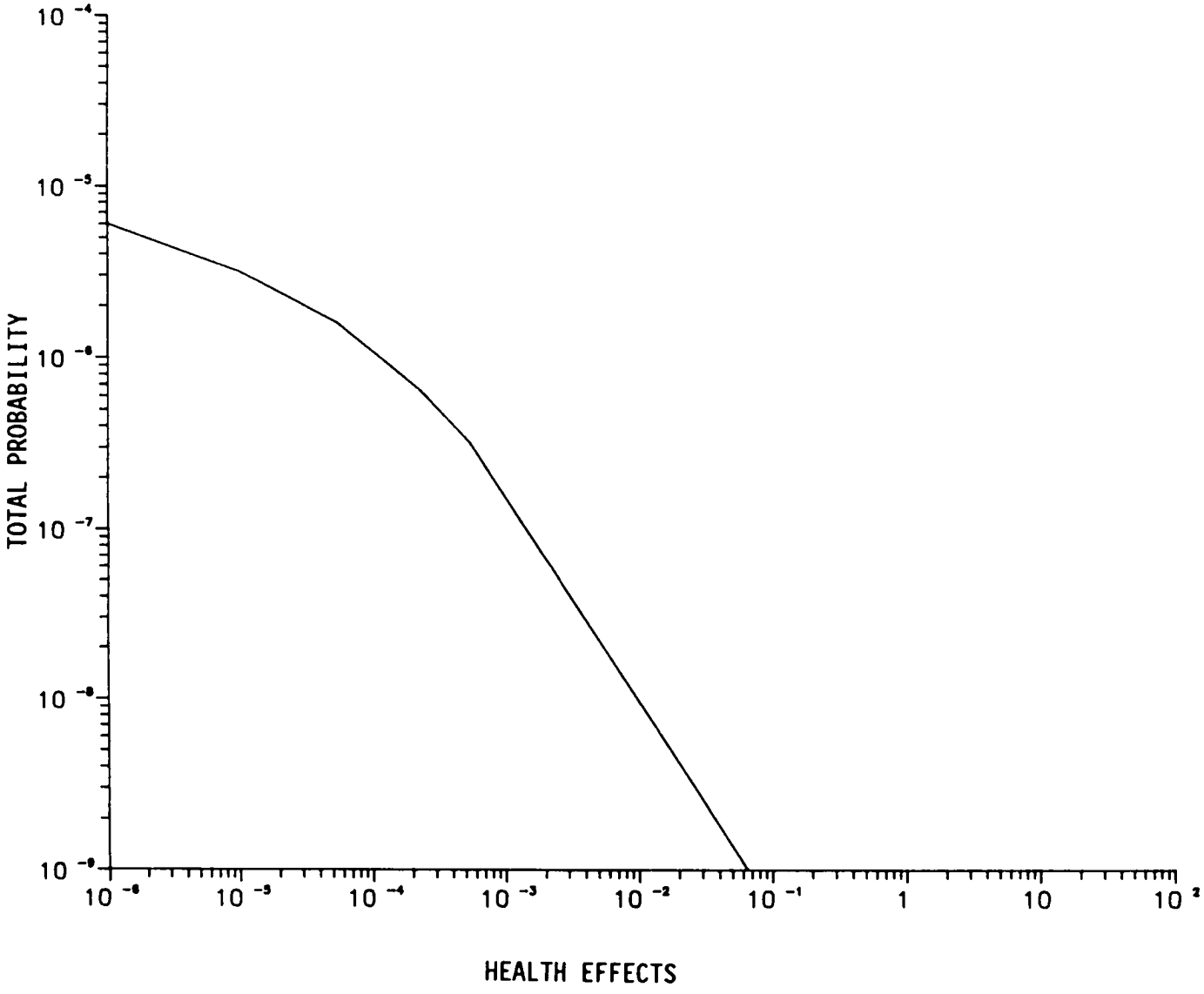


FIGURE C-7. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION OF HEALTH EFFECTS CONSEQUENCE DURING PHASE 2

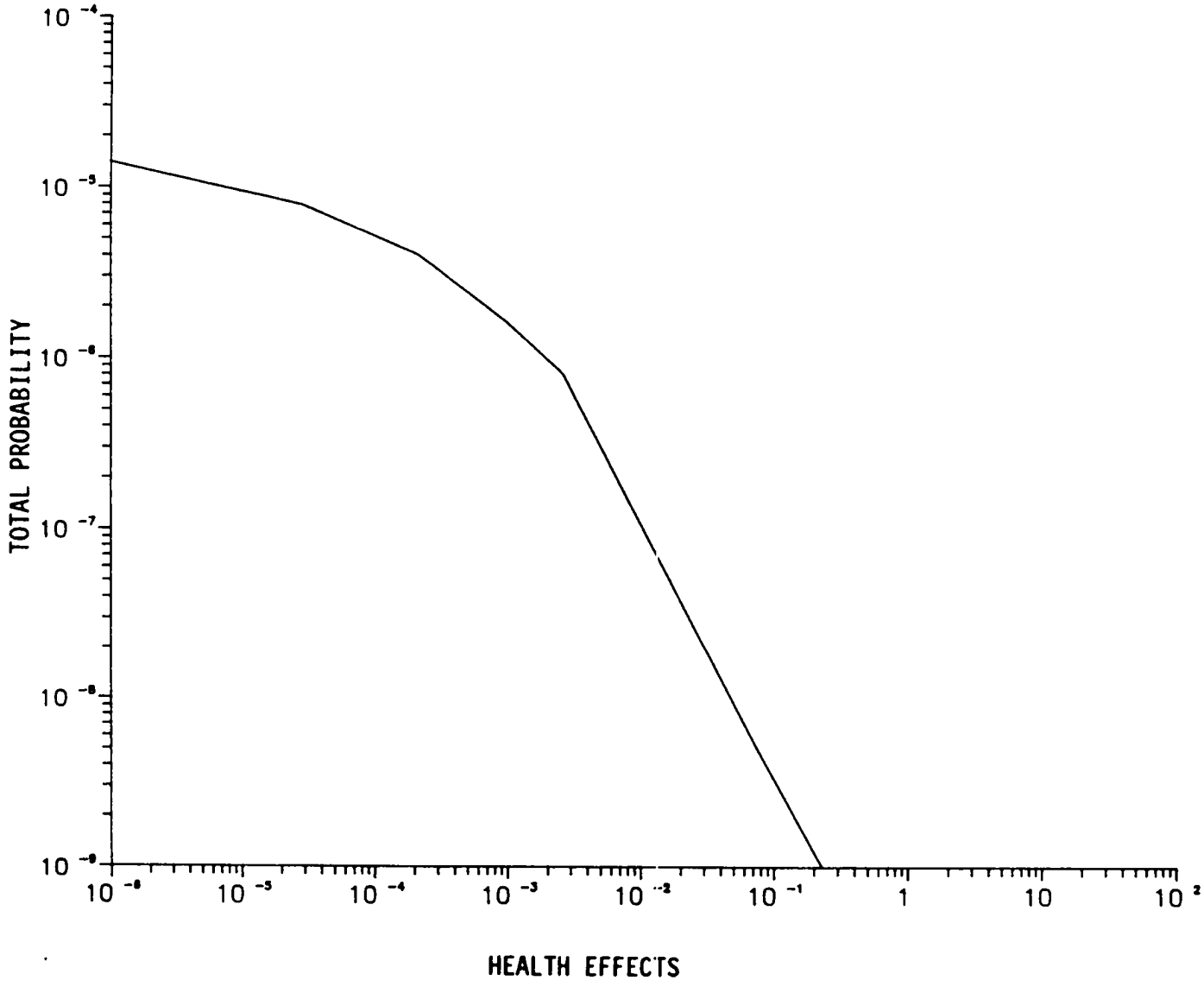


FIGURE C-8. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION OF HEALTH EFFECTS CONSEQUENCE DURING PHASE 3

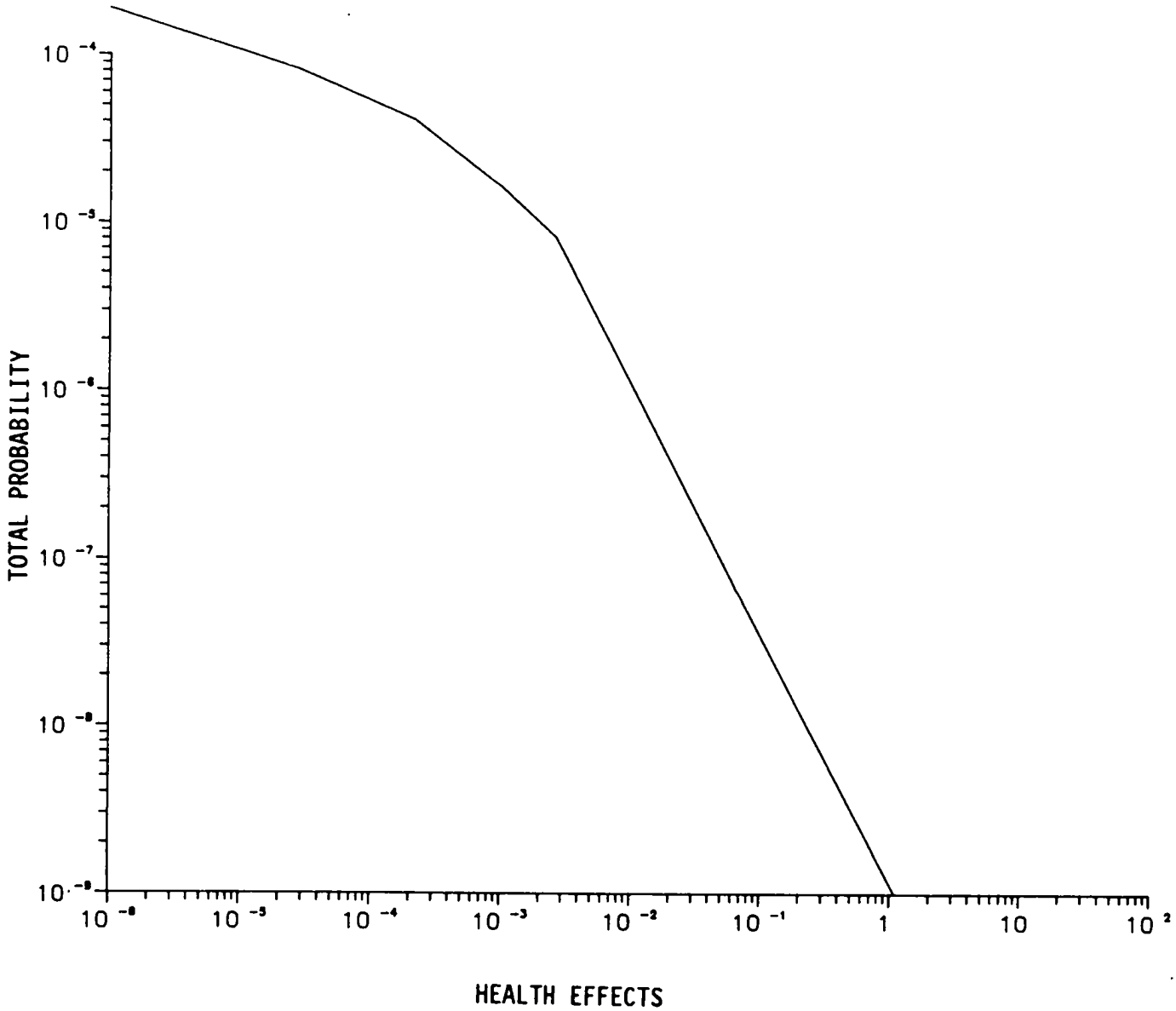


FIGURE C-9. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION OF HEALTH EFFECTS CONSEQUENCE DURING PHASE 4

Figure C-10 shows all of the phase/subphase Complementary Cumulative Distribution Functions plotted together. Figure C-11 is the plot of the overall mission (Phases 1-4 inclusive) Complementary Cumulative Distribution Function for the updated risk analysis compared with that generated from the FSAR analysis.

Following the DOE update of the safety analysis, the integrated risk assessment was performed to extract additional parameters (maximum individual dose, collective dose, land contamination) not explicitly displayed in the FSAR but of interest in an environmental assessment. Results are presented in Tables C-9 through C-17. Tables 4-4, 4-5, and 4-7 of Chapter 4 summarize the findings. The assessment focuses principally on the mean values and cites the 99th percentile values as representative of a "maximum case."

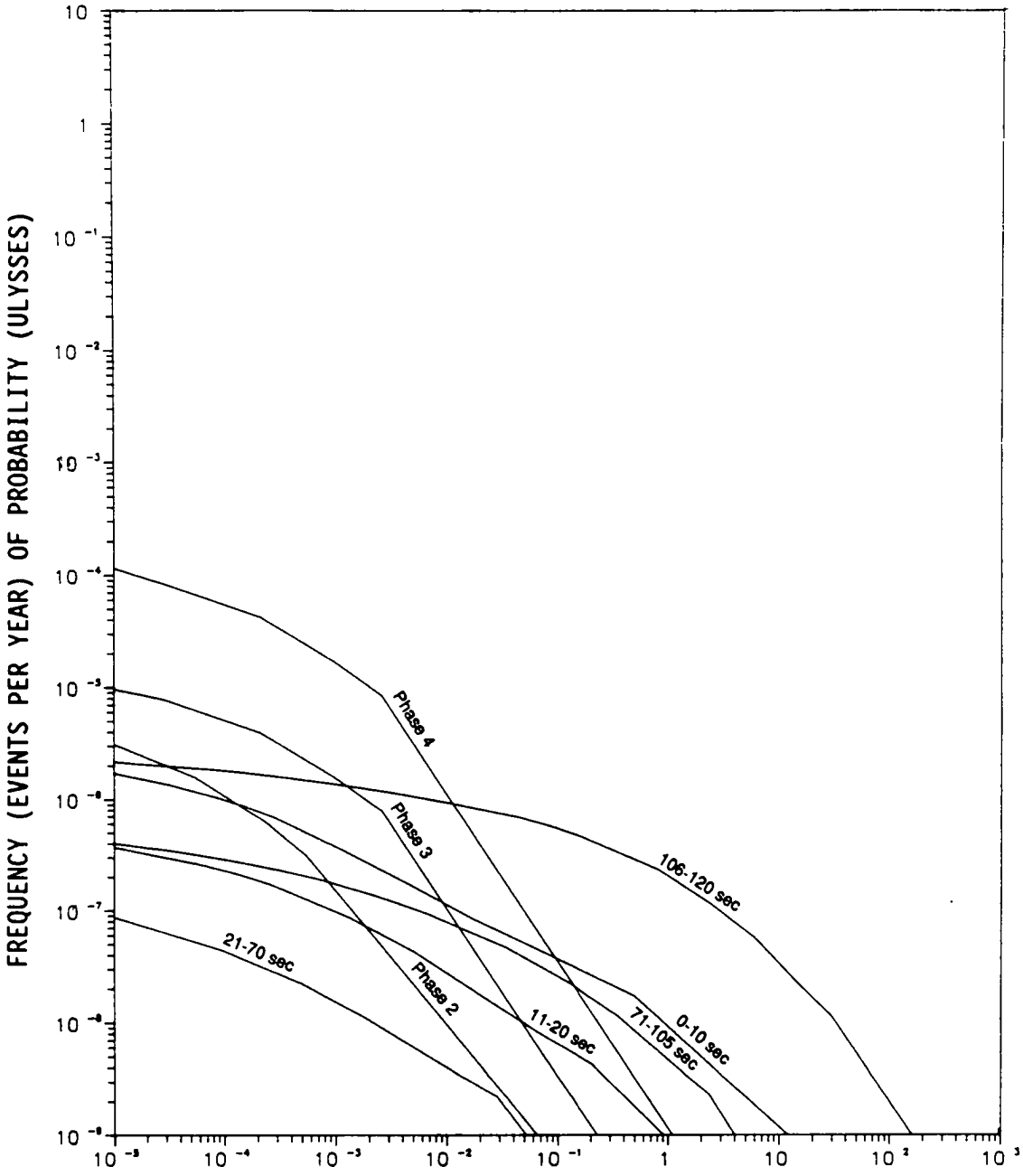


FIGURE C-10. COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTIONS OF MISSION CONSEQUENCES AND COMPARISONS

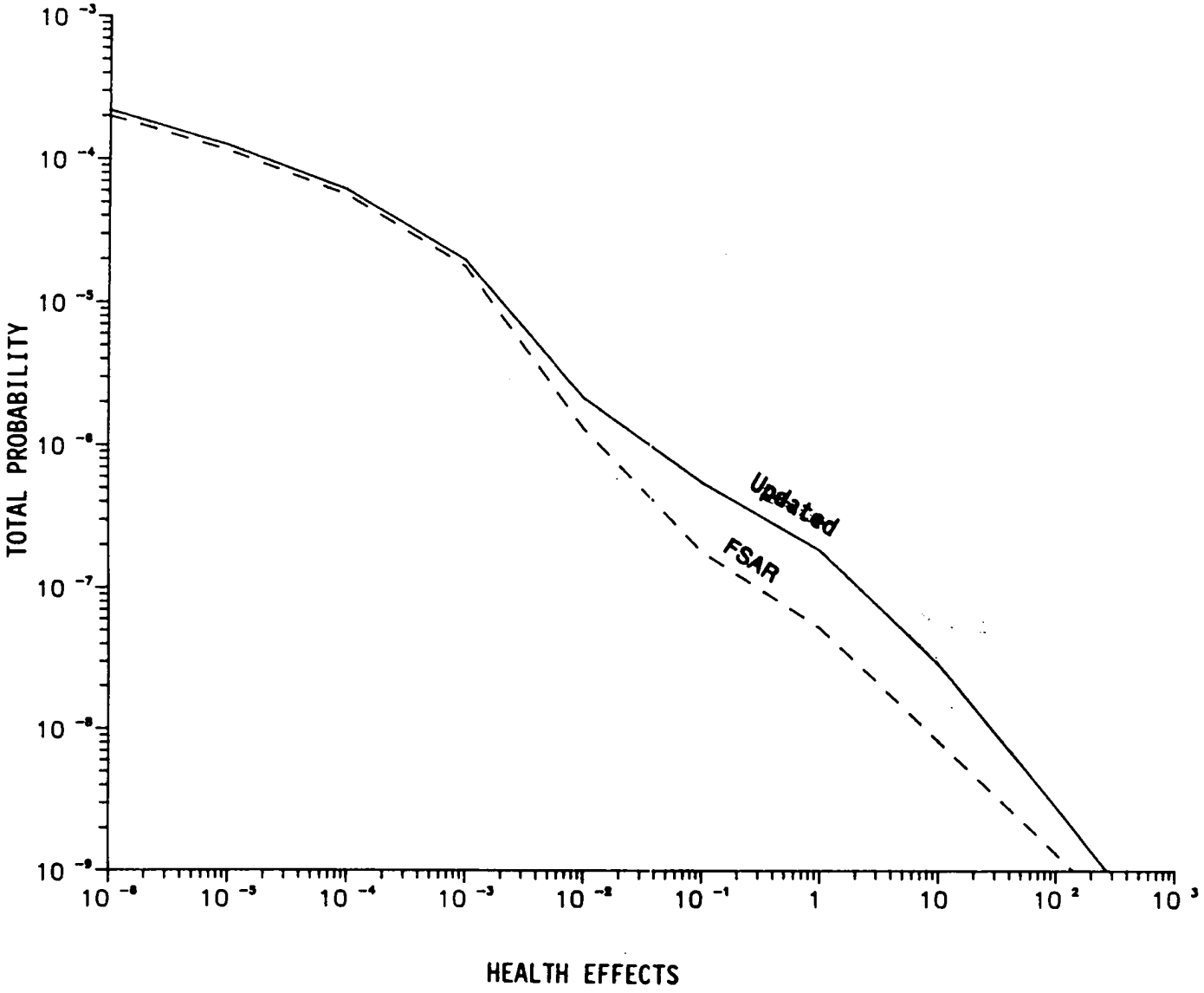


FIGURE C-11. COMPARISON OF OVERALL MISSION CCDF USING FSAR AND UPDATED PROBABILITIES

TABLE C-9. OTHER MEASURES OF RADIOLOGICAL IMPACT FOR THE LAUNCH AREA

| Time Period (Seconds, Met) | Maximum Individual Dose (REM) | | | Area of Land Exceeding 0.2 $\mu Ci/m^2$ Deposition $Km^2$ | | |
|---|---|---|---|---|---|---|
| | Mean | 50% | 99% | Mean | 50% | 99% |
| 0 - 10 | $3.8 \times 10^{-3}$ | $1.3 \times 10^{-6}$ | $2.3 \times 10^{-2}$ | $4.7 \times 10^{0}$ | $1.7 \times 10^{-2}$ | $1.1 \times 10^{2}$ |
| 11 - 20 | $1.6 \times 10^{-3}$ | $1.2 \times 10^{-6}$ | $2.1 \times 10^{-2}$ | $5.2 \times 10^{-1}$ | $9.9 \times 10^{-3}$ | $9.0 \times 10^{0}$ |
| 21 - 70 | $1.9 \times 10^{-4}$ | $3.2 \times 10^{-9}$ | $2.6 \times 10^{-3}$ | $8.5 \times 10^{-1}$ | $8.5 \times 10^{-3}$ | $2.3 \times 10^{1}$ |

Source: DOE 1990g

## TABLE C-10. ULYSSES MISSION SUMMARY OF COLLECTIVE DOSE

| Phase | Time Period (sec) | Total Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | Collective Dose, person-rem | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Percentile Level | | | |
| | | | Mean | 5 | 50 | 95 | 99 |
| 1 | 0-10 | $3.36 \times 10^{-6}$ | $7.78 \times 10^{1}$ | $2.23 \times 10^{-8}$ | $2.61 \times 10^{-2}$ | $1.14 \times 10^{1}$ | $4.57 \times 10^{2}$ |
| | 11-20 | $8.47 \times 10^{-7}$ | $1.24 \times 10^{1}$ | - | $8.86 \times 10^{-3}$ | $1.38 \times 10^{1}$ | $1.57 \times 10^{2}$ |
| | 21-70 | $4.37 \times 10^{-7}$ | $2.15 \times 10^{0}$ | - | $3.54 \times 10^{-5}$ | $1.58 \times 10^{0}$ | $2.90 \times 10^{1}$ |
| | 71-105 | $4.58 \times 10^{-7}$ | $1.93 \times 10^{2}$ | $6.73 \times 10^{-3}$ | $8.46 \times 10^{-1}$ | $3.29 \times 10^{2}$ | $2.97 \times 10^{3}$ |
| | 106-120 | $2.27 \times 10^{-6}$ | $2.27 \times 10^{3}$ | $1.38 \times 10^{-2}$ | 8.03 | $6.97 \times 10^{3}$ | $4.16 \times 10^{4}$ |
| 2 | - | $6.16 \times 10^{-5}$(*) | $3.68 \times 10^{-2}$ | - | - | $2.61 \times 10^{-2}$ | $5.77 \times 10^{-1}$ |
| 3 | - | $1.55 \times 10^{-4}$(*) | $1.92 \times 10^{-1}$ | - | - | $7.16 \times 10^{-2}$ | 2.88 |
| 4 | - | $1.66 \times 10^{-3}$(*) | $1.92 \times 10^{-1}$ | - | - | $7.16 \times 10^{-2}$ | 2.88 |

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

## TABLE C-11. ULYSSES MISSION SUMMARY OF HEALTH EFFECTS

| Phase | Time Period (sec) | Total Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | Health Effects | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Percentile Level | | | |
| | | | Mean | 5 | 50 | 95 | 99 |
| 1 | 0-10 | $3.36 \times 10^{-6}$ | $3.69 \times 10^{-2}$ | $9.98 \times 10^{-12}$ | $9.29 \times 10^{-6}$ | $4.67 \times 10^{-3}$ | $1.18 \times 10^{-1}$ |
| | 11-20 | $8.47 \times 10^{-7}$ | $9.35 \times 10^{-3}$ | - | $2.84 \times 10^{-6}$ | $5.14 \times 10^{-3}$ | $6.25 \times 10^{-2}$ |
| | 21-70 | $4.37 \times 10^{-7}$ | $1.14 \times 10^{-3}$ | - | $1.16 \times 10^{-8}$ | $5.02 \times 10^{-4}$ | $8.52 \times 10^{-3}$ |
| | 71-105 | $4.58 \times 10^{-7}$ | $6.39 \times 10^{-2}$ | $2.30 \times 10^{-6}$ | $3.11 \times 10^{-4}$ | $1.24 \times 10^{-1}$ | 1.03 |
| | 106-120 | $2.27 \times 10^{-6}$ | $8.61 \times 10^{-1}$ | $4.58 \times 10^{-6}$ | $3.15 \times 10^{-3}$ | 2.48 | $1.45 \times 10^{1}$ |
| 2 | - | $6.16 \times 10^{-5}$(*) | $1.56 \times 10^{-5}$ | - | - | $1.01 \times 10^{-5}$ | $2.36 \times 10^{-4}$ |
| 3 | - | $1.55 \times 10^{-4}$(*) | $7.54 \times 10^{-5}$ | - | - | $2.86 \times 10^{-5}$ | $1.03 \times 10^{-3}$ |
| 4 | - | $1.66 \times 10^{-3}$(*) | $7.54 \times 10^{-5}$ | - | - | $2.86 \times 10^{-5}$ | $1.03 \times 10^{-3}$ |

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

## TABLE C-12. ULYSSES MISSION SUMMARY OF MAXIMUM INDIVIDUAL DOSES

| Phase | Time Period (sec) | Total Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | Maximum Individual Dose, rem | | | | |
|---|---|---|---|---|---|---|---|
| | | | | Percentile Level | | | |
| | | | Mean | 5 | 50 | 95 | 99 |
| 1 | 0-10 | $3.36 \times 10^{-6}$ | $3.84 \times 10^{-3}$ | $1.10 \times 10^{-12}$ | $1.29 \times 10^{-6}$ | $5.63 \times 10^{-2}$ | $2.26 \times 10^{-2}$ |
| | 11-20 | $8.47 \times 10^{-7}$ | $1.64 \times 10^{-3}$ | - | $1.17 \times 10^{-6}$ | $1.83 \times 10^{-2}$ | $2.08 \times 10^{-2}$ |
| | 21-70 | $4.37 \times 10^{-7}$ | $1.93 \times 10^{-4}$ | - | $3.17 \times 10^{-9}$ | $1.42 \times 10^{-4}$ | $2.60 \times 10^{-3}$ |
| | 71-105 | $4.58 \times 10^{-7}$ | $5.86 \times 10^{-8}$ | $2.04 \times 10^{-12}$ | $2.57 \times 10^{-10}$ | $9.98 \times 10^{-8}$ | $9.01 \times 10^{-7}$ |
| | 106-120 | $2.27 \times 10^{-6}$ | $6.92 \times 10^{-7}$ | $4.21 \times 10^{-12}$ | $2.45 \times 10^{-9}$ | $2.12 \times 10^{-6}$ | $1.27 \times 10^{-5}$ |
| 2 | - | $6.16 \times 10^{-5}$(*) | $4.67 \times 10^{-3}$ | - | - | $3.31 \times 10^{-3}$ | $7.32 \times 10^{-2}$ |
| 3 | - | $1.55 \times 10^{-4}$(*) | $1.31 \times 10^{-2}$ | - | - | $4.89 \times 10^{-3}$ | $1.97 \times 10^{-1}$ |
| 4 | - | $1.66 \times 10^{-3}$(*) | $1.31 \times 10^{-2}$ | - | - | $4.89 \times 10^{-3}$ | $1.97 \times 10^{-1}$ |

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

TABLE C-13. ULYSSES MISSION SUMMARY OF RISK

| Phase | Time Period (sec) | Risk Mean |
|---|---|---|
| 1 | 0-10 | $1.24 \times 10^{-7}$ |
| | 11-20 | $7.92 \times 10^{-9}$ |
| | 21-70 | $4.98 \times 10^{-10}$ |
| | 71-105 | $2.98 \times 10^{-8}$ |
| | 106-120 | $1.95 \times 10^{-6}$ |
| 2 | - | $9.61 \times 10^{-10}$ |
| 3 | - | $1.17 \times 10^{-8}$ |
| 4 | - | $1.25 \times 10^{-7}$ |

TABLE C-14. ULYSSES MISSION SUMMARY OF INDIVIDUAL RISK

| Phase | Time Period (sec) | Individual Risk — Mean | Reference Population |
|---|---|---|---|
| 1 | 0-10 | $1.24 \times 10^{-12}$ | $1.0 \times 10^{5}$ |
| | 11-20 | $7.92 \times 10^{-14}$ | $1.0 \times 10^{5}$ |
| | 21-70 | $4.98 \times 10^{-13}$ | $1.0 \times 10^{5}$ |
| | 71-105 | $0.59 \times 10^{-17}$ | $5.0 \times 10^{9}$ |
| | 106-120 | $0.39 \times 10^{-15}$ | $5.0 \times 10^{9}$ |
| 2 | - | $9.61 \times 10^{-13}$ | $1.0 \times 10^{3}$ |
| 3 | - | $2.40 \times 10^{-12}$ | $5.0 \times 10^{3}$ |
| 4 | - | $2.50 \times 10^{-11}$ | $5.0 \times 10^{3}$ |

## TABLE C-15. ULYSSES MISSION SUMMARY OF LAND CONTAMINATION

| Phase | Time Period (sec) | Total Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | Area ($km^2$) with Levels Exceeding 0.2 $\mu Ci/m^2$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | Mean | Percentile Level | | | |
| | | | | 5 | 50 | 95 | 99 |
| 1 | 0-10 | $3.36 \times 10^{-6}$ | 4.65 | $1.80 \times 10^{-4}$ | $1.72 \times 10^{-2}$ | 1.43 | $1.11 \times 10^{2}$ |
| | 11-20 | $8.47 \times 10^{-7}$ | $5.24 \times 10^{-1}$ | $9.09 \times 10^{-5}$ | $9.86 \times 10^{-3}$ | $7.17 \times 10^{-1}$ | 9.00 |
| | 21-70 | $4.37 \times 10^{-7}$ | $8.51 \times 10^{-1}$ | - | $8.51 \times 10^{-3}$ | 2.15 | $2.28 \times 10^{1}$ |
| | 71-105 | $4.58 \times 10^{-7}$ | - | - | - | - | - |
| | 106-120 | $2.27 \times 10^{-6}$ | - | - | - | - | - |
| 2 | - | $6.16 \times 10^{-5}$(*) | - | - | - | - | - |
| 3 | - | $1.55 \times 10^{-4}$(*) | - | - | - | - | - |
| 4 | - | $1.66 \times 10^{-3}$(*) | - | - | - | - | - |

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

## TABLE C-16. ULYSSES MISSION SUMMARY OF LAND CONTAMINATION (Continued)

| Phase | Time Period (sec) | Total Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | Area ($km^2$) with Levels Exceeding 10 mrem/yr[a] | | | | |
|---|---|---|---|---|---|---|---|
| | | | Mean | Percentile Level | | | |
| | | | | 5 | 50 | 95 | 99 |
| 1 | 0-10 | $3.36 \times 10^{-6}$ | $2.35 \times 10^{-2}$ | - | - | $3.41 \times 10^{-3}$ | $6.28 \times 10^{-2}$ |
| | 11-20 | $8.47 \times 10^{-7}$ | $1.50 \times 10^{-2}$ | - | $1.95 \times 10^{-5}$ | $1.83 \times 10^{-2}$ | $2.04 \times 10^{-1}$ |
| | 21-70 | $4.37 \times 10^{-7}$ | $2.44 \times 10^{-2}$ | - | $1.68 \times 10^{-5}$ | $5.49 \times 10^{-2}$ | $5.17 \times 10^{-1}$ |
| | 71-105 | $4.58 \times 10^{-7}$ | - | - | - | - | - |
| | 106-120 | $2.27 \times 10^{-6}$ | - | - | - | - | - |
| 2 | - | $6.16 \times 10^{-5}$(*) | - | - | - | - | - |
| 3 | - | $1.55 \times 10^{-4}$(*) | - | - | - | - | - |
| 4 | - | $1.66 \times 10^{-3}$(*) | - | - | - | - | - |

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

[a] Time period of exposure: 1 day - 1 year

## TABLE C-17. ULYSSES MISSION SUMMARY OF LAND CONTAMINATION (Continued)

| Phase | Time Period (sec) | Total Probability of Release (Phase 1)/ Land Impact (Phases 2-4) | Area ($km^2$) with Levels Exceeding 25 mrem/yr[a] | | | | |
|---|---|---|---|---|---|---|---|
| | | | Mean | Percentile Level | | | |
| | | | | 5 | 50 | 95 | 99 |
| 1 | 0-10 | $3.36 \times 10^{-6}$ | $2.16 \times 10^{-3}$ | - | - | $1.43 \times 10^{-4}$ | $3.42 \times 10^{-3}$ |
| | 11-20 | $8.47 \times 10^{-7}$ | $1.38 \times 10^{-3}$ | - | $8.18 \times 10^{-7}$ | $7.67 \times 10^{-4}$ | $1.11 \times 10^{-2}$ |
| | 21-70 | $4.37 \times 10^{-7}$ | $2.24 \times 10^{-3}$ | - | $7.05 \times 10^{-7}$ | $2.30 \times 10^{-3}$ | $2.81 \times 10^{-2}$ |
| | 71-105 | $4.58 \times 10^{-7}$ | - | - | - | - | - |
| | 106-120 | $2.27 \times 10^{-6}$ | - | - | - | - | - |
| 2 | - | $6.16 \times 10^{-5}$(*) | - | - | - | - | - |
| 3 | - | $1.55 \times 10^{-4}$(*) | - | - | - | - | - |
| 4 | - | $1.66 \times 10^{-3}$(*) | - | - | - | - | - |

* These are the probabilities of the modules hitting land. The probabilities of a fuel release are even lower. The conditional expectation probability of one or more modules hitting rock and one or more clads releasing fuel after striking rock or similar unyielding surface is 0.102 for Phase 2 and 0.129 for Phases 3 and 4.

[a] Time period of exposure: 1 day - 1 year

# APPENDIX E

# RESPONSES TO PUBLIC COMMENTS

# APPENDIX E

# RESPONSES TO PUBLIC REVIEW COMMENTS

## E.1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) published a Notice of Availability for the Ulysses mission (Tier 2) Draft Environmental Impact Statement (DEIS) in the Federal Register on February 23, 1990. The 45-day public review and comment period closed on April 9, 1990. Timely comments were received from the Federal, state, and local organizations and individuals listed in Table E-1.

This Appendix provides specific responses to the comments received from the individuals and organizations listed in Table E-1. Copies of the comment letters are presented in the following pages. The relevant comments are marked and numbered for identification along with the National Aeronautics and Space Administration's (NASA's) response to each comment. Where changes in the text were appropriate, such changes were noted.

TABLE E-1. LISTING OF COMMENTORS

| Commentor Number | Date of Comment | Organization | Person Presenting Comments |
|---|---|---|---|
| 1 | 3/19/90 | Citizens to Stop Plutonium in Space | Bethany Bechtel |
| 2 | 3/20/90 | Federation of American Scientists | Steven Aftergood |
| 3 | 3/21/90 | Private Citizen | Lance J. Bollinger |
| 4 | 4/2/90 | Florida Coalition for Peace and Justice | Bruce K. Gagnon |
| 5 | 4/2/90 | Private Citizens | Mr. & Mrs. Paul Puchstein |
| 6 | 4/4/90 | Physicians for Social Responsibility | Richard Saxon |
| 7 | 4/5/90 | Southern California Federation of Scientists | Sheldon C. Plotkin |
| 8 | 4/6/90 | Committee to Bridge the Gap | Daniel Hirsch |
| 9 | 4/6/90 | The HERO Project | Patricia Axelrod |
| 10 | 4/6/90 | National Space Society | Glenn Harlan Reynolds |
| 11 | 4/6/90 | Department of Health & Human Services | Kenneth W. Holt |
| 12 | 4/8/90 | Sierra Club, Committee on Military Impacts on the Environment | Anne H. Ehrlich |
| 13 | 4/9/90 | Florida Coalition for Peace and Justice, Christic Institute, and Foundation on Economic Trends | Edward Lee Rogers |
| 14 | 4/9/90 | Committee for Risk Analysis in Regulation | Anand P. Patwardhan |

# Citizens to Stop Plutonium in Space

522 S. Melville Street, Philadelphia, Pennsylvania 19143


19 March 1990

Dr. Dudley G.McConnell
Deputy Director (Advanced Programs)
Solar System Exploration Division (Code EL)
NASA Headquarters
Washington, D.C. 20546


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John Taylor, Esq.

Rev. Kenneth J. Thomas

Rev. Margaret Orr Thomas


Dear Dr. McConnell:

On behalf of the national organization Citizens to Stop Plutonium in Space (CISTOP) I have reviewed the draft environmental impact statement for the Ulysses mission (Tier 2). My comments are as follows:

1) The EIS document contains a variety of tables, reporting numerical estimates of plutonium release and subsequent damage to human population and the environment. However, these values are meaningless since none are reported with associated error estimates. The "overall approach" outlined on p. C-15 necessarily generates multiple and complex sources of error which must be accounted for if this study is to be considered valid. 1-1

2) Although requested by CISTOP the current version of the EIS does not address the methodology's susceptibility to bias in data generation and interpretation. 1-2 The EIS also does not discuss sufficiantly hazards of electromagnetic radiation to ordinance (HERO effects), another issue upon which we requested analysis. 1-3

3) The assumptions 1 through 3 on p. C-10 require more extensive justification. 1-4

We feel that the above shortcomings preclude the use of this EIS in determining the safety of the Ulysses mission.

Sincerely,

Bethany Bechtel

Bethany Bechtel, Ph.D. (Biophysics)

RESPONSES TO COMMENTS
Commentor No. 1: Citizens to Stop Plutonium in Space

Response to Comment No. 1-1

Uncertainties have been addressed throughout the Ulysses safety review and analysis. As discussed in Appendix C of the FEIS, the Safety Status Report (SSR) (DOE 1990a, DOE 1990b, DOE 1990c) describes the Monte Carlo simulation which accounts for uncertainty bands for the conditions, parameters, and assumptions affecting the final results. Uncertainties are further addressed in the Final Safety Analysis Report (FSAR) (DOE 1990d, DOE 1990e, DOE 1990f, DOE 1990g) in Vol. III, Book 1, Section 4.0 Integrated Mission Risk Analysis, with back-up details provided in Vol. III, Book 2, Appendix A, Section A.5 and in Section 4 of this EIS. A Monte Carlo technique was used to evaluate the combined effect of the identified areas of variability to arrive at the range of consequences taking account of the range of variability of parameters.

Implicit within the use of LASEP 3 to calculate source term is the consideration of ranges and probability distributions for key parameters. These included, for example, fragment velocities, material properties, and failure threshold. This resulted in a distribution of source terms for each accident scenario in the launch area. The resulting source term distribution was carried through the integrated risk analysis as described above.

Response to Comment No. 1-2

There are a number of steps taken during the analysis process to ensure that improper bias is not included. For accident analyses, the primary data are from specific accidents. Comparative data from multiple sources such as photographs, telemetry, and trajectories are used to insure proper interpretation. In addition, analytical models are developed based on fundamental physical principles to correlate the observed data and to allow extrapolation to other accident scenarios and/or to other mission times. Where assumptions are required, they are generally conservative. Finally, the process and the resulting environmental predictions are subjected to peer review. In addition, special review panels are convened for specific issues, such as the Interagency Explosion Working Group that studied the Challenger and Titan 34D-9 accidents.

Response to Comment No. 1-3

The discussion of HERO effects in Section 2.5.2 has been revised to provide more detailed information.

A more complete discussion is included in Responses to Comments 9-1 through 9-10.

Response to Comment No. 1-4

The statements on page C-10 are features of the analyses. The term "assumption" was misapplied. The items 1 through 3 on page C-10 represent base features of the analysis. Variations in those parameters have been fully addressed in FSAR, Volume III, Appendix A, Section A.5, and incorporated into the integrated risk analysis. The effect of these variations are implicit in the percentile confidence ranges associated with the best estimate results and in the complimentary cumulative distribution functions (CCDFs). Statements 1 and 2 reflect test results. Statement 3 is simply a feature of the analysis noting that the point of release is important. Statement 4 is a measure of conservatism.

# F.A.S.

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March 20, 1990

Dr. Dudley G. McConnell
Code EL
National Aeronautics and Space Administration
Washington, D.C. 20546

Dear Dr. McConnell:

Attached please find my comments on the Draft Environmental Impact Statement for the Ulysses Mission (Tier 2).

Thank you for your assistance in addressing this rather complicated issue.

Yours sincerely,

Steven Aftergood
Senior Research Analyst


*National Council Members*

| | | | | |
|---|---|---|---|---|
| *Julius Axelrod | Steven F. Cohen | *Dudley R. Herschbach | Jessica Tuchman Mathews | Arthur H. Rosenfeld |
| Bruce Blair | E. William Colglazier | Art Hobson | Matthew S. Meselson (ex officio) | Stephen H. Schneider |
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Comments on Draft Environmental Impact Statement for the Ulysses Mission

The Draft Environmental Impact Statement (DEIS) concludes that an accident leading to release of plutonium fuel is extremely improbable. But for the reasons discussed below, the validity of this conclusion seems uncertain or inadequately justified.

1. Shuttle Accident Probabilities are Incorrect (False Precision)

NASA provided shuttle accident probability estimates to DOE "with an order of magnitude range for each system" (DEIS p. B-1). Yet throughout the DEIS, probabilities (and consequences) are typically cited with three significant figures and no error bands. This is an elementary calculational error. There is no basis for this extraordinary (but false) degree of precision. 2-1

DEIS page 4-4 indicates that shuttle accident probabilities for the Ulysses FSAR were provided to DOE in July 1988. However, at least a couple of revisions of shuttle accident probabilities have been performed since that time (by Code Q, Code M). Do the analyses based on the earlier probabilities need to be revised accordingly? 2-2

2. No Discussion of Uncertainties

Virtually no information is provided on uncertainties. It is therefore difficult to decide how much weight to give to the estimates reported, how much confidence NASA has in these numbers, or why.

It would be useful if some space in the EIS could be devoted to itemizing the many sources of uncertainty in estimating accident consequences for Ulysses; explaining how the uncertainties can be bounded, if at all; and why NASA will recommend launch of Ulysses notwithstanding the uncertainties. 2-3

(I note that, unlike earlier EIS's for Galileo, the Summary Comparison of Alternatives in Table 2-3 does not even provide estimates of the maximum credible accident, but rather only the "expectation" case. Why?) 2-4



RESPONSES TO COMMENTS
Commentor No. 2: Federation of American Scientists
(Continued)

Response to Comment No. 2-1

NASA understands the importance of significant figures and error bands to the conduct of the safety analysis. Accident probabilities are represented with additional significant figures to avoid the accrual of rounding error in the results of subsequent safety calculations.

The integrated risk assessment has addressed uncertainties (see Appendix C).

Response to Comment No. 2-2

The DEIS was based upon the probability data furnished by NASA to the DOE for use in both the Galileo and Ulysses FSARs. There has only been one official NASA update of those probabilities. That update reflects a reassessment of the previous data, and does not reflect new data. The update was completed in April 1990 and the updated probabilities were immediately incorporated in the Ulysses safety analysis. The updated values are reported in Section 4 of this FEIS and the updated safety analysis is summarized in Appendix C. This FEIS is based upon the updated accident scenario probability values.

Response to Comment No. 2-3

See Response to Comment No. 1-1.

See Appendix C for treatment of uncertainties.

Response to Comment No. 2-4

Although the maximum case is not explicitly described, it has been effectively included in the integrated risk analysis (see Section 4.1.4.3). That is in the analysis of variations, the entire source term distribution, including the maximum source term, was accounted for in the Monte Carlo analysis to arrive at percentile confidence bounds on the best estimates and the Complementary Cumulative Distribution Functions (CCDFs) which display consequences down to $10^{-9}$ probability. The 99th percentile has been discussed as representative of a "maximum" case.

3. To What Extent Have Computer Models been Validated?

NASA/DOE conducted an impressive series of tests in which RTGs were subjected to a variety of accident environments. However, the subsequent safety analyses relied upon in the DEIS use computer models that seem to extrapolate far beyond the empirical database generated in these tests. 2-5

Dr. Cuddihy of the Galileo INSRP panel noted that the NUS Corporation would not allow independent evaluation of the EMERGE computer code, claiming a proprietary interest. As he indicated, this refusal to allow independent review significantly limited confidence in the accuracy of the output estimates produced by this code. (EMERGE is again being used for Ulysses, as noted on page C-7). 2-6

Has this concern been rectified?

More generally, to what extent have the various computer models relied upon for the Ulysses DEIS been validated? 2-7

If they have not been or cannot be completely validated, how does NASA take into account the possibility of systematic error (i.e. incorrect modeling), as opposed to merely statistical errors? 2-8

Monte Carlo simulations can serve to model random events, but what about human factors, quality control problems, or other non-random events that can lead to, or exacerbate, accident scenarios? 2-9

4. What is the Correct "Expectation" Probability of Launch Accident Fuel Release?

In the "expectation" case, the quantity of Pu-238 released to the biosphere during a launch vicinity accident causing release is estimated to be 388 curies at a probability of $1.77 \times 10^{-7}$ (DEIS page 2-21), or about one in five million. 2-10

In the Galileo mission, the expectation case for the same category was estimated to be 894 Curies at $3 \times 10^{-4}$. (Galileo EIS Tier 2, page 2-21)

Why is the expectation probability of release three orders of magnitude lower for Ulysses? (Similarly, what accounts for the steep drop in the expectation case for 2-11





Response to Comment No. 2-5

The safety analysis relies upon the extensive testing program wherever possible. However, because of the costs and scarcity of materials involved, it is necessary to use analyses and analytical models to fill in between data points. For instance, the Los Alamos and Sandia National Laboratories conducted a series of fragment/fuselage tests that simulated the interaction of SRB fragments with portions of the Shuttle Orbiter. Sections of SRB casing were fired through Orbiter wing and fuselage structures in the vicinity of the RTGs. The structures were obtained directly from the manufacturers - Rockwell International, Downey, CA and Grumman Space Systems, Bethpage, NY, where they had been used for previous non-destructive (static load and acoustic) tests. These test items were identical or nearly identical to the appropriate Shuttle structures. Naturally the availability of such test items for destructive tests, such as these under discussion was limited. In order to make the best use of these targets and maximize data return, tests involving small (1' x 1') SRB case sections were conducted, and results were verified with one large fragment (5' x 5') test. Case sections were fired at a velocity typical of the fastest observed SRB fragments at a wide range of spin rates and impact orientations. The test series was quite adequate to establish consistent velocity reduction factors for subsequent safety analyses, and it is incorrect to say that these test results have been extrapolated "far beyond the empirical database." In general, tests are designed to bound the range of the needed data.

Response to Comment No. 2-6

The EMERGE Kernel used in the KSC-EMERGE System is made up of over 40 separate modules (subroutines and functions). All of these modules were independently tested and validated before being introduced into the EMERGE System. The KSC-EMERGE System grew out of several other NUS-developed computer codes: NUSPUF Model, AQPUF Model, and the EMERGE Model. The AQPUF model was validated through $SF_6$ tracer studies in complex terrain. Aside from extensive testing of each submodel prior to its incorporation in the EMERGE kernel, the performance of the system as a whole was tested by comparison with results from the NUS ATMOS model, the Savannah River Center PFPL model, the Sandia Laboratory DIFOUT model, and the Lawrence Livermore National Laboratory ARAC (MATHEW-ADPIC) MODEL. During installation of the KSC-EMERGE System at KSC in 1986, the empirical sea/land breeze algorithm was tested with four meteorological data bases. The algorithm successfully predicted the occurrence of the tow sea breeze events and the rate of propagation of the convergence from those events. The FSAR-EMERGE system has been described, discussed, and critiqued at numerous joint Interagency Nuclear

Safety Review Panel (INSRP), NASA, and DOE meetings over the years. Whenever valid criticisms and comments were received, they were incorporated in the FSAR-EMERGE System in an effort to upgrade and improve the predictive capability of the methodology. The INSRP adopted the EMERGE model for use in its safety evaluation of the Galileo mission.

In NASA's judgment, there are adequate bases of validation and operational experience to use EMERGE in this EIS. The concerns raised by Dr. Cuddihy have been addressed.

Response to Comment 2-7

First, the basic philosophy used in developing the models is: when in doubt err on the side of conservatism. As an example, in modeling the LO2/LH2 ET explosion environments (Tables 4.1-4.3, Shuttle Data Book) one of the Monte Carlo parameters used was the mix density; larger densities lead to larger overpressures. To account for uncertainties in our knowledge about what densities are actually possible, densities as high as 0.3 gm/cc were used even though current wisdom by people close to the problem, and recent experiments, indicates that the upper value will be an order of magnitude less. If each model has a bias in the conservative direction, which to a greater or lesser degree is the philosophic intent, it follows that the accumulated result will be a systematic bias in the conservative direction.

Second, the models are not developed in a vacuum. Experts from around the country are consulted and great effort is made to obtain the most current state-of-the-art experimental and theoretical information available relative to the physical phenomena underlying the accident being modeled. For instance, the ET explosion specifications are rooted in the extensive PYRO test program run in the '60s. To better understand those tests a comprehensive investigation was undertaken where all of the raw data was scrutinized and re-analyzed. In addition, the original investigators were brought in for consultation and to assist in developing the model. Another example has to do with developing the SRB fragmentation model (Section 5.2, Shuttle Data Book). In that case virtually every organization involved or knowledgeable about solid rocket motors was consulted and their advice solicited.

Third, the models are calibrated with experimental and/or accident data whenever possible. When no such information is available, reasonable but conservative upper level values are used. In developing the SRB fragmentation model, the intermediate results were checked against and correlated to observational data from the Challenger accident and from the Titan 34D-9 accident. Outside the parameter regimes defined by these two databases, systematic error was accounted for by the development of three independent analytical models which were repeatedly checked against each other and the observational data. These models represented the SRB breakup process in three radically different ways using different computational and physical approaches. The model that best encompassed the complexities of the physical phenomena was chosen to form the basis for the

Shuttle Data Book SRB environments. It used of the PISCES numerical hydrodynamics computer code. PISCES, authored, maintained and distributed by Physics International Corp., is a well established and validated code, which has been in wide use within the aerospace community for many years. The process of development, comparison and validation of the three models underwent extensive peer review at all stages. The analytical models used in the analysis have been reviewed extensively. For instance, the Fairchild hydrocode analysis has been published (Eck and Mukunda 1989; Eck and Mukunda 1990), and the analysis of SRB fragments which was subjected to intensive review by an expert, independent, outside panel (see Moore 1989).

Fourth, finally, the models were subjected to extensive peer review. In the case of the SRB model development, organizations which participated included the ESMC, RDA, Fairchild Space Corp., DOE Headquarters, LANL, Research Triangle Institute, several NASA centers, NASA headquarters, and the Air Force Aeronautics Laboratory. When the models are finally used, they have been scrutinized by some of the country's most knowledgeable experts.

Response to Comment No. 2-8

See Response to Comment 2-7.

Response to Comment No. 2-9

The "human factor" is an integral consideration in the development of the Shuttle failure probabilities, i.e., the initiating accident probabilities, supplied to DOE for the development of the Final Safety Analysis Report. Thus the "human factor" is an integral consideration in the FSAR analyses which in essence begins once the initiating accident (which accounts for the "human factor") has been postulated to occur.

Model validation is addressed in the Response to Comment 2-7.

Response to Comment No. 2-10

The correct total probability of a Phase 1 launch accident fuel release is $7.37 \times 10^{-6}$, based on the updated Ulysses safety analysis.

land contamination from Galileo [141 sq. km.] to Ulysses [12.3 sq. km.]?) If the Galileo estimate was "off" by three orders of magnitude, could the Ulysses estimate be off by the same factor? 2-11

Is it NASA's position that more than five million launches of a Ulysses-type payload aboard the Space Shuttle would have to take place before a launch accident occurred that could lead to a release of plutonium fuel? What level of confidence is associated with this estimate? 2-12

Does NASA now believe that flyby reentry of the Galileo spacecraft is more probable (expectation case: $5 \times 10^{-7}$) than a Ulysses launch accident leading to fuel release? 2-13

6. Increased Release Probability Compared to Galileo from SRB Fragment Impact

Judging by the Safety Status Report for the Ulysses Mission, (Accident Analysis, Book 1, p. 3-41), the probability of fuel release due to impact from Solid Rocket Booster (SRB) fragments is greater for Ulysses than for Galileo because of the way it is located in the Shuttle cargo bay: 2-14

> Because the Ulysses RTG is oriented with its longitudinal axis parallel to the Z-axis of the Shuttle, it presents a larger target for the SRB fragments due to the larger angle subtended. In effect, the Ulysses RTG presents a rectangular projected cross-section to the RTG [should read: SRB] fragments; the cross-section presented by the Galileo RTGs is the much smaller circular area. Also, the Ulysses orientation now presents the possibility for fragment impacts against the end of the RTG, whereas for Galileo, the end of the RTG could not be hit. In addition, the Ulysses RTG can be impacted by fragments from both SRBs in a Range destruct accident, whereas the Galileo RTGs could be hit only by fragments from the SRB nearest their location; the opposite SRB was shielded from the RTGs by the spacecraft and IUS. (emphasis added). 2-15

For all of these reasons, it is particularly difficult to understand why the probability of launch accident fuel release for Ulysses is given as a thousand times lower than



RESPONSES TO COMMENTS
Commentor No. 2: Federation of American Scientists
(Continued)

Response to Comment No. 2-11

The text on Phase 1 consequences has been expanded to address fully the following points. First, the safety analysis of space nuclear power systems is an ongoing activity within the DOE. Testing and analysis for the Galileo mission continued even after the formal documentation (FSAR, EIS) were prepared. The results of that further analysis were published in the Galileo FSAR Supplement (DOE 1989b). Those results provide the baseline starting point for the Ulysses safety analysis. In summary, the Galileo FSAR Supplement indicated that the earlier Galileo FSAR was quite conservative. The Supplement showed that the number of accident scenarios which could lead to a release was much lower than in the Galileo FSAR, and concluded that, for all practical purposes, only edge-on fragment impacts could lead to in-air source terms. The "hit" probability is directly related only to air releases.

The Phase 1 expectation includes both air and ground releases and it is in fact the ground releases which dominate the release probability for the expectation case. The ground releases are due to secondary impacts. That is to say, as a result of a fragment impact, a module, graphite impact shell (GIS), or a fueled clad is released. That object then hits a hard surface (steel launch tower or concrete launch pad) giving rise to a release. The ground release probability depends upon the characteristics of the sequential impact and not directly on the hit probability of the initial fragment impact.

The ground release probability in the Galileo FSAR Supplement was reduced by more than a factor of 100 over the Galileo FSAR due to incorporation of test results which were not available for the FSAR: the sequential impact series and the LFT series. The results from the sequential impact test series showed the ground release threshold for multiple impacted clads could be increased. The Sequential Impact Tests indicated no releases up to base clad distortions of 44 percent, whereas the Galileo FSAR used 15 percent distortion as a release threshold. In view of these sequential impact tests, the Ulysses FSAR used a threshold of 35 percent for previously impacted clads and sampled randomly between 20 and 30 percent for not previously distorted clads. The LFT series allowed increased case and graphitics removal thresholds. (See also FSAR Vol.II, Bk.1, Sec. 3.0., DOE 1990f). The net result of the incorporation of the test data has been to reduce the amount of plutonium release from a given fragment impact situation.

Response to Comment No. 2-12

NASA means only to state that the probability of a fuel release and attendant possible consequences for this mission are as stated in this EIS. Each Shuttle launch is a statistically independent event.

Response to Comment No. 2-13

No. The probability of fuel release on the Ulysses mission is higher than the flyby reentry of the Galileo spacecraft. In Phase I, the total probability of fuel release is $7.37 \times 10^{-6}$.

Response to Comment No. 2-14

See Response to Comment 2-11.

Response to Comment No. 2-15

See Response to Comment 2-11.

for Galileo. It would seem that the probability ought to be higher, even if the quantity of fuel released might be lower (since there is one rather than two RTGs). 2-15

DOE officials have told me that the Safety Status Report is incorrect here and that the Ulysses RTG overall presents a smaller cross-section to SRB fragments than the Galileo RTGs. In either case, the fact that such modeling errors can occur underscores the need for model validation and independent review. 2-16

7. "Microfracturing" May Lead to Particle Size Reduction

Fuel particle size is a critical determinant of the magnitude of accident consequences, since smaller particles are more readily inhaled and retained, more easily resuspended, more highly soluble, more likely to be widely dispersed, and more difficult to recover. DEIS page C-10 indicates that the accident consequence estimates assume that particle size distributions are unchanged following the accident except for the effects of vaporization in fireballs (Assumption 2). 2-17

However, because of their high level of radioactivity, $^{238}PuO_2$ particles undergo a process of microfragmentation or microfracturing that, over time, can yield smaller particles sizes, as noted by the Galileo INSRP panel.

Therefore, this assumption may be non-conservative.

8. Consider Solar Power Option for CRAF

DEIS page 2-26 states that the earliest possible application of the Advanced Photovoltaic Solar Array (APSA) would be March 1996. The Comet Rendezvous/ Asteroid Flyby (CRAF) mission is tentatively scheduled for 1995. 2-18

APSA development should be accelerated, or the CRAF launch delayed, to allow consideration of non-isotopic power sources such as APSA for this mission.

Aside from important environmental considerations, this may also be a practical imperative, since the Department of Energy (DOE) has told Congress that "the current plutonium-238 inventory will be exhausted by about FY 1994." (DOE FY 1991 Congressional Budget Request, Volume 2, p. 140) 2-19





Response to Comment 2-16

See Response to Comment 2-7 regarding model validation.

Response to Comment No. 2-17

There is no evidence from all of the safety testing performed by DOE that the level of radioactivity of plutonium dioxide causes microfragmentation or microfracturing. (It should be noted that by usual radiation standards plutonium dioxide is not considered to have a high level of radioactivity. Moderate would be more accurate.) Testing conducted in the GPHS safety test series shows that fuel pellets that have been "aged" for as long as six years show the same or slightly lower levels of fine particle material than pellets that have only one or two years of age. There is some indication that a resintering could actually be taking place which would tend to reduce the number of respirable particles. In the event of resintering, the FSAR analysis would be conservative.

Response to Comment No. 2-18

The issues of the CRAF mission are beyond the scope of this EIS.

Response to Comment No. 2-19

The issue of the plutonium inventory is not within the scope of this EIS.

(Even if Pu-238 production is resumed, there is ample reason to question the ability of DOE to produce such nuclear materials in a safe manner. The selection of isotope power supplies for NASA missions therefore involves a "hidden" environmental penalty even prior to launch.) 2-19

9. TECS Development Has Been Terminated

The Department of Energy has recently terminated further development of the radioisotope-fueled Turbine Energy Conversion System (TECS). This system is therefore unlikely to be available as a power supply for future missions, as suggested on DEIS pages 2-7 and 2-8. 2-20

10. Titan IV Availability

As a factual matter, it is unclear why no Titan IV rockets would be available for Ulysses prior to 1995 (DEIS, p. 2-18). As far as I know, Titan IV production has exceeded actual and projected utilization by the Department of Defense. 2-21





Response to Comment No. 2-20

The issue of TECS for future missions is not germane to this EIS.

Response to Comment No. 2-21

The availability of a Titan IV for the Ulysses mission is dependent on two items: (1) the commitment of a Titan IV to NASA for use in a mission and (2) the modification of the assigned Titan IV and spacecraft as required for launch. The Titan IV is a military launch vehicle that is not commercially available; NASA may obtain the Titan IV vehicle only through the U.S. Air Force. The Air Force informed NASA in 1988 that a Titan IV would not be available for the planetary back-up launch in 1991 (see Galileo FEIS), and so NASA stopped preparations for use of a Titan IV and stopped consideration of a Titan IV alternative (see Galileo FEIS, NASA 1989a). Even if a Titan IV were made available to NASA at this time, it would not be a feasible alternative as approximately three years are required to make mission-specific modifications.

Dr. Dudley G. McConnell
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Solar System Exploration Division (Code EL)
NASA Headquarters
Washington, D.C.

Having reviewed the Draft Environmental Impact Statement for the Ulysses Mission (Tier 2), and as a private citizen, offer the following comments.

1. Reference Section 2.2.4.3, pg 2-12: The validity of sweeping statements regarding plutonium releases is questionable. The comments regarding releases (e.g. reentry) are subjective interpretations of limited data. Other equally valid scientific evaluations have reached dissimilar conclusions. The DEIS should recognize the limitation of the available data and recognize the potential spectrum of possible release scenarios, particularly for those situations where the data is limited and scientific/engineering judgement must be applied. 3-1

2. Reference Section 4: The potential radiological consequences of accidents involving the RTGs is based solely on the EMERGE computer program which is a proprietary code that has never been peer reviewed nor validated. Simple comparison against another computer code is by no stretch of the imagination considered validation. Therefore, all the radiological consequences expressed in the DEIS could be considered suspect. 3-2

3. Reference Section 2.5.1.2, pg 2-24: The data does not exist to support contentions regarding release due to reentry, this is subjective opinion. Also, given the minimal population exposure, it is implied that exact knowledge exists regarding impact points of clads during reentry which is a ridiculous assumption at best. 3-3

4. Reference Section 4.1.4.3, pg 4-7: The application of ICRP 30 weighting factors to internally deposited high LET radiation to obtain a risk factor equivalence to whole body irradiation from low LET radiation (the effective dose equivalent or committed effective dose equivalent) is questionable. Applying BEIR IV organ risk factors for high LET radiation (albeit they were not developed for plutonium) would appear to be a more logical approach. 3-4

Also, total risk appears to be based on an average source term release while ignoring the potential for larger releases, which although may have a lower probability of occurrence have larger environmental/health impacts. 3-5

5. Reference Section 4.1.4.3, pg 4-11: The DEIS implies that 25 mrem/yr is an acceptable level for mitigation activities. NCRP Report 91 indicates that whenever a potential exists for an individual member of the public to exceed 25% of the annual effective dose equivalent limit attributable to any single source, then there should be assurances that the annual exposure of a maximally exposed individual from all sources should not exceed 100 mrem on a continuous basis. The DEIS fails to address this issue. 3-6

Secondly, the EPA 0.2 uci/$m^2$ is a screening level but does not imply that additional monitoring would not be required below this level to ensure that exposures are maintained below the recommended doses of 1 mrad and 3 mrad per 3-7



RESPONSES TO COMMENTS
Commentor No. 3: Lance Bollinger

Response to Comment No. 3-1

Text of Section 2.2.4.3 has been modified. That section is meant to be a brief summary of the extensive test data which is more completely summarized in Ulysses FSAR Vol. II, Book 2, Appendix G. The integrated risk assessment takes account of uncertainties, as well as ranges of views in the scientific community.

See Response to Comment 2-5.

Response to Comment No. 3-2

Reliability of the EMERGE model is based on far more than comparison with other computer codes.

See Response to Comments 2-6.

Response to Comment No. 3-3

Section 2.5.1.2 states that an IUS failure in Phase 4 leads to spacecraft breakup, reentry of the RTG modules, and surface impact of the modules, including a probability of impact on hard rock.

Reentry trajectory heating and ablation calculations, supported by arc jet test of ablation, have shown that the modules will survive reentry over the full range of possible reentry speed and path angles. The probability of impact of a module on rock is based on the calculated dispersion of the modules in flight (i.e., the size of the surface footprint of the 18 modules) and the proportion of rocky surface relative to soil and ocean. The population dose is calculated from the population density distribution and the size of the areas affected by module release. The results are subjective only to the extent that engineering judgement is involved. Specific knowledge of impact is not implied, only average (expectation) on a probability basis.

Data do exist to support the statement that tests have demonstrated that the RTGs will survive orbital decay reentry heating conditions with no release of plutonium. Ablation tests have been conducted on the GPHS aeroshells (DOE 1989a) in which the GPHS module was subjected to heating equivalent to five (5) times that predicted for orbital decay before the aeroshell was completely ablated on the leading face. The graphite impact shells (GISs) were still retained within the aeroshell body after the leading face was totally ablated in the test.

There is no implication that exact knowledge exists regarding impact points of the clads following reentry. The document on which this section of the EIS is based (i.e., Vol. III, Book 1, DOE 1990g) indicated on p. 2-4 the following statement: "In the case of African impacts or worldwide reentry impacts on

hard surfaces that might result in RTG fuel releases, average population densities for the affected areas have been used in calculating radiation doses..." Thus, the implication is that the impact point could be anywhere within the applicable region, and the average population is chosen for that purpose, which is the usual approach in a probabilistic risk analysis. This was also the case for the Safety Status Report on which the DEIS was based.

Response to Comment No. 3-4

Although ICRP-30 dose factors were used with low LET radiation weighting factors to arrive at committed effective dose equivalents, adjustment factors were developed based on BEIR-IV to estimate health effects from high-LET radiations. These calculations are described in the FSAR, Vol. III, Appendix B (DOE 1990g).

Response to Comment No. 3-5

See Response to Comment No. 2-4.

Response to Comment No. 3-6

Section 4.1.4.3 of the FEIS states that "the level of 25 mrem/yr is indicative of an intermediate level and reflects DOE experience in its Formerly Utilized Site Remedial Action Plan (FUSRAP) activities. No areas exceeded 100 mrem/yr; however, some limited areas would exceed the U.S. Environmental Protection Agency (EPA) screening level indicating that some monitoring would be required to determine the actual concentrations...." The NCRP-91 guidance refers to doses (100 mrem/yr and 25 mrem/yr) to members of the general public in off site areas which are uncontrolled, and where members of the public have the potential for "continuous" exposure. In addition, the intent of NCRP-91 is to provide guidance for radiation dose limits to workers and the general public from the normal operation of nuclear facilities, not contamination from serious accidents. An acceptable level of public exposure in off site areas contaminated as the result of a highly unlikely accident can only be set a posteriori when information about actual conditions are available. It was not the intent of the DEIS to imply that 25 mrem/yr is an accepted value for mitigation, only that for purposes of the NEPA assessment, 25 mrem/yr is a reasonable value against which hypothetical accident consequences can be compared. The rationale for use of this "benchmark" value is explained further in Section 4.2.

With regard to the concern for long-term monitoring of areas contaminated in excess of the EPA screening criteria, it is expected that in the event of a serious accident, long-term monitoring would be required in those on site and

year to the lung and bone. The DEIS is misleading. } 3-7

6. Reference Section 4.2.3, pg 4-15: The arbitrary use of 25 mrem/yr minimizes the economic impact of potential accidents. Assuming mitigation activities to reach the EPA screening level, then the economic impact will be orders of magnitude different Also, the EPA cost estimations are well below those estimated by the DOE. } 3-8

7. Reference Section 4.2.3, pg 4-18: Inference that Federal agencies have adopted 25 mrem/yr from subsurface disposal facilities as a "reasonable level" for deriving acceptable surface contamination limits is inappropriate. The 25 mrem/yr specified by the NRC in 10 CFR 61.40 clearly indicates that the 25 mrem/yr is the maximum exposure to any member of the public from subsurface disposal facilities, but that reasonable efforts should be maintained to reduce radioactivity in effluents to the general environment to a level as low as reasonably achievable. The DEIS is misleading in that the 25 mrem/yr is the maximum, not a minimum, and is not considered ALARA. } 3-9

8. Reference Section 4.3.2.3, pg 4-26: The DEIS is apparently attempting to equate the 0.2 uci/$m^2$ to 25 mrem/yr which is incorrect and misleading. } 3-10

9. Reference Section 4.3.2.4, pg 4-29: Arbitrary and unilateral use of 25 mrem/yr as an acceptable level to define radiological consequence of an accident is inappropriate. } 3-11

10. Reference Appendix C, pg C-10: The DEIS attempts to equate the concept of "de minimis" with the concept of "below regulatory concern" when in fact the two are separate concepts. The "de minimis" concept is more like the NCRP concept of negligible individual risk level (NIRL) detailed in NCRP Report 91. The DEIS needs additional clarification on this issue. } 3-12

The overall thrust of the DEIS appears to be minimization of the potential hazards from an accident during the Ulysses mission without a realistic definition of spectrum of possible consequences. While this in no way implies that radiological sources can not be safely and effectively used in space applications (as Galileo and others have proven), it does appear to provide a good basis for the environmentalists to continue to challenge such uses. Failure on the part of NASA to provide an adequate, realistic assessment can only lead to future complications.

Lance J. Bollinger
Health Physicist

off site areas where annual exposures might present an unacceptable risk to workers or members of the public. Actual monitoring will be determined only after an accident has occurred and may call for long-term continuous monitoring.

Response to Comment No. 3-7

See Response to Comment 3-6.

Response to Comment No. 3-8

As noted in the response to Comment No. 3-6, the use of 25 mrem/yr is not arbitrary, it is based on other Federal experience. Nor is it the intent of the EIS to imply that value is an acceptable level for accident mitigation purposes. Rather, in the absence of specific guidance for mitigation of public impacts following severe accidents, it is a reasonable value against which the potential impacts of hypothetical accidents can be compared.

We are not sure of the significance of the following statement: "the EPA cost estimations" being "well below those estimated by the DOE." We agree that estimates of economic impacts of mitigation are highly uncertain, especially in the absence of National consensus standards.

See Response to Comment No. 3-6 on 25 mrem/yr; the costs are based on best estimate given the areas affected and would change based on type of land affected, and the degree of contamination.

Response to Comment No. 3-9

The use of 25 mrem/yr as a "reasonable value" is discussed in responses 3-6 and 3-8. However, as noted above, use of 25 mrem/yr has been used for planned exposures as the result of normal operations, not accident situations. In accident situations a balancing of costs and benefits of various levels of mitigation will be necessary in order to reach a decision about the appropriate level of mitigation. The ALARA determination will flow from that decision.

Response to Comment No. 3-10

The EIS does not equate 0.2 $\mu Ci/m^2$ with 25 mrem/yr. Rather, the discussion indicates mitigation measures available for areas exceeding either value.

Response to Comment No. 3-11

See Response to Comments 3-6 through 3-9.

Response to Comment No. 3-12

As indicated in Appendix C, this EIS does not use the de minimis concept.

FLORIDA COALITION
FOR PEACE AND JUSTICE

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April 2, 1990

Dudley McConnell
NASA
Code EL
Washington DC 20546

Dear Mr. McConnell:

This letter is written to raise questions and issues about the Ulysses Draft Environmental Impact Statement that is now up for public comment.

As you know, our organization has for the past two years, been deeply concerned about the use of nuclear materials for power on-board space satellites. Our comments are directed toward that concern.

In the EIS you refer to "potential adverse health and environmental effects" of plutonium. But nowhere do you really spell out what plutonium really is, where it comes from, its long term harm or the like. We believe that the EIS should be much more specific along these lines.

In the EIS you state that "DOE conducts a detailed program of safety, verification, testing..." of the RTG's. First, we question the integrity of DOE. It is clear that DOE has a terrible public record when it comes to covering up issues related to nuclear -- it is clear that the nuclear industry dominates the DOE and we don't see how they could be considered capable of critical analysis of such a sensitive issue.

The so-called "shielding" of the RTG is not something that we have confidence in. In the December 15, 1988 General Electric (who also have a vested interest in seeing nuclear power in space) report it is stated that under certain conditions the RTG's can be destroyed. During the public debate over Galileo the NASA public relations team over and over gave the impression to the public that the RTG's were indestructable and ridiculed our claims that the RTG's were not as solid as they were made to appear. The EIS reveals no such evidence that the RTG's are of questionable capability.

During the debate over Galileo NASA stated that there was a 1 in 10,000 chance of a plutonium release. Now for Ulysses NASA claims that the chance is 1 in 6 million. Once again we believe that NASA is playing fast and loose with the numbers, creating them as

4-1

4-2

E-17

RESPONSES TO COMMENTS
Commentor No. 4: Florida Coalition for Peace and Justice

Response to Comment No. 4-1

Plutonium is a radioactive element produced in nuclear reactors. While little naturally occurring plutonium remains on the Earth, many tons of plutonium were produced naturally in the Earth from "natural reactors" long before man evolved. Contrary to popular belief, plutonium is not the most dangerous substance known to man, but ranks behind other potentially hazardous materials, such as natural animal toxins which can result in immediate fatality. While the FEIS assumes the linear, non-threshold hypothesis to be correct, it should be emphasized that there are no statistically meaningful data that indicate that the risks from inhalation of the small amounts of plutonium, which might result from any of the accidents shown in Table 4-2, are greater than zero. The half-lives and characteristics of the plutonium isotopes used in the Radioisotope Thermoelectric Generator (RTG) fuel are presented in Table 2-2.

Response to Comment No. 4-2

Under certain conditions, fuel can be released from the RTGs. Neither the Galileo EIS nor the Ulysses EIS has stated otherwise. Rather, the EIS and the safety reports on which it is based describe the very low chances that fuel will be released and that public health will be affected as a consequence if the decision is made to proceed with Ulysses. The low chances of a release are, in turn, the consequence of a 25-year program aimed at making the RTG as impervious to launch accident environments as practical.

The reduction in the risk estimates are the result of data from tests conducted as part of the test and analysis for the Galileo Mission, documented in the "Supplement to the Final Safety Analysis Report for the Galileo Mission (DOE 1989b) and were incorporated into the methodology used to develop the Ulysses FSAR (DOE 1990d, DOE 1990e, DOE 1990f, DOE 1990g) analyses.

Also see Response to Comment No. 2-11.

you go along hoping to keep public concern at a minimum. We believe that the risk of a plutonium release is far greater than you project and seriously question your risk assesment methodology.

Prior to the launch of Galileo I got a call from a NASA employee in Washington DC that told me she had spoken to a man who you approached on the train ride home. I was told that you, Mr. McConnell asked the man from NASA how one comes up with the risk assesment numbers. I was told that you stated that you had to come up with the numbers for Galileo and needed help. While wewould have a difficult time proving that such a conversation ever took place, we absolutely believe that NASA is capable of such tactics to create the illusion that everything is ok. Trust us!

What would happen to the RTG if Ulysses reentered earth orbit and burned up upon reentry like the recent DOD spy satellite did? Would the RTG's contain the plutonium? What if they were weakened and hit a hard surface? 4-3

When looking at the issue of acid rain caused by the shuttle launch of Ulysses the EIS states that "Damage would be confined...". What kind of damage would result? Spell it out please. The EIS states that no long term consequences are expected. What independent studies have been done over the past ten years to reflect that thinking? 4-4

In the Federal Register (11-21-89) NASA states that Ulysses "will never be closer to the Sun than is the Earth". In a letter to Senator Harry Reid (7-11-89) NASA states that "Ulysses will be using RTG's because it will be operating too close to the Sun for solar panels to function properly". It is confusing to us why these two statements seem to contradict each other. Is the real reason that NASA is not considering solar for Ulysses because the nuclear industry is pushing the use of nuclear power in space? 4-5 4-6

The JPL study entitled "The Systems Impact of a Concentrated Solar Array on a Jupiter Orbiter" was not addressed in the EIS to the best of my knowledge as I reviewed the discussion on alternatives. This JPL study states that "Based on the current study, it appears that a Galileo Jupiter orbiting mission could be performed with a concentrated phtovolaic solar array power source without changing the mission sequence or impacting science objectives." While it is true that we did not get our hands on this study until after the Galileo launch, would it not hold that solar would work on the Ulysses -- especially since it isn't going closer to the Sun than the Earth is? 4-7

It is our hope that NASA will hold the Ulysses and not launch until the necessary steps have been taken to ensure the safety of the public and and the environment by using a solar power source on the mission. On page 2-26 in the EIS you have outlined other launch dates that Ulysses could use. In the meantime NASA could take the three years that the JPL suggests to develop the solar source. 4-8





Response to Comment No. 4-3

The DOD satellite referred to reentered the Earth's atmosphere under orbital decay conditions, typically at a velocity around 25,000 feet/second and at a relatively shallow angle. Under these conditions, the RTG converter is predicted to burn off and release the general purpose heat source (GPHS) modules at an altitude of 240,000 to 290,000 ft, a velocity of 24,000-25,400 feet/second, and an angle of 0.5 - 1.2 degrees from the local horizonal. The remaining reentry of the GPHS modules is predicted to result in 16-21 mils of ablation in a tumbling mode or 40-41 mils of ablation in a stabilized mode, the latter corresponding to about 22 percent of the total thickness. Ablation tests have been conducted on the GPHS aeroshells (reported in DOE 1989b) in which the aeroshell was subjected to heating equivalent to five (5) times that predicted for orbital decay before the aeroshell was completely ablated on the leading (stable) face. The graphite impact shells (GISs) were still retained within the aeroshell body after the leading face was totally ablated in the test. This test confirms the prediction by analysis and demonstrates that the module would not fail or release fuel during reentry. As indicated in the text of this EIS, plutonium dioxide is likely to be released if the module or impact shell were to hit rock or steel. Given an orbital re-entry and land impact, the conditional probability of impacting rock with fuel released from one or more fueled clads is 0.129.

Response to Comment No. 4-4

This EIS addresses impacts of the Ulysses mission. Acid rain impacts are attendant to every Shuttle launch, and as noted in Section 2.5.1.1 and Section 4.1.2, the discussions of these impacts have been summarized from, and referenced to the previous NEPA documents. The discussion in the Galileo Tier 2 EIS also contained updated information and citations. With reference to Section 4.1.2, pages 4-3 and 4-4 of the Galileo Tier 2 EIS, the types of impacts described included significant changes in vegetative community structure over time in the near-field environment (within about 900 feet of the launch pad) associated with successive launches. Total vegetative cover becomes reduced over time, and the unvegetated areas expand in size. Impacts of Shuttle launches have been studied and documented since STS-1. The near field impacts are judged to be short term because there was recovery during the cessation of Shuttle flights following the STS 51-6.

Response to Comment No. 4-5

The two statements contradict each other because the earlier statement to Senator Reid was in error. The phrase "operating too close to the Sun" should have read "operating too far from the Sun." When the error was found, NASA promptly informed Senator Reid of the mistake. Ulysses will operate too far from the Sun to use solar energy when it flies by Jupiter and uses the giant planet's gravitational field to sling it out of the ecliptic into a polar orbit

about the Sun -- an orbit that, at the point of closest approach, will only bring the spacecraft to within 1.3 Astronomical Units (AU) of the Sun, just inside the orbital distance of Mars.

Response to Comment 4-6

NASA is not considering solar for Ulysses because there is no launch system capable of conducting a solar powered Ulysses mission using available solar power technology.

The notion that NASA decisions on spacecraft power are somehow being manipulated or in any way influenced by the nuclear industry is entirely unfounded. NASA does not make decisions to use nuclear power lightly. RTG utilization involves complicated safety reviews and unique handling procedures that may not be required for other power sources.

Response to Comment 4-7

Solar power is not a feasible alternative for the Ulysses mission. Even though Ulysses is not going closer to the Sun than the Earth is, there is no combination of launch vehicles that can propel Ulysses directly from Earth, out of the ecliptic plane, to the polar latitudes of the Sun. Thus, Ulysses will conduct a gravity-assist flyby of Jupiter in order to swing out of the ecliptic plane back towards the Sun. Jupiter is 5.2 AU from Earth. There is no available launch system capable of conducting the mission with mission ready solar power technology.

The article to which the comment refers is a conceptual design that was performed at JPL in the early 80's. It documents a study by JPL to understand the applicability of a concentrator design to planetary missions. Beyond any conceptual study stage, several developmental steps are still necessary before a technology becomes ready for assignment to a mission. The concentrator solar array is still years away from being flight qualified. In the very same paragraph to which the commentor refers, the author states: "As for Galileo, the severe environmental constraints and the embryonic state of CSA development indicates that CSA will not displace the RTG on the Galileo mission. Galileo was selected as a trial case for a hypothetical CSA mission because its mission objectives are well defined and because a large amount of detailed planning already exists for the RTG spacecraft."

Response to Comment No. 4-8

NASA's consideration of alternative power systems indicates that there are no feasible solar alternatives available for the Ulysses mission in 1990 or 1991. To await solar alternatives would entail an indefinite delay of the mission. The safety analysis indicates that the currently planned mission entails very small risks, and all necessary steps will be taken to ensure the safety of the mission.

I can already anticipate your response to this solar issue. It doesn't exist you will say. Congress has not appropriated the funds to develop the Ulysses solar power source you will say. Our question is when did NASA ask for funding for the solar source for Galileo or Ulysses? When did you ask Congress for funding for Craf and Cassini? And if you have not yet ask Congress for funding for solar development then why not? 4-9

I can assure you that groups and individuals from all over the world are still contacting our organization because of what came to light before and after the Galileo launch. People all over the world are very surprised to learn that our space program is pushing the use of nuclear power in space. People understand that enormous profit lies ahead for the nuclear power industry if NASA can successfully convince the public that solar won't work and nuclear is our only choice.

We pledge to you that we shall continue to educate the public about NASA's plans to pave the gold road to space for the nuclear industry. We pledge that we shall do everything in our power to stop this dangerous and costly attempt to develop a market for the DOE and the nuclear industry.

We will be eager to hear your response to our concerns. Be sure that I shall share them with our members and the public at large.

In peace,

Bruce K. Gagnon
State Coordinator



RESPONSES TO COMMENTS
Commentor No. 4: Florida Coalition for Peace and Justice
(Continued)

Response to Comment No. 4-9

The earliest out-of-the-ecliptic missions considered using either Solar Electric Propulsion (SEP) or a refurbished Pioneer 10/11 spacecraft which was RTG powered. The SEP mission was discarded as not feasible and the refurbished Pioneer 10/11 spacecraft was used for the initial study. Subsequently, the Pioneer 10/11 spacecraft was discarded in favor of a new RTG powered spacecraft. A solar powered spacecraft was not considered feasible because of size and weight problems with the launch vehicle. Because of this, NASA did not ask for funding for a solar powered Ulysses mission.

Project funding for Galileo began in FY 1978. Project funding for Ulysses began in FY 1978.

CRAF/Cassini is not germane to this EIS. NASA has a long-standing and continuing program of solar power system development as demonstrated by the use of solar power on all spacecraft missions launched during the 1980's with the sole exception of Galileo.

April 2, 1990

Dr. Dudley G. McConnell
Deputy Director, (Advanced Programs)
Solar System Exploration Division (Code EL)
NASA Headquarters
Washington, D. C. 20546

Dear Dr. McConnell:

We have reviewed the Draft Environmental Impact Statement for the Ulysses Missison (Tier 2) and offer the following comments:

2.1. ALTERNATIVES CONSIDERED. Add a third alternative to your two "launch...in October 1990 or in the backup opportunity in November 1991" and "Cancellation of any further commitment of resources to the mission": . Return the Ulysses spacecraft to European Space Agency, ESA for open, world-wide bidding for a launch contractor who will use non-nuclear power sources and the earliest possible launch date. 5-1

2.2.4.1. (Last sentence on page) "NASA and other agencies of the Federal government support a wide range of research and technology development programs in spacecraft power systems." It would be very helpful to have listed exactly how much money "NASA and other agencies" have actually requested/received for non-nuclear R&D power sources for each year since the development of the RTGs. 5-2

2.2.4.2. What nuclear radioisotopes are planned for use on your new power sources AMTEC and TEC and are either of them reactors? 5-3

2.2.4.3. Radioisotope Thermoelectric Generator (RTG)
. The RTGs "protective material" should be clearly explained, including the thickness of each layer. (ie. iridium shell 0.022 inch min., two graphite shells less than ¼ inch each, aluminum outer shell 1/16 inch) 5-4
. The "vent ends" of the RTGs should be more thoroughly tested because according to some of the pictures in the "Final Safety Analysis Report for the Galileo Mission Vol II book 2", prepared and tested by General Electric (the same contractor who built the RTGs) most of the fueled clads that obviously did crack open seem to originate at the "vent end" (fig. G 14, G 17, etc.) RTG tests should be publicly conducted with oversight and evaluation by independent experts. 5-5 5-6
. Accident Scenarios (Appendix B) should clearly include "tip-over" and "push-over" (G.E. Report 1984 p. 2-18 Table 2-2 showing psi pressures as high as 19,600 and at least 10 other examples over the 2,210 psi at which the fueled clads are breached and 1,070 psi at which the bare clads are breached) 5-7
. How many Radioisotope Heater Units (LWRHU) are used on Ulysses and where in the DEIS are they mentioned? 5-8

(More)



RESPONSES TO COMMENTS
Commentor No. 5: Mr. and Mrs. Paul Puchstein

Response to Comment No. 5-1

This alternative is already encompassed in the "no action" alternative from the standpoint of a commitment of U.S. resources.

Response to Comment No. 5-2

While the amount of money received for R&D of non-nuclear power sources is not germane to the discussion of whether to complete the preparation and operate the mission, it should be noted that NASA and DOE are the major sponsors of research on non-nuclear energy sources for space applications. NASA funding for the five year period FY 1985 to FY 1989 has totaled in excess of $14 million.

Response to Comment No. 5-3

Both of these power sources will utilize the same GPHS power source, containing the same isotope (Plutonium 238), currently utilized in the Ulysses RTG. Neither is a reactor.

Response to Comment No. 5-4

The dimensions of all components of the RTG and GPHS are given in Volume I, the Reference Design Document, of the Ulysses FSAR, (DOE 1990e). The iridium clad is 0.022 inch thick minimum. The plutonia fuel pellet is 1.085 inches long and 1.084 inches in diameter. The graphite impact shells have a minimum thickness of 0.167 inch. The graphite aeroshell has a minimum thickness of 0.185 inch. The RTG assembly is made of aluminum which is designed to melt away quickly to release individual heat source aeroshell modules. This eliminates the chance of an intact RTG reentering as a unit, and striking a hard surface. The insulation system for the converter assembly of the RTG, not the GPHS heat source, consists of a multifoil assembly consisting of 61 layers of very thin (0.0003 inch) molybdenum foil interspersed with layers of astroquartz ($SiO_2$) cloth supported on a molybdenum frame. This multifoil system minimizes the loss of heat other than that conducted through the thermocouples that convert the heat to electrical power. The thermocouples penetrate the multifoil system. The total insulation thickness is around 0.70 inch.

A pair of GISs inside insulation packages is placed inside an aeroshell, which is also composed of graphite having a maximum thickness surrounding GISs of less than 0.18 inches. The outside dimensions of the aeroshell are 3.826 inches wide by 3.668 inches deep by 2.090 inches high. The top of the aeroshell is 0.095 inches thick. This aeroshell is the exterior of the GPHS module.

Thus, each GPHS module contains 4 fuel pellets inside iridium shells, surrounded by graphite cases, shock absorbers, and insulators. Each GPHS is independent of the others. The RTG contains 18 GPHSs stacked into a single column.

The exterior of the RTG is an aluminum outer shell and inner and outer pressure domes. This aluminum has a nominal thickness of 0.060 inches.

Detailed dimensioned drawings are found in the FSAR, Volume I (DOE 1990b).

Response to Comment No. 5-5

The commentors are likely referring to the picture of fueled clads that underwent the Bare Clad Impact test series, rather than to the RTG itself. It should be noted that the objective of this series of tests was to determine the failure threshold of the bare clad. Without failures such as those pictured in the Galileo Final Safety Analysis Report (Vol. II, Book 2, Appendix G, pages G-34 through G-38), a failure threshold cannot be determined.

Response to Comment No. 5-6

The results of the tests are published in the open literature by Los Alamos National Laboratory (LANL) staff, inter alia.

Response to Comment No. 5-7

Tip-over and push-over were scenarios documented in the then current Shuttle Data Book (SDB) NSTS 08116, Rev. B. The following tests (from SDB section 3.2.3.1) is quoted from this SDB which summarizes the analysis and justifies the credibility/noncredibility of various failure modes:

> Failure Mode Number 2 -- Pushover on Launch Pad due to ignition failure for both Solid Rocket Boosters (SRBs). This scenarios assumes the SSMEs ignite and the holddown bolts are released, but both SRBs fail to ignite. As a consequence, the thrust of the SSMEs pushes the vehicle over on the pad. Since the same redundant, computerized, electrical commands are used to release the holddown bolts and ignite the SRBs, this failure mode cannot occur without multiple component failures. If neither the holdown

bolts nor the SRBs are fired, the result is the same as for Flight Readiness Firing (FRF) or pad abort after SSME start. If the holddown bolts are fired, the commands to ignite the SRBs have been issued. Since the electrical/initiation components that ignite the SRBs are independent (and redundant down to the NASA Standard Initiators, or NSIs), no reasonable common cause for both SRBs failing to ignite can be postulated. The failure of a single SRB to ignite is discussed under failure mode Number 5.

Failure Mode Number 5 -- Tipover on Launch Pad due to loss of thrust on one SRB. In this scenario, the Shuttle attempts to lift off with the SSMEs and only one SRB thrusting. The other SRB has failed to ignite or does not provide adequate thrust for vehicle stability.

Current analysis indicates that the malfunctioned SRB will fall away and the remaining SRB-ET-Orbiter stack will fly an uncontrolled trajectory which has sufficient flight time to permit RSS destruct action prior to ground impact ....Exceptions to this scenario occur if there is either no ignitions or an immediate loss of thrust on the left SRB during the two-second interval after ignition. This case would result in a collision with the launch platform tower with a potential for structural failure of the ET and subsequent explosion of pooled liquid fuels. SRB detonation is not considered to be a threat (see representative Tower Impact scenario, paragraph 3.4.1.2 of the SDB).

In summary, the pushover scenario is not credible. The tipover scenario, or more correctly, an accident due to a SRB thrust failure, however, is a credible event. The accident scenario and associated environments depend on which SRB fails. For no ignition or an immediate loss of thrust on the left SRB during the first 2 seconds mission elapsed time (MET), the Tower Impact scenario is used. For loss of thrust of the right SRB, the RSS Destruct scenario is used. Both of these scenarios were addressed in the analysis.

Response to Comment No. 5-8

Radioisotope Heater Units are not used on the Ulysses mission.

2.2.4.4 RTG Performance History

. It should be plainly stated in this section and reference made to page 3-49, Table 3-7, that when the Navy's Transit-5BN-3 and its RTG burned up in 1964 according to "design criteria" that it released 17,000 curies of pu-238, tripling the total world environmental burden. 5-9

. It should be plainly stated that the two SNAP 19B2 RTGs that landed in the Santa Barbara Channel (DEIS states "Pacific Ocean") took five months to locate and nearly hit Santa Barbara and Catalina Island. 5-10

. A Table should be included which lists all Nuclear Payload Launches showing their status and for those still in orbit, when they are expected to fall back to earth, specially Les 8 and 9 launched in 1976 with 318,800 curies of Pu238 on board. It would also be helpful to know what is meant by "station shut down" status and the environmental Impact of Apollo 12, 14, 15, 16 and 17 still on the moon. Also a table listing Nuclear-powered spacecraft launched by the USSR and the environmental consequences of their accidents, specially the cost of clean-up for re-entry of Cosmos 954 into Northern Canada. 5-11, 5-12

2.5 COMPARISON OF ALTERNATIVES

. It should include the environmental impact clean-up costs and the cost of defending law suits to halt launch, compared with "the $150 million current investment." 5-13

3. AFFECTED ENVIRONMENT

"If an accident environment leads to a release of plutonium dioxide ($PuO_2$), that release is called a '<u>source term</u>.'" (p4.4) "Source term" and "<u>base case</u>" terminology is used throughout the DEIS as a basic assumption. Exactly what percentage of total 23.7 lbs of Pu238 or "worst" case is intended? (Galileo DEIS "<u>maximum case</u>" was 1/200 of a pound of its 50 pounds of Pu238) 5-14

. Risk Assessments should use an "actuarial" model (not Monte Carlo) and include the "human factor" which has been the actual cause of most "accidents" like Challenger, Chernobyl, Three Mile Island, etc. 5-15

. Potential environmental effects should include a clear, up to date statement on the known hazards of Pu238 from documents in open literature. 5-16

. When the DOE Final Safety Analysis Report (FSAR) for Ulysses is complete, please send us a copy.

Sincerely,

Paul Puchstein

Mr. and Mrs. Paul Puchstein
1733 Athens Court
Lakeland, Florida 33803

COPY: Rep. Andy Ireland
Senator John Glenn

RESPONSES TO COMMENTS
Commentor No. 5: Mr. and Mrs. Paul Puchstein
(Continued)

**<u>Response to Comment No. 5-9</u>**

**Comment noted; text modified, (see Section 2.2.4.4).**

**<u>Response to Comment No. 5-10</u>**

**Comment noted; text modified, (see Section 2.2.4.4). The two SNAP-19 RTGs fell into the Santa Barbara Channel following range destruct at 30 km altitude during an attempted launch of the Nimbus-B1 satellite. The two RTGs were retrieved intact 5 months after the launch failure.**

**<u>Response to comment No. 5-11</u>**

**Such a table has been added to Section 2.2.4.4 of the EIS.**

**<u>Response to Comment No. 5-12</u>**

**The Soviet Union has launched 30 reactors and 6 RTGs. None have been on interplanetary missions. Of these, 2 RTGs have reentered the atmosphere and three reactors have reentered including COSMOS 954. Canadian cleanup costs for the cleanup of the COSMOS 954 totaled $14 million (see Canadian AECB, 1980).**

**<u>Response to Comment No. 5-13</u>**

**The environmental impact cleanup costs in the event of an accident are estimated in Section 4.2.3 of the FEIS. The cost of defending lawsuits is not considered an environmental impact within the meaning of NEPA and is not germane to programmatic, technical or environmental and safety factors of the mission.**

Response to Comment No. 5-14

The integrated risk assessment which generated the distribution of consequences took account of the whole range of release and dispersion pathways. This EIS uses the 99th percentile consequence as indicative of the maximum credible case. The largest source terms for the Ulysses Mission are associated with the early ascent phase - Phase 1. The maximum air, ground, and ocean releases associated with a Phase 1 SRB case rupture accident, were estimated in the accident modeling conducted for the Final Safety Analysis Report for the Ulysses Mission, specifically Volume II, Book 1 (DOE 1990f). A review of Section 3.4.5.1 of the Ulysses FSAR indicates the following maximum source terms for Phase 1.

| | |
|---|---|
| Maximum Air Release: | 10,300 Ci |
| Probability of Release: | $4.25 \times 10^{-10}$ |
| Phase 1 Time Interval: | 106-120 sec. |
| | |
| Maximum Ocean Release: | 11,500 Ci |
| Probability of Release: | $4.25 \times 10^{-10}$ |
| Phase 1 Time Interval: | 106-120 sec. |

This represents a maximum release of 21,800 Ci or 16.5 percent of the total RTG inventory of 132,500 Ci. The updated probability of these releases would be $1.7 \times 10^{-9}$.

It should be noted that, because of atmospheric dispersion pathways, the maximum release scenario may not present maximum consequences.

Response to Comment No. 5-15

See Response to Comment 2-9.

Response to Comment No. 5-16

See Response to Comment 4-1 for the hazards of plutonium dioxide.

PSR
PHYSICIANS FOR SOCIAL RESPONSIBILITY
Affiliate of International Physicians for the Prevention of Nuclear War
Los Angeles Chapter • 1431 Ocean Avenue, Suite B • Santa Monica, CA 90401 • (213) 458-2694

April 4, 1990

Dr. Dudley McConnell
Deputy Director, (Advanced Program)
Solar System Exploration Division (CODE EL)
NASA Headquarters
Washington D.C. 20546

Dear Dr. McConnell:

The Los Angeles Chapter of Physicians For Social Responsibility joins in the comments of the Southern California Federation of Scientists and Committee To Bridge The Gap regarding the draft environmental impact statement for the Ulysses Mission. 6-1

Sincerely,

Richard Saxon, M.D.
President

PS:srf

Affiliations for identification purposes only

NATIONAL SPONSORS
Partial List
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RESPONSES TO COMMENTS
Commentor No. 6: Physicians for Social Responsibility

Response to Comment No. 6-1

Comment noted.

SOUTHERN CALIFORNIA FEDERATION OF SCIENTISTS
3318 Colbert Avenue
Suite 200
Los Angeles, California 90066
(213)390-3898

April 5, 1990

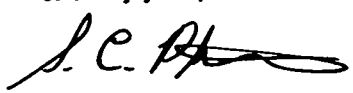


Dr. Dudley McConnell
Deputy Director (Advanced Program)
Solar System Exploration Division (Code EL)
NASA Headquarters
Washington, DC 20546

Dear Dr. McConnell;

The attached statement from the Southern California Federation of Scientists is submitted in response to solicited public comments on the Draft Environmental Impact Statement for the Ulysses Mission. If there are any comments or questions regarding our declaration, please contact us at the letterhead address or phone.

Cordially yours,



Sheldon C. Plotkin, Ph.D., P.E.

SCP:sp
Enclosure:

SOUTHERN CALIFORNIA FEDERATION OF SCIENTISTS

Comments on Draft Environmental Impact Statement for Ulysses Mission

We, the undersigned officers of the Southern California Federation of Scientists (SCFS), declare as follows:

1. The organization office is at 3318 Colbert Avenue, Suite 200, Los Angeles, CA 90066. Phone (213) 390-3898.

2. SCFS was organized in 1951 as a local chapter of the Federation of American Scientists, originally out of concern for the apocalyptic consequences of nuclear war. While the threat of nuclear war remains a primary concern of SCFS, the organization is also involved with various other aspects of science in the public interest.

SCFS is an interdisciplinary organization of scientists, engineers, technicians, scholars, and concerned citizens dedicated to providing independent scientific and technical analyses and expertise on issues affecting science, society, and public policy.

3. SCFS would like to make clear that we are aware of the importance of space exploration and are not opposed to the Ulysses project per se. Rather, the purpose of this declaration is to explain that there exists a serious, but avoidable, danger to human life and health if there should be an accident during the launch or flight of the Ulysses mission. We believe that alternative approaches should be found to carry out the scientific goals of the mission. 7-1

4. We have reviewed the Draft Environmental Impact Statement (DEIS) for the Ulysses mission, and are disturbed by several issues; particularly, the lack of serious consideration of alternative power sources and launch 7-2

RESPONSES TO COMMENTS
Commentor No. 7: Southern California Federation of Scientists
(Continued)

Response to Comment No. 7-1

Comment noted.

Response to Comment No. 7-2

See Responses to Comments 2-21 and 4-7.

configurations. We believe that by failing to consider these alternatives, NASA is subjecting the natural and human environments to unnecessarily high risks of exposure to dangerous radioactive material. 7-2

5. NASA has implied in the DEIS that the cost and delay involved in exploring alternative power and launch sources is of greater importance than the risks presented by not exploring the alternatives. We disagree. Not only will the alternatives be much safer, the research and development will be useful for future space missions. Since economic emphasis is currently shifting from military to civilian activities, now is the perfect time to expend the resources to research and develop these alternatives. It is regrettable that this resarch and development was not begun years ago, and we believe that the best remedy is to begin immediately. 7-3

6. Alternative Power Sources:

Solar Power: NASA stated in the DEIS that solar power is not a viable alternative. We disagree. More research and development should be done to make light weight solar concentrators available. As stated above, now seems to be the time to expend the resources to develop a reliable, deep-space solar power source, such as JPL's deployable mylar parabolic trough design.* Current solar array design could be used for the Ulysses mission provided the added weight were accommodated by use of a larger booster assembly. One interesting alternative not considered is the use of excess Soviet launch capability, particularly their heavy launchers. 7-4 7-5

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* While we believe that existing or advanced solar power supplies should be given primary consideration for all current and all currently proposed future space missions, there may someday be missions requiring operation at very great distances from the Sun for which solar technology might not be feasible. To the extent nuclear power is considered for these missions, however, RTG's should be avoided, as they cannot be launched cold.



## RESPONSES TO COMMENTS
## Commentor No. 7: Southern California Federation of Scientists (Continued)

**Response to Comment No. 7-3**

The analysis of alternatives indicated that there are no feasible alternatives available to conduct the proposed mission, and there is no certain date when alternative power sources would be available to accomplish this mission. Hence, the delay would be an indefinite delay.

**Response to Comment No. 7-4**

See Response to Comment 4-7.

**Response to Comment No. 7-5**

Soviet launch vehicles are not available for NASA use. The use of a Soviet launch vehicle, assuming one was available for a U.S. mission, is not an alternative appropriate to be addressed in this EIS because such use invokes issues of foreign relations, foreign policy, and national security, which are outside the scope of this EIS. Finally, even if such a vehicle were made available, it would not be a feasible alternative for the 1990 or 1991 launch opportunities.

7. Alternative Launch Configuration: We believe that a Titan launch is safer than use of the STS, and we are concerned that NASA has said that they will not consider the Titan alternative. Use of a Titan launcher will not endanger a flight crew and will mitigate the prospective damage to the RTG due to launcher failure. There are several reasons for the disposable booster being safer. The reduced complexity makes for enhanced reliability primarily because of the launch vehicle's being unmanned. Once people are placed on a spacecraft, the possible failure modes increase by orders of magnitude. In addition, there is the actual physical placement of the spacecraft relative to the main booster rockets of the launch vehicle. In the STS, Ulysses will be in the main storage bay next to the large booster rockets, while in the case of the Titan or disposable booster, the Ulysses will be placed on top of the rocket assembly, the largest rockets being located at the bottom. Catastrophic explosion forces for large rocket boosters are almost always radial. Thus, the STS configuration presents much larger failure mode consequences than a Titan-type configuration. 7-6

Once again, NASA's reasonning for not using the alternative is based on fear of delay: first, that the military cannot immediately deliver a Titan, and second, that, once delivered, modifications will take several more years. It is disturbing to think that the Department of Defense could not adjust its schedule if NASA stressed the importance of obtaining a Titan for the Ulysses Mission. Just as disturbing is the fact that NASA does not think it worthwhile to delay the Ulysses mission to prepare a superior and safer launch system. 7-7

8. Solar data time criticality: NASA's contentions that use of other launch vehicles and/or power sources will result in expensive delays and dispersion of scientific teams are doubtless true. We think the returns in improved safety for all future deep-space missions are worth those added 7-8



RESPONSES TO COMMENTS
Commentor No. 7: Southern California Federation of Scientists
(Continued)

Response to Comment No. 7-6

A Titan IV launcher is not available for a 1990 or 1991 launch. At this point, a comprehensive safety analysis of the Titan IV for an RTG payload has yet to be completed. The Shuttle has safer abort modes, allowing the craft and its cargo to return intact, while the only abort mode for the Titan IV is destruction of the vehicle and cargo. It is NASA's preliminary assessment that the Titan IV, like the Shuttle, can achieve safe missions.

Also, see Response to Comment 2-21.

Response to Comment No. 7-7

The question of delaying the mission to wait for the availability of an alternative launch vehicle was addressed in Section 2 of the EIS.

Also see Response to Comment 2-21.

Response to Comment No. 7-8

See Response to Comment 2-21 and 7-3.

In addition, delay to await these alternatives would eliminate the opportunity of gaining correlative data (e.g., Pioneer data) and could require either refueling the RTG or acquiring less data.

costs. The additional worry that the data on the solar system will be delayed seems preposterous. The environment of the sun will not change so much in the next few years that we risk missing something important. 7-8

9. Conclusion: As scientists who are aware of the possible opportunities for vast improvement in space exploration safety and efficiency, we urge NASA to utilize the above power and launch alternatives for the Ulysses Mission. We believe that now is a perfect time to do the required research and development. If a Plutonium-free power source is developed concurrently with the Titan modifications, then the final product will eliminate the risk of radiation exposure in case of an accident. Not only will this be valuable for the Ulysses Mission, but, also, it will continue to be important for all future space exploration.

| Signed | Date |
|---|---|
| Jack R. Jennings, PhD | April 5, 1990 |
| Sheldon C. Plotkin, PhD | April 5, 1990 |

**COMMITTEE TO BRIDGE THE GAP**
1637 BUTLER AVENUE, SUITE 203
LOS ANGELES, CALIFORNIA 90025
(213) 478-0829

6 April 1990

Dr. Dudley McConnell
Deputy Director, (Advanced Programs)
Solar System Exploration Division (Code EL)
NASA Headquarters
Washington, D.C. 20546

Re: COMMENTS ON ULYSSES DEIS

Dear Dr. McConnell:

Enclosed please find the comments of the Committee to Bridge the Gap (CBG) on the Draft Environmental Impact Statement (DEIS) for the Ulysses nuclear-powered mission. As you know, we have had a long interest in issues associated with the proposed use of nuclear power sources in space. We therefore appreciate the opportunity to provide our views on the Ulysses DEIS.

CBG has been primarily concerned with the use of nuclear power sources, both reactors and Radioisotope Thermal Generators (RTGs), in earth orbit. We have, in fact, proposed a ban on such uses. That ban, however, would not necessarily exclude the careful use of certain forms of nuclear power for deep space missions; i.e., missions so far from the sun that they cannot use solar energy. If such carefully selected missions were to require--and I underscore require--nuclear power, we would prefer the use of small, low-enriched uranium reactors, which can be launched cold (i.e., non-radioactive), as opposed to RTGs, which are "on" all the time, always radioactive, always capable of accident dispersing substantial quantities of plutonium. 8-1

In other words, we are prepared to accept that there are some space missions for which there might be no alternative to nuclear power, although the choice of which form still leaves much room for enhancing safety and minimizing risks. What has begun to concern us is that NASA appears to be making decisions in favor of using space nuclear power for missions where there *are* environmentally superior alternatives. And we are concerned that NASA is viewing the environmental impact review process as a bureaucratic hoop to jump through for a preordained agency decision on behalf of routinely using RTGs, rather than a genuine, scientifically based "hard look at alternatives" as mandated by the National Environmental Protection Act. Whatever one felt about the Galileo mission--the first U.S. spacecraft getting its electricity from plutonium launched after a hiatus of more than a decade--it was, at least, just a single launch, with a finite, if unknowable, risk of accident. Now, however, NASA is to launch another such mission within a mere year of the first, and the agency has several more planned for subsequent years. This launching of plutonium into space is thus becoming a routine activity, and the hard look necessary to determine whether these missions really require such a hazardous energy source just isn't being done, at least not by the agency. 8-2

In that sense, this DEIS is a serious disappointment. It provided NASA an opportunity, indeed one required by law, to seriously examine prospective alternatives and the environmental impacts associated with each, prior to making a major federal action such as the decision as to how to launch and provide power to the Ulysses mission. Yet, despite containing some sections which appear competently prepared, it is by and large a misleading document, making claims to justify a decision already made, claims which even insiders at the agency and in the Ulysses project itself find somewhat ludicrous. Committed to doing the project in a way already decided, NASA has prepared a DEIS that is an awkward justification of a predetermined outcome, not a serious, 8-3



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap

Response to Comment No. 8-1

Space nuclear reactor technology has not yet reached the stage where power density (i.e., power per unit weight) is competitive with RTGs at power levels less than, say, one kWe.

Response to Comment No. 8-2

NASA policy is to fulfill not only the letter, but also the spirit of the National Environmental Policy Act (NEPA). NASA evaluated alternatives (launch vehicles and power systems among others) during the course of the development of the Ulysses mission.

The NASA launch rate of nuclear powered space systems is not now greater than, say, during the 1970s when NASA launched four Apollo Lunar Surface Experiment Packages (1970 - 1971), two Viking Landers (1975), Pioneers -10 and -11 (1972, 1973), and Voyagers -1 and -2 (1977). Thus, there were ten launches of nuclear powered systems by NASA during the 1970s.

Response to Comment No. 8-3

As the commentor notes, the EIS is an informational document required by law. It is informational in that it is intended to be utilized by the decision maker and the public in understanding the environmental implications of a proposed course of action and the reasonable alternatives thereto. The proposed action at hand is completion of the preparation and operation of the Ulysses mission, including its planned launch on the STS/IUS/PAM-S in October 1990 or in the back-up opportunity in November 1991. As noted in the text, a "hard look" was taken at alternatives, and neither alternative launch vehicles nor alternative power were available.

scientifically honest appraisal of the range of alternatives and the associated potential environmental impacts.

Furthermore, NASA appears to be frustrating the NEPA requirement of providing a genuine opportunity for public involvement in the NEPA process. For example, serious consideriation of alternative power souces and of the environmental risks associated with the nuclear source were excluded from the TIER I EIS, saying that they would be dealt with in TIER II and that failure to consider them in depth at the earlier stage would not preclude subsequent consideration of the delay alternative if needed. Late last year, however, NASA announced in a Federal Register notice, purportedly soliciting scoping comments for the TIER II DEIS, that no matter what those public comments might be, NASA had decided not to consider any alternative that might involve delay, which effectively precludes any alternative power source or launch system. Furthermore,by soliciting these public scoping comments for the DEIS long after the bulk of the DEIS had been prepared and within weeks of its issuance, the agency made clear it had no real intention to listen to those public scoping comments, because it had solicited them too late to take them into account. Additionally, the subsequently released DEIS states that the final EIS, which will not be subject to public comment, will be based largely on a Final Safety Analysis Report for Ulysses which is not yet available for public review, thus effectively sidestepping true public scrutiny of the basis for the entire environmental review for Ulysses. 8-4 8-5 8-6

Perhaps the most indicative aspect of NASA's compliance with the NEPA requirements for public participation in the environmental review process has been the filling of the DEIS with conclusions, often unsupported in the text by detailed facts, referring the reader instead to underlying documents which are included by reference, and then making those documents unavailable to the public for review in the public comment period. 8-7

Members of the public were directed in the covering memo of the DEIS to the reading rooms at NASA Installations and the Jet Propulsion Laboratory. I have attached hereto a declaration by Martha Early, a law student working with CBG, attesting to the difficulties she experienced at JPL in attempting to review the underlying documents referenced in the DEIS. From a practical standpoint, many of the referenced documents are not available for public review, at least not in the time period allotted for public comment on the DEIS. We suggest that the agency correct these problems regarding public access to the documents included by reference in the DEIS. We hereby formally request:

(a) The Final Safety Analysis Report be made available for public review at the earliest possible time.

(b) The public reading rooms at JPL and NASA Installations be provided as soon as possible with a complete set of the references included in the DEIS and FSAR, and that a means of copying desird documents be assured.

(c) To speed matters, that you assist interested parties such as CBG in obtaining in a timely fashion the underlying references they need to perform an adequate review of the DEIS.

and (d) That you provide opportunity for supplemental public comments on the DEIS, based on review of the FSAR and underlying references, due within 45 days of NASA completion of the items above. 8-8

It seems to us to bypass the intent of NEPA to issue a DEIS which is based largely on references not available in a practical sense for public review and to additionally indicate that the final EIS will be based in large measure on a FSAR not available for review at all during the 8-9



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

Response to Comment No. 8-4

The conduct of the EIS process is in full, detailed compliance with CEQ and NASA NEPA requirements and guidelines.

Response to Comment No. 8-5

NASA solicited scoping comments by Federal Register Notice dated November 21, 1989. It is NASA policy to allow 30 days for scoping comments to be received (as was the case in the Galileo and Ulysses Tier-1 DEIS, and the Galileo DEIS Tier-2). So the Federal Register notice should have shown the scoping period as closing on December 21, 1989. It was due to a typographical error in the Federal Register that the Federal Register Notice indicated January 22, 1990 as the close of the comment period. That error was corrected both in the Federal Register and by NASA mailing to organizations and individuals on the NASA mailing list. The Federal Register acknowledges that the error was on their part.

The DEIS notice of availability was published on February 23. The Final Safety Analysis Reports was available in March 1990 and was provided to requestors. The preparation of this EIS has followed all the CEQ guidelines and NASA regulations on preparation of an EIS.

Response to Comment No. 8-6

The FEIS will be available for review for a period of 30 days. Comments will be received pursuant to the guidance in 40 CFR 1503.1(b).

Response to Comment No. 8-7

Information in support of conclusions in the EIS is in the publicly available literature cited. The information from these documents has been incorporated by reference in accordance with CEQ regulations 40 CFR 1502.21.

Response to Comment No. 8-8

NASA has made available for public inspection both its DEIS and the basic reference document, the Safety Status Report -- from which the DEIS derives much of its basic safety data. The reference section of the FEIS (Section 7) consists of previously published documents (e.g., NASA's Galileo Tier 2 EIS), and documents which are publicly available. Documents prepared specifically for this EIS either appear in Appendix G, or have been made available (e.g., the Ulysses FSAR) to various recipients of the EIS.

Response to Comment No. 8-9

See Response to Comment 8-8.

comment perod on the EIS. NASA should not try to shield the basis for its environmental decisions from effective public review. We urge you in the strongest possible terms to announce publicly that you are granting our requests above and will assure that the full bases for the environmental review of Ulysses are readily available for public scrutiny and comment prior to the agency making its final environmental decision on this important matter. We look forward to hearing from you shortly on this. 8-9

Let me say it is very much in NASA's interest to comply fully with the spirit and letter of NEPA regarding both a hard look at alternatives and full opportunity for public review. NASA, perhaps more than any other federal agency, is uniquely dependent upon public support and good will. It has enjoyed a reservoir of public enthusiasm and, until marred by the disclosures after the Challenger disaster, public trust. It needs both if it is to survive the difficult periods ahead. Launching large quantities of plutonium routinely when there are safer alternatives will cause NASA to lose support for those few missions that eventually may genuinely need at least some form of nuclear power and for which there may not be safer alternatives. And playing games with spurious claims in EIS's and seeming to hide underlying documents can only seriously erode public confidence. 8-10

I am sure you recognize that the Committee to Bridge the Gap has been a useful ally of sorts to NASA in the past. As one of the leading critics of the use of space nuclear power, we were careful, after consultation with key NASA officials, to craft our proposal with Soviet scientists to ban only orbiting nuclear power devices, leaving open an option for some limited uses for deep space purposes where there is clear demonstration of no alternatives. But NASA's new practice of routinely and repetitively using plutonium power supplies for missions where there are indeed safer alternatives and front-loading environmental statements with scores of unrealistic assumptions to radically minimize the real risks associated with accidents involving release of plutonium is causing CBG to rethink its position.

A national consensus could be built, we continue to think, around the following principles: no nuclear power, of any sort and for any purpose, in earth orbit; use of solar and other non-nuclear power sources wherever possible, even if there is some added cost or weight penalty; for those few missions where there really is no alternative, use nuclear, but only a device that can be launched cold and turned on after it is far from earth. 8-11

But if NASA uses nuclear sources when there are alternatives, and if it inappropriately minimizes the risks and cuts corners with public review in the NEPA process, that potential consensus will be shattered. The likely outcome would be sufficient public outcry over any use of nuclear power in space as to ban any use whatsoever.

It is to NASA's interest to do it right. And this DEIS is not part of doing it right.

It is not too late to correct matters.

Our detailed comments follow.

Sincerely,

Daniel Hirsch
President

Response to Comment No. 8-10

See Response to Comment 8-2.

Response to Comment No. 8-11

See Response to Comment 4-9.

COMMENTS ON THE DRAFT ENVIRONMENTAL IMPACT STATEMENT (TIER 2)
FOR THE ULYSSES PLUTONIUM-POWERED SPACECRAFT

Summary

Our primary concerns about the DEIS, based on our review of it and of those few underlying documents referenced therein that we have been permitted to review to date, are as follows:

(1) NASA's artificial restriction of the alternatives to only two: a Shuttle launch of the Ulysses with a nuclear power source, as planned, or scrapping the entire mission forever. This leaves out the genuine alternatives which should have been examined in depth--a launch vehicle other than Shuttle, and a power source other than nuclear. Dismissing both from consideration because they would assertedly involve delay is dishonest and violates the intent of NEPA for a "hard look at alternatives." 8-12

(2) The claims about why no delay alternative will be considered are disingenuous. Nowhere in the DEIS is it mentioned that Ulysses has already been delayed about a decade. If it has survived that delay and is still scientifically useful, a more honest assessment of potential impacts of further delay are in order, rather than sweeping generalizations about destroying the scientific utility of the mission. The assertions about the necessity of launching now due to solar cycles and coordination of the mission with other spacecraft appear spurious at best, as that was not part of the original plan and the sun is likely to be here for quite a long time to come. 8-13

(3) The Tier 2 DEIS seems to be a reversal of Tier 1 on the question of the solar alternative. Tier 1 dismissed solar power in a few lines, saying it couldn't be used on such a mission. Tier 2 admits solar alternatives currently exist that could provide the necessary power, and that more advanced alternatives are on the way, but then it makes rather flimsy excuses for not using solar, saying it would require redesign of the spacecraft and/or the launcher. But this is entirely circular. An EIS is to be the agency's honest look at the environmental impacts of various alternatives prior to undertaking a major federal action, so that environmental considerations can be a major part of that decisionmaking and so the environmentally superior alternative will tend to be chosen. But NASA is essentially dismissing from consideration alternatives it admits are environmentally superior because they would require "redesign"--i.e., we can't choose an environmentally superior design, because we have already chosen an environmentally more dangerous design, and changing would require redesign. An EIS is not to justify a past decision, but to consider potentially environmentally superior alternatives in making a pending decision. NASA should have included serous consideration of such alternatives when the decisions were being initially made, so that it now wouldn't face delay if it included them at this stage. 8-14



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

Response to Comment No. 8-12

NASA took a hard look at various options, and on the basis of that, framed the proposal to gain the benefits of the mission as soon as possible consistent with prudent management of the Nation's resources. The alternatives were also stated realistically with respect to the proposed action.

At the earliest, alternative (e.g., solar) power systems would not be available for mission assignment before the mid-to-late 1990s. And the U.S. Air Force, which procures Titan IV launch vehicles for the U.S. government (these are not commercially available vehicles) has indicated to NASA that a Titan IV would not be available before 1995. Therefore, neither of these alternatives are reasonable alternatives to the proposed action.

Response to Comment No. 8-13

It is true that the launch of the Ulysses mission was delayed several times since its original 1983 launch date. Those delays were due to several factors beyond the control of the program including changes in U.S. policy on upper stage launch vehicles and the Challenger accident. Indeed, the 1983 launch was timed for solar passage near solar minimum.

The issues of solar cycle variations and the coordination with other spacecraft has always been part of the scientific strategy of the mission. Although a launch at particular phases of the solar cycle or coordination with other spacecraft is not a hard requirement of the Ulysses mission, the scientific utility of the data would be improved if the mission could arrive at the solar minimum and coordinate Ulysses observations with the aging Pioneer and Voyager spacecraft.

Response to Comment No. 8-14

The Tier 2 EIS does not reverse the Tier 1 EIS, it expands upon the discussion. In any event, the solar power alternative requires a launch vehicle which does not currently exist. Therefore, solar power is not a feasible alternative to the proposed action.

(4) The Tier 2 DEIS appears to significantly underestimate both the probability of an accident involving the RTG and the consequences of such an accident. Nowhere in the DEIS that I could see is there given an estimate for the maximum release fraction assumed in the worst case accident. It is apparent, however, from the claims that the supposedly worst accident would result in 0 health effects that NASA has somehow managed in the DEIS to add sufficient "fudge" factors to what should be a worst case analysis to reduce effects by something like four orders of magnitude. Just scaling from old UNSCEAR estimates of casualties from plutonium release from weapons testing, correcting slightly for BEIR-IV dose-response figures, gives cancer deaths in the range of tens of thousands, should all of the Ulysses plutonium be released to the environment. (This is assuming high altitude release; it could be worse if released at low altitude.) The amount of plutonium to be launched is really remarkably large from a public health standpoint. It is on the order of the plutonium of all isotopes, measured in curies, released from past U.S. atmospheric tests. It is the equivalent of 3 tons and a half of plutonium-239, in terms of activity. Somehow NASA has worked the "worst case" accident down to something thousands of times smaller than the worst case, trivializing a serious concern. To claim that the worst accident possible involving a 130,000-curie souce of plutonium-238 is 59.3 person-rem is, one must say, untenable. 8-15

The same thing must be said on the probability side. These numbers given (e.g., .0000000816), to three significant figures, no less!, have no meaning nor any real basis. Every time NASA has put forward such numbers and a real accident has occurred, the accident was orders of magnitude sooner than such predictions. 8-16

If the DEIS said: This is a huge source of plutonium, from a radiological protection standpoint; if even a small fraction of it were released, there could be very serious consequences; we recognize the risk, and are taking every measure possible to reduce it; then perhaps the public could have greater confidence that NASA had the necessary respect for the hazards involved and was facing them appropriately. But when NASA claims the worst possible accident has a probability of .816 billionths (as though you can know the unknowable with that precision) and even if it happens, there will not be a single cancer, even though if even half of the plutonium were released standard consequence models indicate thousands to tens of thousands of cancers, it is hard to have faith that there is sufficient respect for the dangers inherent to take the necessary measures to avoid them. 8-17

In this regard, this DEIS sounds very similar to the outlandish predictions NASA made before the Challenger accident about the one in a million chance that such a thing could occur. But of course it did, and so can an accident causing thousands of cancers from this planned shuttle mission. And the risks should not be denied, should not be artificially minimized.

Comments by Page

I-3 I don't believe it is accurate to say the Ulysses mission was "planned" to arrive in the Sun's polar regions near the solar minimum. My understanding is that the mission was planned to be launched long ago, and has been repeatedly delayed, and that this launch is simply the first launch date that has become available after those delays. 8-18

The DEIS lacks a discussion of the origins of the mission--when it was designed, when it was first intended to be launched, and the cause of the various delays. This is particularly important because of the repeated assertions made in the DEIS that other launch configurations or other power sources, even if very much safer, will not be considered because of the delays that 8-19



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

Response to Comment No. 8-15

See Response to Comments 2-11 and 5-14.

Response to Comment No. 8-16

The probability is the estimate of the frequency of occurrence of the accident. It does not address when the accident will occur. For example, if an event has a probability of 0.1, we say that out of a large number of trials, the event will occur with a frequency of 1 in every ten trials. That event could occur at any time (e.g. the 5th of 10 trials, or the last of 10 trials). The use of three significant figures is to avoid rounding error in calculations involving the number and is not indicative of the precision.

Response to Comment No. 8-17

While the RTG contains 23.7 pounds of plutonium dioxide (132,500 Ci), the testing program indicates that even in a severe accident, only a small fraction would be released. Of this release plutonium dioxide, an even smaller portion will have particle sizes in the respirable range.

It is because of the recognition of the hazard associated with plutonium that the RTG has been designed to contain and confine the plutonium dioxide in the event of a severe accident.

Response to Comment No. 8-18

The Ulysses mission was originally planned to survey the Sun's polar regions near solar minimum. It was argued on scientific grounds that the coronal latitude structure is best developed, simplest, and only slowly changing at solar minimum. The scientists preferred to first traverse the totally unexplored polar regions when they were not suffering constant rearrangement because of disturbances on the Sun. A major concern has always been the ability of the mission to separate temporal from spatial variations. This discrimination was judged to be easiest when the spatial structure was simplest and changing the least (i.e., solar minimum). The original launch date in early 1983 would have placed the spacecraft over the poles near solar minimum.

The delay to a 1986 launch meant that the traversal of the polar regions would occur near solar maximum. The scientific objectives were unchanged but the scientists were concerned about complications in interpreting the measurements. They decided that so little is known about the polar regions that obtaining information during solar maximum would still be of great value. It was

would ensue. This gives the impression that there have been no delays to date and that this is the launch date for which the entire mission was planned from the beginning.

The truth is that this mission was planned to be launched long ago and has already sat around waiting due to delays on the order of a decade. To honestly assess the impacts of a further delay due to reconfiguring for a safer launch vehicle or non-nuclear power source, one must be honest about the past delays and what effect if any they have had.

If delay of more than a year or two is as devastating as the DEIS claims, then the decade-long delay to date should have destroyed any scientific usefulness for the Ulysses mission. If that is true, then cancellation of it now or an additional delay should not have much impact. If the mission retains virtually all of its usefulness even after a decade's delay, then an additional delay in order to use alternative launchers or power sources so as to eliminate the risk of widespread plutonium release should have marginal effect on the benefits to be gained from the mission.

In any event, an honest discussion of the history of the Ulysses mission and the many delays that have already occurred to date is necessary to put into perspective the rather flimsy claims made in the DEIS about the assertedly catastrophic impact of a delay alternative.

The same comments hold true for the paragraph on the bottom of the page. Ulysses was not planned to be launched to coincide with the current configuration of Pioneer and Voyager spacecraft. It was planned to be launched a decade ago, when they were in very different positions. My understanding from senior officials in the Ulysses program is that it has almost nothing to do with simultaneous measurements from other spacecraft, is an almost entirely self-contained data acquisition effort, independent of others. These officials were frankly stunned by the claim NASA has made in this NEPA process about the mission being useless if delayed, and frankly stunned by the claim that it was necessary to launch while these other spacecraft were where they are. They said no data would be lost if there were a delay, so long as there were a power source available when the launch occurred. They don't like the idea of a further delay, but loss of data, they say, is a fraudulent reason to give to attempt to prevent it.

The sun has been here a long time, and will be here a long time more. Measurements of the sun can be made in other years besides 1990. It will still be there a few years from now.

To the extent it would be interesting to have other spacecraft elsewhere in the solar system when measurements are being made, there will be other such spacecraft in the future too. Ulysses was not designed to be launched in 1990 or 1991; and it wasn't designed around simultaneous measurements with other spacecraft at the locations you show in the 1990 column in Table I-1;. The DEIS should give an honest portrayal of the origins of the Ulysses mission, its original plans and timetable, and then explain if it could be useful ten years ago, before the current delays, why it will lose all scientific utility if it is delayed a little longer to fix the design oversight of not designing it around a non-dangerous power source and launch configuration.

That history should further make clear that the basic design for Ulysses and its RTG were frozen before Three Mile Island, before Chernobyl, and before the Challenger accident. The design assumptions at the time were that serious nuclear accidents were "non-credible" and thus didn't have to be considered, and that a shuttle accident was likewise inconceivable and its possibility need not be considered in choosing or designing power sources. The DEIS slides over this, implying the RTG was designed with these accident environments in mind; when in fact the designers excluded from consideration the very kind of accident Challenger faced. Subsequent to the accident, which could have involved overpressures greater than the RTGs were estimated to be



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

anticipated that the spacecraft lifetime would permit a return to the poles at the succeeding minimum (since the orbital period is approximately 6 years or half a solar cycle). Although this timing would reverse the preferred sequence it was reasoned that it was better to start as soon as possible to make measurements over a solar cycle than to wait until the next minimum while foregoing scientific information in the interim.

Launch at this time will return the mission to the preferred well-ordered solar regime.

Response to Comment 8-19

The history of the Ulysses mission is available in the public record. The delays up to this point were, from the Program's standpoint, unavoidable. The delays were due to changes in the availability of the Shuttle and changes in U.S. policy on upper stage launch vehicles. The mission was planned to be launched on the Shuttle from the beginning. At this time, there is a particularly beneficial set of circumstances, including the availability of a constellation of other spacecraft to provide extremely valuable correlative data. The earlier unfortunate delays make it more necessary to avoid any further unwarranted delay.

8-19

Even more basic is the issue of spacecraft life and the aging of subsystems. The Ulysses mission was originally scheduled for launch in 1983. The adoption of the Centaur upper stage caused the delay to 1986, and the mission redesign following the cancellation of the Centaur program caused the delay to 1990. The mission, as now planned, will be completed in September 1995. That calls for a spacecraft and subsystem life of just over 10 years. In terms of "design life" that is at the limit of existing technology. Beyond 1991, the mission could not be flown because the available power from the RTGs would not meet the mission requirements. This might require reduction of science objectives or refueling of the RTGs. From the science perspective, delays would not allow correlation of Ulysses data with the data of other spacecraft such as Voyagers and the Pioneers.

The RTG design has evolved from earlier designs as discussed in Section 2.2.4.3 of the EIS. Much of the design effort has been focused on understanding accident environments and designing the RTG to confine the fuel in the event of an accident.

able to withstand had the Galileo IUS been aboard, as was planned for the next mission, a lot of paper studies have been performed to try to retrospectively prove that the RTGs are stronger than previously thought, can withstand accidents for which they were not designed. This is a kind of backfitting the paper analyses, rather than backfitting the design.

1-3 Same comments apply, at top and bottom of page. The mission was not "planned" to do these things; its original plans were scrapped when they faced a series of delays. The DEIS should give the history of original plans, the numerous delays, and indicate what fraction of its original value has been lost, if any, by these long delays, so as to better judge claims about the death of any scientific value if there is a new delay to reconfigure to prevent a major nuclear accident. 8-19

1-5 Same comments apply about timeliness claims.

1-6 Senior Ulysses officials laughed when told of these claims. These other spacecraft were not keyed to the original Ulysses mission; there will be other spacecraft in the solar system if Ulysses is launched later; Ulysses' data are valuable in and of themselves; and the only potential loss of data due to delay would be if the RTG decayed to such a low level that it couldn't provide the necessary power, but other RTGs would be available, and other non-nuclear power sources could do the job. These repeated implications that Ulysses was planned originally to be launched in 1990 or 1991 and its scientific data would all be lost if not launched then are misleading and untrue.

2-1 It seems clear you are only considering two alternatives: "do it our way, or don't do it at all." The fact that you discuss delay alternatives in the next sentence and briefly in following subsections creates a confusion, which you should address specifically, one way or the other. Are you going to do a serious analysis of alternatives which may entail delay, or are you not going to? The DEIS, although clearly not looking at any but the two alternatives of the proposed action and the no-action alternative, slides over this with a few words on the delay issue. Be up-front about it: you are not going to assess the environmental impacts of solar or alternative launch configurations. Or decide to do so, fully. But the current language is unbecomingly slippery. 8-20

At the bottom of the page is a misleading implication that the "principal opportunity for launch occurs in October 1990." In fact, there is a similar launch opportunity ever 13 months, year after year. 8-21

2-3 If delay is so devastating, how did Ulysses survive the delays to date. And there is no weighing of what the honest results of delay are against the potential for thousands of cancer deaths if a substantial fraction of the plutonium were released in an accident. NASA has delayed for a decade or so this very mission, for a number of bureaucratic and other reasons. Why is a smaller delay for public health reasons so out of the question? 8-22

2-4 Please give some dimension in this diagram, and specify weight. My understanding is that the entire Ulysses is about 800 kg, compared to 6000 kg for Galileo. This is very important for putting into perspective the strange claims made in the next page about alternative spacecraft power sources. 8-23

2-5 This section is embarrassing. This new section makes clear that there is indeed sufficient solar intensity at Jupiter for solar power to work, and that the only concerns in the new analysis are that current solar devices would add some weight and require redesign of the spacecraft, primarily with regards 3-axis control as opposd to the current spin-stabilized approach. Yes, a different design would require a different design, but that is totally circular. If you had designed it originally for solar, you wouldn't have to redesign it now. Yes, you may not today have a specific launch vehicle currently configured the way you say you would want for solar, but the 8-24



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

Response to Comment 8-20

The proposed action is to launch at the earliest possible opportunity available to the Ulysses mission in order to receive the benefits as soon as possible. That would be to launch in 1990, with the 1991 opportunity as a back up. This is consistent with prudent management of fiscal and human resources. The range of launch dates stated takes account of science benefits, the decrease of RTG power level and spacecraft life (subsystem aging). Any alternatives considered should meet those launch dates.

Response to Comment No. 8-21

See Response to Comment 8-20.

Response to Comment No. 8-22

Some of the impacts of further delay are addressed in Response to Comment 8-19.

Response to Comment No. 8-23

A scale is provided on Figure 2-6, which can be utilized in determining the dimensions of the spacecraft. The approximate weight of the Ulysses spacecraft is noted in line 1 of Section 2.2.3. To simplify review of Figure 2-2, approximate dimensions of the spacecraft have been added. Please note that Ulysses is 809 pounds and Galileo was 6,000 pounds.

Response to Comment No. 8-24

See Response to Comments 4-7 and 4-8.

purpose of an EIS is to figure out which way you want to configure the launch vehicle to have the least environmental impacts. To say that the development of such a vehicle hasn't been approved or authorized is also circular; NASA never asked for such approval or authorization. The question in a DEIS is what federal actions should be approved or authorized, given a hard look at the alternatives and what their environmental impacts can be. 8-24

The increased weight argument also seems somewhat misleading. Ulysses at present is only 800 kg; with even 1200 pounds additional weight for an environmentally safe power system, it becomes about 1350 kg, still less than a fourth the weight of Galileo. 8-25

And if you are really worried about the weight, which doesn't seem to be a problem, given the above discussion, but if that is a worry, an alternative that the DEIS should consider is asking the Soviets to launch a solar-powered Ulysses for us, using their excess heavy-launcher capability. 8-26

The FEIS should eliminate the sentence claiming that "Solar power technologies haven't yet progressed to a stage of development consistent with the requirements of the Ulysses mission and use of available launch vehicles." The material which follows really doesn't support that statement, nor does the chart on the next page. What is really being said here is that solar can do just fine in providing the needed energy, but we would have to change the design of the spacecraft and launcher somewhat to build them arond a solar instead of a nuclear power source. 8-27

The Advanced Photovoltaic Solar Array discussion is likewise misleading. Again, so what if it would require redesign? NEPA is designed to decide actions, not justify past ones. APSA will be used on some mission initially, so why not Ulysses. The argument that its first uses increase likelihood of failure would suggest that NASA should tell Congress to cut the funding on APSA; since you support the program in one venue, it really is not appropriate to cut it down in another, just to make a case for the RTG configuration for Ulysses. And, again, if there is a further delay, should that not be balanced against the vastly increased environmental protection of not having to use 130,000 curies of plutonium-238 in a device launched by igniting something like a hundred tons of highly explosive fuel surrounding it? 8-28

2-6 This chart looks far more favorable than the comments on the previous page. We have flown the rigid array on Magelland, Mars Observer and TOPEX; lots of experience; available now; SAFE flown on Shuttle experiment. There is no serious assessment here of implications of the spacecraft adaptation or other comments--none seem to be showstoppers. The EIS should be explicit--are you considering alternative power sources, or not? If yes, then do the full review, including it in the comparisons in other sections that look at environmental impacts of the two alternatives you have already selected for consideration. The DEIS looks as though you chose not to consider any alternatives besides nuclear-Shuttle and no-action, but threw in a few lines here and there about alternative power sources and launch vehicles, hoping to protect yourselves from legal action. Either consider the alternatives fully, or be direct about not considering them. 8-29

2-8 I don't believe the first paragraph under 2.2.4.3 is accurate when it says the GPHS is the culmination of 25 years of design evolution. When was the last major design change made? Additionally, when one says they have included some of NASA's "most impressive successes," you need to immediately add "as well as three of its most worrisome accidents." 8-30

A key point you slide over is that the actual failure rate involving RTG's is 15%. Of the three that reentered, one burned up entirely, another was retrieved, and the third is lost in the ocean, with unknown long-term potential for release of its plutonium. The actual failure data are many orders of magnitude higher than the estimates used in the DEIS. Just as in the pre-Challenger risk estimate case, where NASA threw out real failure data for SRBs and substituted 8-31



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

Response to Comment No. 8-25

The Galileo mission utilized a large spacecraft with a relatively low launch energy to Venus while the Ulysses spacecraft is smaller with a very high launch energy directly to Jupiter. The Ulysses spacecraft is not flying to orbit Jupiter, it is using Jupiter to change the orbit plane nearly 85 degrees so that the spacecraft can get out of the ecliptic plane and fly over the poles of the Sun. The Galileo interplanetary injection energy was approximately 16 kilometers$^2$/sec$^2$ and a Venus Earth Earth Gravity Assist (VEEGA) trajectory is being used to get to Jupiter. The Ulysses spacecraft requires a tremendous velocity at Jupiter flyby (15 km/sec) in order to climb out of the ecliptic plane. In order to obtain this tremendous energy, the two stage IUS had to be augmented with a PAM-S to inject the 809 lb. Ulysses spacecraft into a direct trajectory to Jupiter with injection energy of 130 kilometers$^2$/sec$^2$.

Response to Comment No. 8-26

See Response to Comment 7-5.

Response to Comment No. 8-27

See Response to Comments 4-7 and 4-8.

Response to Comment No. 8-28

See Response to Comments 4-7 and 4-8.

Response to Comment No. 8-29

There is much experience using solar arrays in Earth orbit and for inner solar system missions. Solar arrays have never been used in outer solar system missions (i.e. missions to Jupiter and beyond).

SAFE was a deployment demonstration, no power was generated.

It should be noted that neither TOPEX nor Mars Observer have yet been launched.

Response to Comment No. 8-30

The present design of the GPHS module was completed in 1981. This does represent around 25 years of evolution of isotope powered heat source designs for space applications starting back with the SNAP-3A in the mid 1950s, then to SNAP-9A, SNAP-19, SNAP-27, Transit, MHW, and the GPHS.

Response to Comment No. 8-31

It is true that, of the 22 missions that have been launched with RTGs, there have been 3 mission aborts with the RTGs returning to Earth. However, it is also true that in each case the RTGs (SNAP-9A/Transit, SNAP-19B/Nimbus, SNAP-27/Apollo 13)

performed exactly as designed. The SNAP-9A was designed for intentional burn-up and dispersal in the upper atmosphere. This was the safety philosophy at that time. The SNAP-19 and the SNAP-27 were designed for intact reentry. While the SNAP-27/Apollo-13 heat source was not recovered, it now resides in the deepest part of the Pacific Ocean, the Tonga Trench, where it will not interact with the surface waters nor with any marine life that can enter the food chain. None of the radiological surveys of the atmosphere and ocean indicated any release of radioactivity following the SNAP-27 reentry. The SNAP-19B/Nimbus never reached orbit and the RTGs were recovered fully intact and used on a later mission. This experience demonstrates that the RTGs can be involved in missions that abort and/or reenter the atmosphere without releasing nuclear material.

Response to Comment No. 8-32

The fuel pellets for the Ulysses RTG were fabricated over a period from January 1982 to November 1983. Final assembly of the RTG with heat source modules occurred in February 1985. The RTG then was placed under a controlled atmosphere of argon where it remained until shipment to Kennedy Space Center.

Los Alamos has examined the effect of the plutonium-238 alpha, neutron, and gamma radiation upon the physical degradation of the iridium clad with age. Damage was limited to about a six (6) micrometer depth on the clad interior and did not change with extended time nor was it significant in the mechanical response to accident environments as demonstrated in tests. The temperature of the iridium clad at launch is around 1090°C average; operation in vacuum (space) occurs at a temperature around 1287°C. The material system of the GPHS modules, composed only of plutonia fuel, iridium alloy, and graphite, has been shown by materials compatibility tests to be completely compatible without interactions over the temperature range for the mission application and under the controlled atmosphere conditions imposed. Also the temperatures of the other components of the RTG over their operating range and environment have not resulted in any material reactions. There is neither tantalum nor vermiculite materials in or near the RTG. There are no affects of alpha bombardment on these other materials since the alphas are stopped in the iridium clad. Alpha particle damage and helium release microstructural changes in the plutonia-238 fuel have also been examined at Los Alamos. It was found that the operating temperature of the GPHS fuel is sufficient to liberate helium at its generation rate and results in minimal helium damage. The high energy level of the alpha particle recoil energy can be envisioned as a mechanism to promote bulk microstructural damage. However a countering mechanism, the resulting thermal energy, affords a self-annealing of atom displacements; microfragmentation interior to the fuel matrix effectively does not occur in the sense of creating finely divided, separated material. Testing conducted in the GPHS safety test series with fuel pellets exceeding six (6) years in age has not indicated any significant difference in the particle size distributions than for pellets having one to two years of age.

guesses many orders of magnitude more rosy, this DEIS tries to paint a pleasant face on past RTG accidents and ignores the existing failure rate data to substitute calculated estimates astonishingly more optmistic. 8-31

Also, please give us the details about this particular RTG? When was it built? 15 years ago? If so, 15 years of "design evolution" have passed it by? How long has it been sitting around? What are the effects of all that alpha-bombardment of the cladding and the fuel matrix? What temperature is the clad skin at? What effect of that alpha activity and high temperature on the materials? What material interactions have occurred, especially in light of the test data that showed strong interactions with tantalum and vermiculite contact at temperature, resulting in greatly reduced impact strength, what other materials interactions are there? What has been going on with the graphite under those conditions? What is the effect of helium buildup due to alpha decay--on the plutonium pellet itself, and the other consituents? Will not alpha bombardment and helium buildup of the ceramic make fragmentation and breakup more likely? 8-32

Dimension need to be given. How thick is the clad? Size of Pu pellet? Thickness of graphite shells. Reporters have been led to believe that each plutonium pellet is individually wrapped in fifty different layers of protection. It would appear instead that each is covered by a very thin layer of iridium-titanium cladding, inserted into a not particularly large amount of graphite, which is not bound to the clad in any way, but just serves as a kind of container. Is it correct that the RTG assembly itself is aluminum? If so, the DEIS should make clear that Al melts at a very low temperature, and is assumed to melt away quickly in many of the accident sequences. 8-33

What is the nature of the helium-relief valve in each clad? If helium can get out, why can't sea-water get in, for example, if impacted into water. 8-34

Very important--what is the ratio of iridium to tungsten in the alloy. Tungsten is very reactive, the nature of the strength of alloy will depend highly on its constituent parts. Any other component to the alloy? What happens to the tungsten in the alloy at high temperatures, in interactions with other materials, in air, in sea water, etc. 8-35

The claim made elsewhere in the DEIS or a supporting document that in seawater, the heat of the plutonium will attract encrustation that will "encapsulate" the plutonium clad seems very optimistic. The first effect may be encapsulation, but over the 2000 year toxic life of the plutonium, it is more likely that the encrustation will break through the thin clad. Barnacles can be said to "encapsulate" hulls of boats, but they do more damage than good. We saw the same thing with radioactive waste barrels dumped at sea, they became artificial habitats, creating pathways of uptake into the food chain. (Claim made elsewhere in the DEIS, but responded to here: to claim the plutonium oxide is largely insoluble, so don't worry if it gets into the ocean, misses the fact that the non-soluble plutonium leaking out of past ocean dumping containers would adsorb onto bottom sediments, which would then be taken up by bottom-dwelling sea-life that roots through the sediments, then work their way up the food chain. The claims about the safety of these plutonium pellets if dropped in the sea sounds very similar to the claims of safety about past ocean dumping of radioactive wastes that were repeatedly proven wrong when actually observed.) The 2-year tests of clads in seawater are ridiculous for estimating behavior over the 2000 year hazard period. 8-36

2-9, 2-10 Give dimensions, plus more drawings. Very hard to really see how the systems work with these drawings. 8-37

2-11 Put 132,000 curies of Pu into perspective. It is an extrordinary amount of plutonium. TMI is said to have released only 15 Ci of I-131, which has a half-life of only 8 days, compared to the 8-38



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

Response to Comment No. 8-33

See response to Comment 5-4.

Response to Comment No. 8-34

There is no helium relief valve in each clad. Instead there is a sintered iridium porous filter that allows the helium to escape but retains particulate material. If the GPHS modules land in water, water can get into the clad through the filter. However, the clad surface temperature prompts, a natural mineral deposition (anhudrite) to begin within the first 24 hours of ocean immersion. The deposit, after 2 years of ocean exposure was about 1.3 centimeters in thickness. Vent communication with the sea water is stopped almost immediately by the mineral deposit. No evidence of limiting the helium diffusion through the deposit was observed. After exposure and the removal of the deposit, the clad iridium metal surface was bright. Detailed examination revealed no localized or general cladding metal corrosion. Also, no mineral deposits were detected in the vent.

Response to Comment No. 8-35

The iridium alloy used for the cladding around the fuel has a tungsten content of 0.3% by weight. There are other trace elements in the iridium including aluminum, silicon, chromium, iron, molybdenum, tantalum, titanium, sodium, calcium, thorium, and ruthenium. As previously mentioned the fuel, iridium, and carbon materials system of the GPHS is an extremely compatible and stable system. The tungsten is miscible with iridium and is not present as a separate phase in the alloy. There is no indication of any preferential reaction of the tungsten component in the clad material over the temperature range of operation of the RTG, including inadvertent re-entry. Also there is no indication of any preferential reaction of tungsten if the clad is immersed in sea water for extended periods (years).

Response to Comment No. 8-36

The heat within the capsules initiate a natural mineral deposit (see Response to Comment 8-34) formation. The experiments were conducted in the Pacific Ocean, but we believe the mechanism to be universal since the oceans all contain the constituents. Even without the encapsulating mineral deposit as an isolation barrier, the plutonium dioxide exhibits an extremely low solubility. Combining these observations with the potential for large scale dilution by seawater, and it is apparent that, under any circumstances, the concentrations could only be diminishingly small. Plutonium leaking from containers dumped into the ocean on the other hand are mostly in more soluble forms such as plutonium metal as opposed to plutonium dioxide. Therefore, the releases are significantly different.

Response to Comment No. 8-37

See Response to Comment No. 5-4.

Response to Comment No. 8-38

The question of plutonium toxicity has been addressed in response 4-1.

The Maximum Permissible Concentration for insoluble Pu-238 in air for a member of the general public is $10^{-12}$ μCi/ml (10 CFR Part 20, Appendix B, Table II). That means, if a member of the public were continuously exposed to that concentration, 24 hours a day for an entire lifetime, the annual dose to the lung would not exceed 1.5 rem. The resulting effective dose equivalent (i.e., the dose to the entire body resulting in the same level of latent cancer risk) based on more recent recommendations of the International Commission on Radiological Protection (ICRP Report 26 and 30) would be about 12 percent of the lung dose equivalent, or about 180 mrem/yr. As shown in Table 4-6, that commitment is about the same additional dose experienced each year from naturally occurring radon in typical American homes. Given that the projected 50-year committed effective dose equivalents, from all the hypothetical serious accidents, in Tables 4-4 and 4-5 are all less than the annual "permissible" doses presented in 10 CFR Part 20 for planned, normal operations of licensed nuclear facilities, the reader should feel reassured that the risks associated with the Ulysses Project are quite small, and are within the normal range of exposures from naturally occurring radiation which no one can avoid.

half-life of Pu-238, which is nearly 90 years. Give the 10 CFR 20 permissible level in air, which are measured in much less than a millionth of a millionth of a millionth of a curie per milliliter. Explain that plutonium-238 is 300 times more toxic, gram for gram, as is the more familiar plutonium-239, and that Pu-239 is something like a thousand times more toxic, gram for gram, as is cobra venom. Explain that the amount of plutonium available for release from Ulysses is the equivalent, in terms of activity, of on the order of all the plutonium isotopes released from U.S. atmospheric testing. This is a huge source, and if even a small fraction gets out, the effect could be devastating. 8-38

2-12 This page is among the most misleading in the entire DEIS. I have been unable to locate the Turi citation (it is not a published technical paper, but a declaration in a law suit.) I have, however, reviewed some of the literature about the actual tests that have been peformed, and this is an extremely inaccurate summation of them.

The explosion tests did not result in the modules being undamaged at overpressures up to 2210. At 735 psi, the aeroshell was broken and one of thhe impact shells was broken. AT 1035, "all graphite components were stripped from the fueled clads." At 1300-1800 psi, "the test resulted in complete destruction of the RTG and the GPHS test module." And so on...

The "solid propellant fires" makes it sound like lots of tests, involving "clads" in the plural, engulfed in a huge, long-lasting fire. There was only one bare fueled clad and one impact assembly. These were not in the midst of a huge fire, but rather placed near a cube of burning propellant, which they were only in contact with "initially." The entire fire lasted only 10.5 minutes. This makes good copy if the details aren't told, but tells next to nothing in terms of real risks in accident situations.

The passage on high velocity fragments implies that the fueled clads passed these tests with flying colors. For tests 1 through 5, the test bullets breached the fueled clads in three of the five tests. In one case, a weld unzipped nearly all the way arond the fueled clad. In the second, a large hole was observed on vent-cup impact face. In three of the five cases, iridium/aluminum reaction was observed, indicating a continuing problem with potential materials interactions potentially affecting integrity. The next series of tests, with titanium bullets, resulted in breaches in three of three cases. 8-39

In the aluminum plate fragment test, "this test resultd in the fragment completely slicing through all four (4) fueled clads."

The claims about reentry are pretty misleading. First of all, what is not said, is that the reeentry analysis concluded that "reentry of bare fuel clads will result in melting and loss of the iridium fuel clad and some vaporization of the fuel." Secondly, the claims about the GPHS modules surviving with wide margins is based almost entirely on calculations, not tests, and the actual calculations showed the safety margins in several cases to be negative! (i.e., failure was predicted). The analysts subsequently threw out these calculations of their own that produced the unhappy results, a pattern that exists throughout this data set, with calculations or test results that showed failure of the RTG components in accident environments.

Finally, the claim about GPHS modules designed to survive impact is undocumented. I would very much like to see the original design specifications and testing that went into the design to demonstrate that they could meet those criteria.

The claims at the bottom of the page about iridium are undocumented. Are you talking about the characteristics of pure iridium, or of the particular iridium/tungsten alloy? What data do you have 8-40





Response to Comment No. 8-39

See Response to Comment Nos. 2-5, 3-3, 4-3.

It should be noted that in the explosion tests, the fueled clads were not breached by the explosion shock field at overpressures up to 2200 psi. When the statement was made that the RTG and the GPHS test module were destroyed in tests at overpressures in the range of 1300 -1800 psi, it was meant that the graphite components of the GPHS were completely removed and destroyed as well as the simulated RTG shell, but the fueled clads were intact.

The observation that only one bare fueled clad and one impact assembly (i.e., graphite impact shell - GIS - with two simulant fueled clads) were used in the solid propellant fire test is correct. However, testing with post impact shell assemblies (PISAs, equivalent to the GPHS fueled clads) and fuel sphere assemblies (FSAs, equivalent to the GPHS GISs with fueled clads) had been performed earlier on the MHW program. The design of the MHW used the same three basic materials, plutonia fuel, iridium alloy, and carbon-carbon composite graphite. As implied above, the GPHS fueled clad and the MHW PISA are very similar in configuration; the MHW PISA contains 100 watts (thermal) of fuel compared with 63 for the GPHS fueled clad. Since the two material systems and configurations are similar, the results from both test programs are representative for Galileo and Ulysses.

The fact that the GPHS bare fueled clad and the impact assembly were placed initially next to the face of the cube of burning propellant was done to facilitate the placement of the very hot test articles (having been preheated to around 1,100°C) next to the solid propellant without igniting the propellant prematurely. Also, experience from the MHW tests showed that it was difficult to place the hot test articles (the MHW test articles were also preheated) on the solid propellant and have them remain there. They tended to bounce and roll when dropped onto the propellant. It is true that the fire lasted only 10.5 minutes, but that is the longest possible duration that could exist with the fire not contained (i.e., as opposed to being contained in a combustion chamber where the resulting pressure would enhance the burn rate and result in even a shorter duration). That time represents the burn time to progress through the total web thickness as fabricated. In the tests, the burn time was further enhanced by inhibiting all but one face available for combustion in the test. The net test effect is similar to directing a solid rocket motor nozzle exit flame at the test articles. In the real accident situation, the propellant would be broken up, at least partially, with the SRB propellant cases having been ripped open. The propellant would be burning on all exposed surfaces which would significantly shorten the duration of the fire.

In the aluminum bullet tests, three of the five tests did result in breaching of the clads. But, these three tests were at test velocities that were over a factor of two (> 2x) higher than the highest velocity defined for most of the fragments. Also, in the titanium bullet tests, those velocities were also higher

by a factor greater than two (> 2x) than the highest fragment velocities. Therefore, the fueled clads should survive small fragment or shrapnel type impacts without release of fuel. It should also be remembered that the aluminum bullet tests were performed on bare half-module test articles, and the titanium bullet tests were performed on bare fueled clads. Neither of these configurations would exist at the initiation of the accident scenarios. The configuration exposed to the small (and large) SRB fragments would be the full RTG. Thus, the GPHS modules would be protected additionally by the converter shell and the multi-layered insulation and unicouple assembly. The additional protection would further ensure that the clads would not be breached.

The aluminum plate fragment test (i.e., edge-on, 0.125 inch thick, 3000 fps) was an idealized test. The velocity was chosen to represent the upper end of the possible range that could be generated in an auxiliary tank explosion. The only tank that could have generated this magnitude velocity is the He tank in the retropropulsion motor system of Galileo (this tank is not applicable to Ulysses). Possible fragments from all other auxiliary tanks for either Galileo or Ulysses do not exceed 367 fps (112 m/sec). The He tank is 17.5 inches in diameter. Fragments from this tank would thus have a significant curvature such that the mass of the fragment could not act in line with the edge of the fragment. In the test, the fragment used was a perfectly flat plate oriented with the total mass acting in line with the edge. This test, also, was performed on a bare GPHS module, which configuration would not exist when the accident occurred. The module would be additionally protected by the RTG case and insulation system.

None of the re-entry situations for Ulysses result in bare clads being subjected to the re-entry environment. Therefore, the bare clad re-entry is not a feasible case and the clads will not fail. The thermal and ablation design of the GPHS for an orbital decay re-entry has been certified as a complete system with full scale models subject to tests in the 20Mw arc jet facility at NASA/Ames. The test models in the broadside stable (i.e., worst case) orientation were subjected to heating equivalent almost to five (5) times that predicted for orbital decay before the aeroshell was completely ablated on the leading face. The graphite impact shells (GISs) were still retained within the aeroshell body after the leading face was totally ablated in the test. The ablation predicted by analysis for this type of re-entry (i.e., orbital decay) is in the range of 22 - 29 percent of the minimum aeroshell thickness.

The statement that the claim about the GPHS modules designed to survive impact is undocumented is incorrect. The design requirement given in the Product Specification for the General Purpose Heat Source, CP47A14635, is as follows: "The Fueled Clad (FC) shall not be breached when the heat source module is subjected to reentry-equivalent, terminal velocity impact tests." If the Ulysses SSR were to be reviewed, Section G.2.5 in Appendix G, Book 2, Volume II, Accident Model Document - Appendices, (DOE 1990b), presents the complete detailed test

program in which the impact capability was verified (i.e., the Safety Verification Test - SVT - program). Tests in this series were performed at 10 percent above sea level terminal velocity, and the impacts were done mostly on thick steel. Some of the fueled clads in these modules did breach with release of small quantities of fuel (around 0.14 percent maximum) largely confined within the graphite module components. Tests on concrete, even at the higher than terminal velocity impact did not result in breach. Impacts on concrete surfaces (or rock) would be much more likely to occur in an actual re-entry than impacts on thick steel.

about the particular alloy and its respones? You say, also , it resists oxidation in air to 1000 C. but elsewhere indicate the temperature at launch, while being cooled, is on the order of 1100 C. What is the oxidation effect of years of sitting around with the heat of the plutonium decay inside. Against, what about the alpha bombardment, helium buildup, temperature effects, materials interactions with graphite and other materials, and why such strange materials interactions in the impact and other tests if the material is so stable? — 8-40

More details should be provided about the vents--how they can over long periods of time release the helium generated inside the clad while preventing the release of the plutonium. It would appear a strong contender for a failure point--what failure analyses have been done of the vent? — 8-41

2-13 is quite understated about the past accidents. The SNAP-9A was not "peformance as intended." Give the official estimates of the probability of that accident happening that existed before the launch. Burnup was not designed against because it was deemed non-credible to occur. It was a terrible accident; tripling worldwide plutonium-238 inventories, spreading it worldwide. Analyze the accident in more detail. Give the data from Project Stardust, which tracked it. What was the measured particle size? How does that correspond to the assumptions used in the DEIS for assuming so much of the plutonium will be in non-respirable sizes so you don't have to count it? — 8-42

2-14 You should provide all the data available to demonstrate that the SNAP 27 indeed is intact, has released no radioactive material, and is likely to remain that way for the next 2000 years. What measurements have been made, how frequently, how recently? You say there is "no evidence" of any release. That can be a slippery kind of sentence. What evidence exists to the contrary, that there has been no release? — 8-43

2-17 The effect on RTG plutoniu release of the range safety officer detonating the range safety devices at various times to destory the vehicle is not clearly assessed in the DEIS. — 8-44

2-18 The basis for the claim of no Titan IV is a non-available letter, from one NASA official to another, not anything from the Air Force itself. Since the letter is dated mid-January, and the DEIS had been in preparation for many months prior to that and was only released a couple of weeks later, it would be very good to see the analysis NASA had performed of the environmental impacts of the delay alternative when it thought there was a Titan available in the near-term.

Secondly, the fact that Air Force doesn't want to give NASA a Titan doesn't mean that one can't be made available. For example, the President has to sign off on the Ulysses nuclear mission. If INSRP, or NASA, asked the President, saying there were major environmental risks in doing this mission on the shuttle, the "environmental" President may well tell the Air Force to provide such a Titan. Additionally, with the Cold War winding down, what wasn't available last month because of military reasons may become in fact surplus soon. The DEIS is to review alternatives; this DEIS should have reviewed that alternative, and if there were environmental advantages to it, the Air Force should be pressed to make the Titan available. — 8-45

Furthermore, even if true none is available before 1995, there is nothing in the DEIS to convince one that waiting until 1995 to do it safely isn't better than doing it dangerously today.

2-19 The DEIS says explicitly, "This EIS does not consider a delay of the launch as a separate alternative." We remind you that in response to our comments to the Tier I DEIS, NASA said over and over again, it would keep open the delay alternative. (See Tier I EIS, Tier I, appendix with NASA responses to CBG comments.) The argument is misleading, saying delays involving "the — 8-46





Response to Comment No. 8-40

The statements about the characteristics of the iridium apply to either the pure iridium or the iridium alloy used in the GPHS design. There is negligible difference in the temperatures quoted, and the material compatibility in the three material system (i.e., plutonia fuel, iridium, carbon-carbon composite graphite) of the GPHS has been shown to be very stable as is the pure iridium. In the launch situation and until deployment from the Space Shuttle in space vacuum (as well as for all ground handling operations prior to launch), the interior of the RTG is filled with either argon (for ground handling and storage) or xenon (for launch). The RTG interior, and thus the GPHS modules, never operate in an air or oxygen environment. At the 1090°C launch temperature, the iridium is not exposed to an oxidizing environment. There is no effect of the radiation from the plutonia fuel on the oxidation of the iridium since it is never in an oxidizing environment. As previously stated, the GPHS (i.e., plutonium fuel, iridium, carbon-carbon composite graphite) has been shown by prolonged testing to be an extremely stable and compatible system under the operating environment for which it has been designed, including the radiation field, helium buildup and release, and temperature. Iridium can react with other materials to form eutectics if the proper combinations of configuration and other environmental conditions are present. The reactions seen in some of the safety tests were artifacts of characteristics of the test conditions and materials used and even in these cases little or no fuel escaped from the capsules. Materials including iron, aluminum, nickel, chromium, silicon, manganese, and tantalum will form eutectics with iridium. These materials are found as trace elements even in pure iridium, and they exist in the iridium alloy used in the GPHS, generally in concentrations of a few tens of parts per million.

Response to Comment No. 8-41

The vents in the GPHS fueled clads are made of sintered iridium powder bonded to relatively thin iridium sheets; the whole vent assembly is seal welded into the interior of the iridium clad. A pinhole (about 0.017 inch dia), through the clad, provides a gas passage from the vent. Since the sintered iridium vent is porous, helium generated in alpha decay can escape. The gas pathway is tortuous and the pores are small compared to most particulate material, thus minimizing passage of the fines material. However, some fuel material in the form of vapor resulting from its vapor pressure at the temperatures of test and over the extended periods of storage has been found to have transported through the vents and then to have been trapped in the GIS graphite matrix essentially on the inside surface. The vents have not been found to be a failure point, even under the severe test conditions applied in the several safety test series, including the SVT impact tests, the large SRB fragment tests, the bare fueled clad tests, and the (SRB) fragment gun tests.

Response to Comment No. 8-42

On the contrary, the SNAP-9A performed exactly as designed to do in the re-entry environment. It was designed for complete burnup and dispersal in the upper atmosphere, regardless of the magnitude of the probability estimated for the accident. The fuel in the SNAP-9A was plutonium metal, not the plutonium dioxide refractory ceramic used in the GPHS. These two fuels are vastly different in their response to the accident environments. In the SNAP-9A accident and re-entry, the arithmetic mean particle size was measured to be 10 micrometers with a range of 5 - 58 micrometers. There is no assumption needed in this regard. The data exists as a result of all the safety tests performed. The fines fraction of interest from an inhalation standpoint (and this is the dominating hazard) is in the size range of 20 micrometers and smaller. In this size range, the typical mass fraction of the fuel resulting from the tests has been in the range of 0.3 - 1.5% of the total fuel particulate distribution.

Response to Comment No. 8-43

See Response to Comment 8-31.

Response to Comment No. 8-44

As noted in the FSAR, Volume II, Book 1, Section 3.2, page 3-1, (DOE 1990f) the RSS destruct accident scenario is an insignificant contributor to risk. For this reason it was not included in the consequences analyses of the FEIS. The accident was evaluated in FSAR Volume II, Book 1, Section 3.4.5.5, pages 3-69 to 3-73. The Range Safety Destruct is essentially the same as a Random Case burst. Inadvertent destruct is a very low probability (less than 1 in a million) event.

Response to Comment No. 8-45

The U.S. Air Force notified NASA that a Titan IV vehicle would not be available to serve as an expendable launch vehicle (ELV) back up to the Magellan, Galileo, and the Ulysses missions scheduled for launch in 1989 and 1990. For instance, the Galileo DEIS (Tier-2) included a delay alternative based on the presumed availability of the Titan IV for the 1991 Galileo launch opportunity. (Even though NASA was so informed, it was decided to release the DEIS including the alternative because the document was so close to publication.)

NASA has continued periodically to check with the U.S.A.F. on Titan IV availability through the NASA Office of Space Flight which coordinates interagency launch service activities. The memorandum from the Deputy Associate Administrator was intended to document the status just prior to publication of the Ulysses DEIS (Tier-2). Even if the U.S.A.F. made a Titan IV available to NASA at this time, it would still require a minimum of three years to make mission-specific modifications and would require refueling of the RTGs. So an ELV is not a feasible alternative for the 1990 or 1991 launch opportunities. See also Response to Comment 2-21.

same systems" do not yield different impacts; it is, of course, delays involving different systems that produces the markedly reduced environmental impacts. 8-46

2-22 Here is the central failing of the DEIS. You consider only impacts of doing it your way, or not doing it at all. You do not analyze the impacts of alternatives. You have failed your NEPA responsiblity. 8-47

2-24 This is a bypassing of public participation, a shielding from public scrutiny the basis for your environmental decisions, by making the EIS dependent upon the SAR which is not available to public comment and review in their comments on the DEIS. 8-48

The probability and consequence figures given are absolute nonsense, have no relation to the real world, and cannot be relied upon. It will be recalled that similar numbers utilizing similar methodology had to be retracted by the NRC regarding the WASH-1400 report, cited here so approvingly; the peer review concluded that the absolute figures could not be relied upon at all. 8-49

The calcuations use means, rather than ranges with uncertainty bands; estimates of uncertainty are not propagated through the steps of the calculation; real data are thrown out and more favorable estimates thrown in. The DEIS should have a decription of a good test of this methodology upon which it is relying: how good were the estimates for the SNAP-9A accident and the Challenger accident? If you predicted them accurately, then one might rely on the claims here; if the predictions were underpredictions by many orders of magnitude, a multiplier of that same magnitude should be included to correct these estimates here. 8-50

2-26 Now you say merely "some" of the data from Ulysses would be lost were there a delay. Which is it, all or some? How much is some? A little, a lot? 8-51

What about a Soviet launcher? 8-52

The claim of no launcher before 1995 implies you can't get the Air Force to change its mind. This is a DEIS for a federal action; alternatives must be considered; if a Titan is an environmentally favored alternative, the federal action should be taken in that direction. 8-53

4-1 This entire section is based on an FSAR one doesn't have yet. The discussion trivializes plutonium risks and does a disservice thereby. It implies plutonium isn't a problem because it is nonsoluble; you can drink it or eat it and it will go right through you. The larger inhalation risk is trivialized by assuming a particle distribution such that you can breath in large amounts and they will supposedly be breathed out or otherwise not deposit in the lung.

If this were right, one could sprinkle the world constantly with huge quantities of plutoniium and there would be no health impacts. However, plutonium is one of the most toxic materials on earth, and this kind of trivialization does a real disservice. 8-54

Yes, some forms of plutonium are largely insoluble; but that merely means the acceptable concentrations in the insoluble form are a couple of orders of magnitude higher than in the soluble form; it remains a very toxic material, even in minute quantities. And yes, particle size matters; but there is no basis for automatically assuming the particle size distribution will be such that one can inhale large quantities of plutonium and have no health effects.

The amount of plutonium available for release in an accident is huge; the health effects were a major fraction released is in the thousands or tens of thousands; and the DEIS has not been direct and explicit in the reduction factors it has thrown in to get the health effects down to zero.



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

Response to Comment No. 8-46

The delay alternative was eliminated because (a) a delay and launch on the Shuttle at a later time is not a different alternative and (b) the delay for use of alternative launch vehicles or power sources would constitute an indefinite delay since neither the availability of an ELV or a solar power alternative can be assured.

Response to Comment No. 8-47

The range of reasonable alternative have been identified and addressed. Since the proposal is to launch during the next available launch window, which is October 1990, or in the back up opportunity in November 1991, the range of feasible alternatives is limited to those which are reasonable for the timeframe of the proposed action. As noted in Response to Comments 7-4 and 7-5, the change to another launch vehicle or energy source will modify the mission. Therefore, only the alternatives discussed in Section 2 of the EIS are deemed feasible.

Response to Comment No. 8-48

The FEIS is based on the FSAR which has been publicly available since March 14, 1990. The DEIS was based on the SSR which used the same methodology as the FSAR.

Response to Comment No. 8-49

NEPA assessments must be supported by credible scientific evidence, not be based on pure conjecture, and be within the " rule of reason." We believe that the Ulysses FEIS represents the sound assessment of possible risks from hypothetical, low probability, catastrophic accidents and is responsive to both the spirit and letter of NEPA.

The development of the methods used in the risk analyses are described in Appendix B. As noted there, they are based on actual testing data, and reconstruction of accident environments from such accidents as the Challenger accident.

Response to Comment No. 8-50

In actuality, ranges are used. The methods are described in the FSAR (DOE 1990g), and in Section 4 and Appendix C of the FEIS.

Response to Comment No. 8-51

The extent of the data loss depends on how long the delay is and how serious its consequences are. Delaying the launch from '90 to '91 would result in slightly less power at end-of-mission and in the extended mission (provided one is eventually approved and funded). There would then be some data loss because there would have to be power rationing.

For launches after 1991, the RTGs would have to be refueled with new plutonium dioxide fuel. The minimum power required to heat the spacecraft and operate the spacecraft systems at Jupiter, the greatest distance from the Sun that Ulysses would travel, is 260.5 watts. If the power falls below this minimum level, the spacecraft systems and/or thermal control system elements would have inadequate power to function. For a 1992 launch, the estimated power output of the RTG at the time of Jupiter flyby is 258 watts. These power levels are insufficient to support the mission requirements.

Response to Comment No. 8-52

See Response to Comment 7-5.

Response to Comment No. 8-53

See Response to Comment 2-21.

Response to Comment No. 8-54

See Response to Comment 8-48.

It was not the intent of the DEIS discussion to trivialize plutonium risks, but to realistically estimate the potential impacts of hypothetical accidents. Because there have been no statistically measurable increases in the spontaneous risk of latent cancer among workers who were exposed to relatively high concentrations of airborne plutonium as the result of accidents in the workplace, we have taken the conservative approach recommended by various advisory bodies (e.g., ICRP, NCRP, BEIR IV, etc.) and assumed there is no level of radiation exposure below which the risk is zero (i.e., the linear, non-threshold hypothesis). All of the BEIR committees have consistently noted that the risks from exposure to very low doses of radiation given at low dose-rates may include zero (including BEIR V).

With regard to the suggestion that the particle size distribution was selected "such that one can inhale large quantities of plutonium and have no health effects," we reiterate that only small particles (e.g., less than 10 um) can be inhaled deep into the pulmonary portion of the lung where deposition and biological damage can occur. The particle size distribution is based on experimental results which simulated the expected environment of a launch accident, and it is the only data available for NEPA impact analysis. Clearly, the commentor assumes that because large quantities of plutonium are present in the RTG, large quantities of plutonium will be inhaled as the result of hypothetical accidents, but the facts show that this is simply not true. As shown in Tables 4-4 and 4-5, the potential 50-year doses are quite small (much smaller than estimated for workers who have been exposed in workplace accidents), and therefore the quantities of plutonium inhaled would also be quite small. As noted in responses to the Galileo DEIS (Tier 2), (NASA 1989a), the dilution of the respirable particle sizes in the huge explosion fireball postulated at launch followed by further atmospheric dispersion as the cloud is transported off site results in extremely small concentrations of respirable plutonium in off site locations where members of the public might be exposed.

The DEIS should do the following: calculate the health effects (without de minimus, which BEIR V has once and for all killed off--there is no basis for a threshold assumption) for release at high altitude, and then at lower altitude over populated areas, of 50% of the RTG plutonium, in respirable size. It will be many thousands or tens of thousands of cancers. Then show us, step by step, how you managed to reduce that estimated environmental impact by assumptions about tiny release fractions, particle size, and so on. Then the public can readily assess whether the agency has adequately assessed the risks from this proposed activity. 8-55

Somehow, fudge factors of an aggregate five orders of magnitude have been used. You should spell them out.

I would prefer to await commenting in more detail on this section until I have been provided the FSAR upon which it is to be based, because it consists primarily of unsupported conclusions. One comment about p. 4-18--if you use NRC Reg. Guide 1.86 standards for release of formerly used research reactor facilities for unrestricted use, and employ the transuranic standards, as you should, a few curies of plutonium can contaminate an area on the order of 100 square miles to levels not permitted for release for unrestricted use. You should be using such transuranic standards, not the gross 25 mr/yr figure. Furthermore, note that EPA has just released new standards which set permissible doses at 10 mr/yr from airborne contamnation. And when you tell the public 25 mr/yr is acceptable to you, put that in terms they can understand: that means they can get the equivalent of an extra chext X-ray each and every year from the contamination. 8-56

The primary point about the summary of the risk estimates, the details of which are not included, is that there appears to be massive underestimation of both probability and consequences of such an accident. Actual failure data are at about 15%, orders of magnitude higher than assumed here; SNAP-9A alone released about 18,000 Ci of Pu-238, many orders of magnitude greater than you have assumed in this analysis. After each accident, one corrects the previous mistake and assumes everything now is safe; but there is always a new accident waiting, for which one has not prepared. 8-57

Don't you think it would be more sensible to wait a little while and use a solar power source that can't kill tens of thousands of people if the unexpected occurs? Accidents do happen, even when we predict they won't.

Solar can perform the mission, and no one can die from an accident involving it. Sounds like a worthwhile alternative that should be considered. 8-58



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

Response to Comment No. 8-55

See Response to Comment 8-54.

Response to Comment No. 8-56

Use of NRC Regulatory guide 1.86 (Termination of Operating Licenses for Nuclear Reactors) is inappropriate for addressing the issue of mitigation of potential impacts of severe hypothetical accidents.

While it is true that, hypothetically, a few curies of plutonium can contaminate a large area of land to unacceptable levels, the distribution of released material must be considered. Nature simply does not uniformly distribute airborne materials on the ground from a release point. Rather, the much smaller areas closer to the source of the release are contaminated to higher levels than the much larger areas many miles away from the release point.

With regard to the EPA standards mentioned by the commentor, these standards (the National Emission Standards for Hazardous Air Pollutants, or NESHAPs) are only applicable to compliance relative to normal, planned emissions from Federal facilities (54 FR 51654, December 15, 1989), and as such, are inappropriate for use with hypothetical, low probability, severe accident scenarios in NEPA documents.

Response to Comment No. 8-57

SNAP 9A was designed to burn up in the atmosphere. During the launch abort in April of 1964, the Transit Satellite re-entered the atmosphere and burned up releasing 17,000 Ci of Pu-238. Since 1967, the RTGs have been designed to survive re-entry. Two cases demonstrate the success of this design: (1) the re-entry of the Nimbus Satellite in May 1968, and (2) the jettison of the RTG in April 1970, when Apollo 13 aborted its lunar lander. Therefore, the estimated releases from accidents with current RTG design is far less than experienced with SNAP 9A.

Response to Comment No. 8-58

See Response to Comments 4-7 and 4-8. Also, it should be noted that extensive testing and safety analysis indicate that "tens of thousands of people" would not be killed from even the worst accident.

**COMMITTEE TO BRIDGE THE GAP**
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20 December 1989

Dr. Dudley G. McConnell
Deputy Director, Advanced Studies
Solar System Exploration Division
Office of Space Science and Applications
Code EL
National Aeronautics and Space Administration
Washington, DC 20546

BY EXPRESS

Re: Scope of Ulysses DEIS; 54 FR 48168

Dear Dr. McConnell:

Thank you for your letter of 4 December, identifying an error made in the NASA Notice of Intent to Prepare a Draft Environmental Impact Statement for the Ulysses Mission, currently planned to utilize a large plutonium power source. Whereas the Federal Register notice gave members of the public until January 22, 1990, to submit comments concerning the scope of the planned DEIS, your letter shortens that to December 21.

Our comments are as follows:

The National Environmental Protection Act (NEPA) mandates that NASA perform an environmental impact study of the proposed nuclear-powered Ulysses mission because it is a major federal action that could have a significant impact upon the environment. The particular concern here is that an accident could release a very large amount of toxic plutonium. To put the seriousness of the matter in perspective, an accident releasing the Ulysses' plutonium would add to the atmosphere the equivalent plutonium from roughly a third of all nuclear weapons tests that have ever occurred by all the world's nuclear powers since the beginning of the nuclear era. The number of cancers produced could be on the order of those estimated to be produced from the Chernobyl accident.

Thus the environmental risks are serious, and the environmental review should be conducted seriously, without pretense, without just "going through the motions," without preconceived conclusions. I must say that in reviewing the Federal Register notice outlining the proposed scope of the NASA DEIS, a strong impression is given that NASA is not approaching its environmental review responsibilities with the seriousness that both the NEPA law requires and that the potentially catastrophic environmental impacts morally would demand. One comes away with the clear impression that by artificially narrowing the scope of the DEIS, NASA is setting up the question in such a way that there can be only one answer--the desired approval of the mission which NASA wants. That is not good science and not honest compliance with NEPA.



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

In particular, the Federal Register Notice announces that NASA intends not to look at an alternative launch configuration that might be markedly safer than using the Shuttle. While NASA must recognize the possibility that a significant safety enhancement might arise in not having to place a huge amount of plutonium at the center of dozens of tons of what amounts to high explosive (the Shuttle rocket fuel), which is then ignited, you then forbid any consideration of the alternative, the Titan IV configuration, because it would allegedly entail delay. You define the only alternatives as two: proceed with plutonium power launched via Shuttle in October 1990 or in the backup opportunity in 1991, or cancel completely further work on the mission. Surely NASA must realize that by establishing so narrow a set of alternatives it has preordained the answer to the study and blatantly evaded the NEPA requirement of a "hard look at alternatives."

NASA excludes alternative launch configurations from consideration and alternative power sources. In so doing, how can it be said that NASA has fulfilled its NEPA responsibilities of a hard look at alternatives? You have excluded all alternatives from consideration, essentially arguing "either do it my way or do it not at all, we won't look at other options." This flies in the face of NEPA and of honest science.

The Federal Register Notice makes the argument that using the Titan (and one presumes, use of a less dangerous, non-nuclear power source alternative) would entail delay, which would add cost, affect personnel groupings, and "threaten" acquisition of certain "key" scientific data. These are important arguments--which should be contained in an EIS which balances the costs of delay, financial and otherwise, against the prospective environmental and human costs (e.g., the potential for many thousands of cancer deaths) of not using a safer alternative, even if that results in delay. While a case can be made that the dollars involved in the delay are more important than the potential for such a number of deaths--or that the unspecified fraction of the scientific data that might be lost by delaying for a safer alternative launch configuration or power system outweighs the risks of the environmental insult possible in case of severe accident--that case should be made in the EIS, subject to public scrutiny and review. Instead, NASA has precluded that weighing of alternatives by a couple of conclusory sentences in a Federal Register Notice.

So, our comment to NASA on its proposed scope for the EIS is that NASA has artificially and improperly narrowed the scope so as to yield a predetermined answer, rather than complying with the NEPA requirement for a "hard look" at the alternatives--different launch configurations and different power systems. In particular, the alternative concentrated solar power sources proposed by JPL with regards the Galileo, but which were apparently kept out of public discussion of Galileo alternatives in the EIS context, should be examined thoroughly. Public confidence in these missions cannot arise if NASA knows of alternatives--Titan launch configurations and non-nuclear power sources--and does not examine them thoroughly and openly.

If the costs of alternatives, particularly in terms of genuinely irretrievable loss of crucial scientific data, clearly outweigh the risks of launching very large quantities of plutonium aboard a Shuttle system which has already once suffered a catastrophic explosion, then defend that in the EIS. Tell the public honestly what fraction (1%?, 10%?, 99%) of the planned data acquisition from the mission would be irretrievably lost were NASA



RESPONSES TO COMMENTS
Commentor No. 8: Committee to Bridge the Gap
(Continued)

required to wait and use a safer launch or power system. Explain this in detail, and let it be weighed against the prospective injuries in case of catastrophic accident involving the more dangerous system proposed for use to avoid delay. Conclusory statements in a Federal Register notice restricting the scope of the EIS do not meet the NEPA, and moral, requirements of a hard look at alternatives.

A second comment is in order about the appearance of lack of seriousness about honest compliance with NEPA, which mandates a genuine opportunity for public comment on the appropriate scope of NEPA reviews and detailed opportunity to review the adequacy of such reviews. NASA gives itself years to prepare NEPA documents and a mere weeks for the public to comment. And in this case, even with the shortening of the comment period down to December 21, it is hard to believe NASA is serious about soliciting public comments by late December on the appropriate scope of a DEIS when the notice of solicitation says the DEIS in question will be published in January! The DEIS is a very detailed document, long in preparation. How can the public believe that NASA is genuine in its intention of listening to public comments about the scope its DEIS should take if it has arranged to receive those comments only a few weeks before its DEIS, many months in the creation, is due to be published? If public comments about scope were to be heeded, NASA has left itself no time to do so, making it appear that there was from the outset no intention of listening to any of the public comments NASA had solicited as to the scope of the DEIS. (If the scope is enlarged for the Final Environmental Impact Statement, that will be too late, because it will preclude public comment on the content of the widened EIS.)

Thank you for the opportunity, limited though it may have been, to comment upon NASA plans for the scope of its DEIS. May I say that it is in NASA's interest, as well as that of the environment, for compliance with NEPA to be somewhat more vigorous, involving a more genuine review of alternatives and opportunity for public comment? Bypassing these requirements now only undermines public confidence later when NASA wants to go ahead with these nuclear missions and adds to the controversy over their safety. If there are safer alternatives, use them; if there aren't, permit the alternatives to be honestly weighed and publicly reviewed.

The Committee to Bridge the Gap stands ready to assist in any such review. Please keep us on any mailing list for documents related to nuclear power in space.

Sincerely,

Daniel Hirsch

Daniel Hirsch
President

I, Martha M. Early, state as follows:

1. I reside at 2330 Oak Street #5, Santa Monica, CA 90405.

2. I am a law student at Loyola Law School in Los Angeles, focusing my studies on Environmental and Administrative Law issues. My current project involves the Ulysses Mission and the legal environmental issues surrounding it. I am working with the Committee to Bridge the Gap, an environmental group which has a long-standing interest in these issues.

3. The purpose of this declaration is to explain the difficulty I had in obtaining documents related to, and referenced in, the Draft Environmental Impact Statement (DEIS) for the Ulysses Mission. The cover letter accompanying the DEIS directs interested parties to the reading room at Jet Propulsion Lab, which I visited on or about March 15, 1990. After that visit and a number of related phone calls, I believe that getting access to many of the documents is impossible in a practical sense.

4. Section 7 of the DEIS contains a list of the fifty-five (55) documents used to prepare the DEIS. Obviously, without these documents as back-up, the DEIS is merely a collection of conclusory statements. Before going to JPL, I marked approximately thirty-three (33) of the documents that I was interested in seeing. I made an appointment with Mr. Eric Hines, the reference librarian, who had the volumes of the GE Safety Status Report and the NUS Safety Status Report waiting for me. Mr. Hines went over my list of documents (copied directly from the DEIS), and said that most of them were not available in the library, but that he would try a different department. He phoned Ms. Debbie Christian, who said she would search for the documents, but that it would take at least an hour. I said I would wait, and she sent



**RESPONSES TO COMMENTS**
**Commentor No. 8: Committee to Bridge the Gap**
**(Continued)**

**See Attachment 1 to this Appendix, on page E-87.**

a messenger over to get my list.

5. I meanwhile began going over the Safety Status Reports. I asked if it would be possible to get a copy of the reports and was told by Mr. Hines that they could copy a certain number of pages, but not the entire document, because of the cost and manpower involved. I volunteered to do the copying myself, but they said there were no facilities for such copying. There is, however, as I understand it, a copying facility on the premises where I may have been able to order a full copy of the documents. Mr. Hines told me I could check out the documents if I had a library card from a Los Angeles Public Library.

6. About a half an hour later, Mr. Hines brought me a message that Ms. Christian had called back to say that all of the documents I was interested in were work documents which were currently, at that very moment, being used, so I could not see any of them. I found it difficult to believe that all were at that moment in use, so I called Ms. Christian's office, where I identified myself and was put on hold. Everytime the phone rang back to the receptionist I was told that Ms. Christian was either on another line or away from her desk.

7. At about that time, Ms. Christian's messenger, the one who had earlier picked up my list, came back into the library. I hung up the phone and asked her if I could go with her back to Ms. Christian's office. She said yes, but that she had to make some stops. I accompanied her on these stops, then on to the office. When I walked in, the receptionist and the other people in the office seemed very surprised to see me.

8. I never did see Ms. Christian. Instead, Mr. Reed Wilcox, the head of the department, walked out and introduced himself to me. We walked over to get my visitor's pass changed, then back to the JPL library. Mr. Wilcox was

helpful in explaining some of the technical aspects of the Ulysses Mission. He then looked through my list of documents, and asserted that many of them were not available at JPL. This was quite surprising after Ms. Christian's statement that the documents were indeed there, but unavailable because they were in use. Mr. Wilcox suggested other places where he thought I might find them, including the UCLA public affairs library or a Government Printing Office in Westwood (which doesn't seem to exist). [Note: I subsequently located another GPO facility; however, they said they would not have anything like the documents I needed. Additionally, the UCLA Public Affairs Library informed me that these were documents of a type they would not carry.] Mr. Wilcox also told me some of the documents might be impossible to locate, especially the personal letters listed. He said that he himself had been trying to obtain the letter from the NASA Deputy Associate Administrator for Space Flight to the NASA Deputy Director of the Solar System Exploration Division (Jan. 16, 1990). So I left JPL having seen only the GE and NUS Safety Status Reports, and having been told by Mr. Wilcox that JPL had very few of the other documents relied upon in the preparation of the DEIS. This was quite puzzling in that page 5-1 of the DEIS listed JPL as one of the two institutions which prepared the DEIS, and listed Mr. Wilcox himself as Supervisor of the Launch Approval Planning Group, and as the primary JPL official involved in writing the DEIS.

9. I later called Mr. Wilcox to see if it would be possible to either check out or get copies of at least the Safety Status Reports. He said that checking out the documents with the library card was impossible, despite Mr. Hines' statement to the contrary. He claimed that JPL had only one copy of these documents, but I had seen at least two while I was there. As to copying, he said that JPL may copy a limited number of pages (up to $25.00)

as a public service, but not more than that. He suggested that I call Dr. Dudley McConnell at NASA headquarters to get more information, which I did. Dr. McConnell said that NASA is not legally obligated to make all of the documents available in a specific place. As to the Safety Status Reports, he suggested that I call either NTIS or a Dr. Clark. Dr. Clark did mail me the Safety Status Reports.

10. Besides the Safety Status Reports and a few documents which have since been placed in the JPL reading room, many of the other documents referenced in the DEIS are still, in a practical sense, practically impossible to obtain, particularly in the time period provided for DEIS comments. I have found this DEIS process to be extremely frustrating, particulary since the DEIS itself consists largely of conclusory statements, referring the reader to underlying documents that assertedly provide the basis for the conclusions.

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge and belief.

Martha M. Early

Martha M. Early

Executed at Los Angeles, CA
this 4th day of April, 1990

The HERO Project
308 Boyd Ave.
Takoma Park, Md. 20912
(301) 270-8622

April 6, 1990

Dr. Dudley G. McConnell
Deputy Director, (Advanced Program)
Solar System Exploration Division (Code EL)
NASA Headquaters
Washington, D.C. 20546

Subject: Comment regarding the Draft Environmental Impact Statement for the Ulysses Mission (Tier 2)

"It's a world class electrical problem."

These are not my words, but the words of Mr. Steven Agee. Mr. Agee was hired in 1986 by Morton Thiokol as a safety consultant. This comment was made to "The Seattle Times/Seattle Post Intelligencer" and appeared in the May 22, 1988 edition. See Exhibit 1 - "Is the Shuttle Safe?" p3

My name is Patricia Axelrod. I am the same Patrica Axelrod who proffered expert written testimony in the case of Civil Action 89-2682 OG, Florida Coalition for Peace v. George Bush. I function as a research associate with Lancaster University, Richardson Peace Research Institute, Lancaster, England and I specialize in the research and study of the dangerous effects of electromagnetic radiation created by lightning, radar, and radio waves upon weapons systems, including missiles, rockets, and aerospace vehicles, such as the shuttle. This field of study is known by the acronym HERO, the Hazard of Electromagnetic Radiation to Ordnance. (The draft EIS distinguishes HERF, the hazard of electromagnetic radiation to fuel from HERO. I include HERF as a part of the overall HERO factor.)

I am also the founder and Director of The HERO Project, a weapons accident project dedicated to the researching the susceptibility of weapons systems components to electromagnetic radiation. The HERO Project works to inform and advise legislators, the media and the public, civilians and military personnel alike, as to the dangers of HERO and the likelihood of accidents caused by HERO.

It is my opinion that HERO poses a grave danger to the safety of the forth-coming Shuttle-Ulysses mission. Mr. Agee succinctly expressed my concern by his comment, "It's a world class electrical problem." Agee was hired by Morton Thiokol in 1986, after the Challenger explosion, as a safety "trouble shooter". Doing his job, he wrote 221 hazard reports, calling them "221

ways the space shuttle could blow up." Many of the hazards Agee identified dealt with the possibility that static electricity or lightning could set off the rocket's solid fuel. Additionally he reported numerous places in the rocket that were inadequately grounded, and thus HERO unsafe. Mr. Agee was persistent in his criticism of the Shuttle and consequently, Morton Thiokol "removed" him from his position. According to another former Thiokol employee, the company did widen one metal strap near the Shuttle's nozzle to better ground the rocket. Despite that, Agee remains certain that his reports were shelved and that much of his work was buried. My review of the HERO section of the Draft Environmental Impact Statement for the Ulysses Mission convinces me that he is right.

The six rather brief paragraphs beginning on pages 2-24 and ending on 2-25 most decidedly do not reflect careful HERO appraisal. I find that they omit important information, not only about Agee's findings, but about NASA's plans to relax lightning restrictions that might delay launch schedules.

Terms like; "EMI Safety Margins...[and]...radio frequency bonding, fault bonding and launch site bonding criteria, lightning protection criteria, lightning protection criteria, and launch commit criteria concerning weather and other considerations are strictly enforced" mean little or nothing to the average reader. Without basic HERO facts, and discussion of the Space Shuttle technology and its particular susceptibility to HERO, decisionmakers for whom this document was intended for, are unable to understand the real HERO dangers of the Shuttle-Ulysses mission. Therefore, the following information should be included in the text of the Final Environmental Impact Statement.

I. How HERO affects Space Shuttle technology

The Shuttle is a fly-by-wire vehicle. This means that it is computer driven and electronically commanded. Connecting the computer and the electronics are miles of wire, thus the term "fly-by-wire." Performance is solely contingent upon electrical signal. In addition to fly-by-wire technology, the Shuttle incorporates the use of electrically activated fuzes. In short, the Shuttle vehicle relies completely upon electrical signal to function. The failing of the Shuttle design is that it is prone to receive and respond to unwanted electrical signals. Unintentional electrical signals are created by electromagnetic radiation generated by radar, radio and microwaves, lightning and static electricity. The Shuttle's response to unwanted and unintentional electrical signals is called the Hazard of Electromagnetic to Ordnance, (HERO).

A. HERO can cause four Shuttle hazards. Any one of these hazards can cause Shuttle accidents.

1. Scrambling of electronic circuitry. This is called electromagnetic interference, EMI. This is similar to the the interference experienced by computers in an electrical storm or like the television that turns snowy when another electrical appliance is turned on in the same vicinity. The effect upon the Shuttle vehicle would be to cause either an wrong command signal which could override or confuse the correct signal. This occurred during a March 1987, Cape Canaveral launch of an Atlas-Centaur rocket. A four stroke flash of lightning struck within two miles of the Cape. Officials believe that this created "major electrical transients" causing the rocket's digital computer to issue commands to the engines that sent the rocket tumbling out of control. It was necessary to destroy the rocket causing the loss of $161 million dollars. (See Exhibit A, article entitled "Storm Effect Suspected in Rocket Loss" and Exhibit B, article entitled, "NASA Readies New Assault on Still-Mysterious Lightning")

2. Short or burn out of electronic circuitry as caused by surges or an overload of electrical power. This would cause fires inside the Shuttle electronics.

3. Prematurely activate or dud (meaning to render the component unable to function) fuzes via the fuze triggers called the electroexplosive device (EED). The EED is similar in design and intent to the blasting cap commonly used with dynamite. Anyone who has ever seen a sign warning: DANGER--BLASTING-TURN OFF TWO WAY RADIOS--is familiar with the failing of the EED, because just as the blasting cap, the EED will fire regardless of the source of the signal. The accidental firing of the electroexplosive device (EED) can cause the unexpected launch of the Shuttle and or the unplanned separation of the Shuttle booster phases as well as the failure of the stabilizing and guidance systems. Accidental EED firing occurred in June, 1987, when according to NASA officials, lightning ignited and launched three NASA rockets. (See Exhibit C, an article entitled, " Lightning Launched 3 NASA Rockets")

4. Explode Shuttle fuels. Electromagnetic radiation acts as match to gasoline and can serve to ignite and or explode solid or liquid fuels. This is known as the Hazard of Electromagnetic Radiation to Fuel. Recent explosions of solid fuel include the January 1985 explosion of Pershing II solid fuel at Fort Redleg, W. Germany and the explosion of the Morton Thiokol solid fuel plant at Promotory, Utah, Dec. 1987.

II. The Space Shuttle is at unique risk of a HERO accident.

A. The HERO risk of radio, radar and microwaves

The Ulysses mission involves enormous use of and reliance upon a variety of radio and radar tracking devices. Additionally, it can be anticipated that foreign governments may conduct radar surveillance of the launch as well. Each radio and radar device

creates its own individual emission of electromagnetic radiation and electrical signal. Combined emissions are called the electromagnetic environment. Contributing to the electromagnetic environment is the side effect of the coupling of two or more radio or radar signals which serve to create new, generally unplanned for radio signals. These are called "stray" signals. The Ulysses launch of necessity will create an extremely intense electromagnetic environment rife with undesirable signals. As such it is at extreme HERO risk.

B. Lightning poses a grave HERO danger.

Contributing to the electromagnetic environment is lightning and static electricity. Cape Canaveral Florida, is an area with a high occurrence of lightning and static producing thunderclouds. Electrically charged clouds, believed to be lightning conductive, pass over the Eastern Test Range more than 100 days each year, according to U.S. Air Force Col. John Madura. According to Madura, who heads the Eastern Test Range's meteorological program, the range (which includes Cape Canaveral and the trajectory of the Shuttle's flight) experiences thunderstorms every other day from May to September.

A rocket passing through a thunderstorm or an intense electrical field field forming in advance of a thunderstorm, can trigger lightning to strike the rocket, which can damage components in the rocket or payload (as evidenced by the accidental launching of the three NASA rockets and the explosion of the Atlas-Centaur previously mentioned in section I.) Of the 48 countdowns that were conducted at the Eastern Test Range from March 1989 to March 1990, 12 encountered conditions that threatened launch and 6 were scrubbed altogether because of lightning. According to Madura, current lightning restrictions bar flying through thunderstorm clouds less than three hours old out of concern that these clouds may not have yet dissipated their electrical charges.

Despite the extremely well documented risk that lightning poses, NASA has announced that it will commence plans to ease lightning restrictions. Of late other scientists dedicated to the study of the effects of lightning have stated that lightning is little understood and far more powerful than it was thought to be. It seems unwise, at best, for NASA to contemplate easing restrictions. (See "NASA, Air Force Plan Lightning Tests to Ease Launch Rules" and "Lightning Threat Underestimated", Exhibits D and E.)

C. Static electricity is another profound concern. As a rocket such as the Shuttle vehicle breaks through the sky, it creates friction, which can allow for a vehicle induced static charge. This can create electrical sparks or lightning trailers.

III. Adding to the HERO problem is the use of a wire insulation

All electromagnetic emissions are monitored and controlled to specified levels by the Range Safety Officer at all times prior to and during launch and landing of the Shuttle. This includes emissions from media telecommunications devices. The maximum emissions do not exceed 10 volts/m.

Response to Comment No. 9-7

There is a small amount of kapton on board the spacecraft. The Shuttle makes extensive use of kapton insulated wiring. About 90 percent of the wiring on board the Shuttle has insulation of this type. In areas where flexing capabilities are required, such as junction boxes, other types of insulation (e.g. teflon) is used. NASA is well aware of the "problems" with kapton insulation (i.e. its relative "brittleness" and its susceptibility to alkaline liquids which accelerate aging of the kapton). Counterbalancing the "problems" are the desirable characteristics of kapton. It is lightweight, has excellent insulating properties, and is nonflammable (i.e. kapton is self-extinguishing; it chars rather than ignites). As a result of extensive NASA review of the known limitations of kapton, several measures to protect this material in the Shuttle have been instituted. It is not used in locations where flexing can cause damage; it is not exposed to rain or water; it is bathed in cool, dry purge air while the Shuttle is Earthbound; a kapton Protection Program has been instituted to cover and protect the material (e.g. with foam or a wrap of some other type) in areas where it can be vulnerable to damage, such as in areas where manned maintenance activities occur; and NASA has an extensive training program for its maintenance personnel and others who may work inside the Shuttle, which also addresses the sensitivities of kapton and procedures and safeguards to be utilized when working around this material. In addition, there are strict limits on personnel allowed inside the Shuttle. Only specially trained personnel may enter.

The Commentor spoke about "fires" aboard the Orbiter Atlantis in 1983 and the Orbiter Columbia in 1989. The 1983 event involved Challenger, not Atlantis. These events were not "fires." The Challenger incident was an arcing event in kapton insulated wire in the Environmental Control Life support Bay under the deck of the crew compartment. A kapton wire had been inadvertently damaged and arcing occurred when the system was subsequently activated. Since there was no ignitable material at that location, the arcing lasted a few hundred milliseconds charring the kapton before the circuit breaker tripped. Redundant circuits were automatically activated with no effects on the crew or mission.

The event on Columbia in 1989 was an arc-tracking event in a ground-installed kapton insulated cable used to power a teleprinter installed temporarily for that mission. The cable was inadvertently damaged, and when the teleprinter was powered up in flight and the switch turned on, an arc-tracking event occurred, again charring the kapton. The event lasted 1.5 seconds with the kapton self-extinguishing. The mission was unaffected by this event.

Response to Comment No. 9-8

The SP4T switch is not used on the Shuttle. The S/N 10219 "switch" is probably not a switch but rather a serial or part number. In any case, this designation does not occur in NASA's inventory of electrical parts for the Shuttle.

Any inquiries regarding FBI investigations should be referred to that agency.

All components on board the Shuttle and the Ulysses spacecraft have been tested and certified for aerospace use.

Response to Comment No. 9-9

Any questions regarding Morton Thiokol employees should be addressed to that company.

Response to Comment No. 9-10

No.

called "Kapton". This insulation has been known to crack and break as it is twisted and bent, because it is inflexible. Shuttle construction requires elaborate bending and twisting of wires. When a break occurs, this essentially leaves raw wires exposed which allows for an arcing of electrical power from one wire to another creating fires. This has been well reported and documented. Kapton was used throughout the Shuttle vehicles resulting in documented incidents of arcing aboard the Atlantis and Columbia Space Shuttles. It is believed that the use of Kapton has contributed to as many as 219 fires aboard military aircraft. (See Exhibit F.) "Wired For Disaster"

IV. How a HERO accident would happen.

The smallest break, crack or discontinuity in the metal body of the Shuttle or the Ulysses payload can allow for an electromagnetic leak into the electronic circuitry or fuel. Entry may occur at rust or corrosion spots, maintenance portals, O-rings, gaskets, seals or manufacturing defects. If a leak occurs any one of the following accident or incidents could occur:

A. The explosion of the Shuttle while still on the launch pad as the fuel may explode or the electronic circuitry catch fire.

B. An incorrect signal may override the electronic circuitry and or electroexplosive devices that control the command and guidance of the Shuttle or Ulysses. This could cause either vehicle to head for an undesirable destination or to spin out of control and crash.

C. The dudding or the failure to act of either vehicle's electronic circuitry and electroexplosive devices. This would mean in effect that shuttle power could just turn off, causing it to fall out of the sky. The Ulysses is at risk of a similar fate if a failure should occur before it's nuclear power is activated.

###

I suggest that the Final Environmental Impact Statement for the Ulysses Mission include this information in its text as a framework for the paragraphs on pages 2-24 and 2-25. In the interest of elevating this document from a public relations rubber stamp to a meaningful discussion of the actual HERO risks, the following issues should be addressed. 9-1

1. Bonding and grounding to Military Standard B-5087B is a process tailored by each manufacturer to suit the parts components. There have been two recent explosions of solid fuel; the explosion of the Pershing II and the MX missile Morton Thiokol plant. Military standards did not prevent the explosion in either case. Define Military Standard B-5087B and its Shuttle and Ulysses application and testing procedures. How much electromagnetic radiation is shuttle fuel designed to 9-2





Response to Comment No. 9-1

The text of Section 2.5.1.2 has been revised to provide more discussion. It should be emphasized that the Ulysses mission is the focus of this EIS. All of the substantive issues raised in this portion of the commentor's letter are well known to NASA, and as indicated in the revised text, are subject to rigorous adherence to specifications, and testing and design reviews.

Response to Comment No. 9-2

Military Standard, MIL-B-05087B "Bonding, Electrical, and Lightning Protection for Aerospace Systems", prescribes the techniques used by NASA (and its contractors) in the protection of electronic devices, subsystems, and systems from currents induced by lightning. For lightning exclusively, two NASA documents prescribe additional requirements: JSC 07636 - "NSTS Lightning Protection Criteria Document"; and JSC 20007 - "NSTS Space Shuttle Lightning Protection Verification Document." The application of these standards, as well as the overall procedures followed to ensure electromagnetic compatibility of both Shuttle and payload systems are briefly described in the revised text of Section 2.5.1.2 (see Response to Comment 9-1).

The two incidents referred to are unrelated to NASA and were not under NASA jurisdiction or control, and any questions should be directed to the Department of Defense. The radiated electromagnetic fields required to ignite Shuttle fuels are far higher than any levels experienced at Cape Canaveral. The liquid hydrogen and liquid oxygen fuels are stored separately in the External Tank, and do not form an explosive mixture until combined and ignited in the main engines of the Shuttle. The Solid Rocket Booster (SRB) fuel, by virtue of being a solid, is essentially unaffected by the electromagnetic environment at KSC. The SRB fuel requires the extremely high temperatures generated by a NASA Standard Initiator to ignite. As noted in the updated text of Section 2.5.1.2, the pyrotechnic devices onboard the Shuttle are well protected against the electromagnetic environment.

The commentor also requested information on the number of waivers issued to "negate" Military Standard B-5087B. A waiver does not "negate" the standard; in effect, a waiver requires that more stringent measures be applied to components or systems that could be affected by waiving the Standard for a given component. It must be understood that waivers are not routinely granted on any Shuttle system or component. A waiver can be granted only when it can be conclusively demonstrated that added controls and safety margins to negate the risk associated with waiver of the standard have been instituted in the components and/or systems that could be affected. Waivers to Military Standard B-5087B are not granted for payloads.

withstand? How many waivers are issued to negate MilStandard B-5087B or parts thereof the standard. } 9-2

2. Military Standard E-6051D did not prevent the accidental launching of three NASA rockets and the malfunction of a Atlas-Centaur. How frequently is this standard or parts thereof waivered? What is the individual ER threshhold factor applied to the Shuttle/Ulysses mission's electroexplosive devices, electronic circuitry and computers? } 9-3

3. What efforts are underway to relax NASA lightning launch restrictions? How frequently are current restrictions waived? } 9-4

4. Describe procedures involving launch delays. Are explosive components removed? } 9-5

5. To what ER threshhold is the Shuttle and its payload shielded to? Are electromagnetic emissions physically monitored and measured at all times? By whom? Do "controlled" ER emissions include civilian sources of ER including media telecommunication devices? What is the anticipated electromagnetic environment for the Shuttle-Ulysses mission, at launch and prior to? } 9-6

6. Does the Shuttle or the Ulysses satellite utilize "Kapton" wiring? Where and for what components and connections? } 9-7

7. Is either the SP4T switch (SHA85-2221) or the S/N 10219 switch, both manufactured by AVANTEK, in use aboard the Shuttle/Ulysses mission? Both of these parts have been known to fail. An FBI investigation of the use of the SP4T switch was initiated following the launch of the Atlantis/Galileo mission. What is the progress of that investigation? Brian Atwater, an AVANTEK employee claimed that the SP4T switch was not space-tested. Has it and all other Shuttle/Ulysses components been adequately space tested? (See AVANTEK Memo to Chris Schwartz from Gabe Vitorla, exhibit G.) } 9-8

8. What follow on actions were taken by Morton Thiokol in response to Steven Agee's safety hazard reports? } 9-9

9. Does the Shuttle/Ulysses mission violate any International Law or Treaty? } 9-10

Answering these questions and addressing these issues will promote informed decision-making about the actual HERO danger posed by the Shuttle/Ulysses mission. The nature and consequence of an accident aboard the Shuttle or the Ulysses deserves the most careful consideration. I ask that my comment and accompanying exhibits be reprinted in full.

Respectfully,

Patricia Axelrod

Patricia Axelrod



RESPONSES TO COMMENTS
Commentor No. 9: The HERO Project
(Continued)

Response to Comment No. 9-3

The Commentor is referred to Response to Comment 9-2 with respect to the conditions which must be met for a waiver to any NASA standard. Waivers to Military Standard E-6051D are not granted for payloads. System waivers are beyond the scope of this EIS. The launch area is monitored for electromagnetic radiation to levels which will protect the vehicle.

Electromagnetic Interference Safety Margin (EISM) is the ratio between the susceptibility threshold and the interference present on a critical test point or signal line. The EISM for electronic circuitry and components is a minimum of +6 dB for radiated emissions and +6 dB for conducted emissions, with the exception of electroexplosive devices which require a minimum of +20 dB EISM.

Response to Comment No. 9-4

There are no efforts underway to relax NASA's present Launch Commit Criteria for severe weather. Present Launch Commit Criteria for lightning are not waived by NASA.

Response to Comment No. 9-5

Pyrotechnic devices normally are not removed during a launch delay. These devices are "safed" in any case by the intermediate triggering device which consists of a mechanical drum with an aperture. The drum must be rotated to permit the aperture to complete the circuit over which the initiation signal must pass before the pyrotechnic device can be ignited. The triggering device is normally activated by a series of discrete electrical signals that must be received in the proper sequence. In the case of a delay that will last longer than a brief period, such as the several days it may take to change-out a faulty system or component, safing plugs are installed on all ordnance to prevent the buildup of unwanted voltage.

Response to Comment No. 9-6

The minimum criteria are +6 dB for radiated and conducted emissions and +20 dB for electroexplosive devices. In addition, all circuitry and computers on the Shuttle are housed in Faraday cages with some in sub-cages; all significant connecting wires are twisted or twisted and shielded pairs at the minimum; all critical circuits in the forward flight cabin where there are windows, in addition to twisted-shielded pairs, are housed in steel conduit which provides many additional dB of protection; in turn, all of these circuits are housed within the hull of the Shuttle which is completely sealed to further reduce any potential effects of electromagnetic emissions. The few electrical components that are outside the hull have been tested (including simulated lightning) to levels far beyond those to which they could ever be exposed. All of these measures, combined with strict control over grounding and bonding of the entire vehicle to assure that everything is at essentially the same potential, provide the requisite amount of protection and safety margin for the Shuttle and its payload to ensure that circuitry is not scrambled and that explosive devices are not prematurely activated or dudded.

NATIONAL SPACE SOCIETY

April 6, 1990

Dr. Dudley G. McConnell
NASA Headquarters
Code EL
Washington, DC 20546
Via Express

RE: NSS Comments on Ulysses Draft EIS

Dear Dr. McConnell:

In response to NASA's request for public comments, 55 Fed. Reg. 6326 (February 22, 1990), the views of the National Space Society (NSS) follow. NSS is a nationwide grassroots organization dedicated to the exploration and development of outer space and to the creation of a spacefaring civilization. Formed by the merger of the National Space Institute and the L5 Society, NSS has tens of thousands of members nationwide, and affiliate organizations throughout the world. Furthermore, NSS' views generally represent those of the substantial majority of all Americans that strongly supports an expansive and ambitious space program.

Scope of Comments

Because NSS believes that NASA has examined the issues in more than adequate scope and detail, and because NASA possesses expertise and experience in dealing with missions of this kind that no private organization can possibly hope to equal, NSS will not engage in a detailed examination of the technical issues addressed in the Environmental Impact Statement, particularly as NSS would have little to add to NASA's already thorough treatment. Instead, NSS will stress items omitted from the EIS, or given inadequate treatment therein, that NSS believes should have an important impact on the decision whether to proceed with the mission. In short, NSS is of the opinion that the EIS takes inadequate cognizance of the importance of the Ulysses mission in terms of the benefits, as well as potential detriments, that the mission will involve for the earth environment. 10-1

E-67

RESPONSES TO COMMENTS
Commentor No. 10: National Space Society

Response to Comment No. 10-1

The National Space Society asserts that the knowledge accrued by the Ulysses mission may result in some "considerable down-to-Earth benefits." These benefits include: a better understanding of solar flares as a source of communications disruption and as a hazard to manned space missions, and a better understanding of the Sun's effect on the Earth's outer atmosphere as related to orbital debris. NASA agrees that the Ulysses mission will yield information pertinent to better understanding environmental issues and can postulate scientific scenarios supporting each of NSS's specific assertions.

As NSS notes, to the extent that the Earth's climate depends upon the heat and radiation it receives from the Sun, climatological models cannot be complete unless they account for variations in the solar output. Accounting for these variations, however, requires understanding the mechanisms that drive them.

Currently, we know that these variations tend to assume the form of disturbances in the solar atmosphere characterized by sunspots, strong magnetic field disruptions, solar flares, and a variety of other interesting phenomena. Every eleven years or so, these phenomena reach a peak and then begin to decline in prominence. This is called the solar cycle. This activity is believed to be caused by the cyclic variation of the Sun's magnetic field. When the equatorial component of the magnetic field is strongest, more sunspots appear in the mid-latitudes. This area of the Sun is easily observed from the Earth because it too is in the ecliptic plane which is the same plane of the Earth. But as the magnetic component aligned with the poles of the Sun becomes stronger, the mid-latitude sunspots greatly diminish. The polar regions are not observable from the ecliptic plane because this magnetic field component is perpendicular to the line of sight of Earth-based magnetic instruments and hence unobservable. Also, the observations of the polar regions as seen from the ecliptic plane are foreshortened. Ulysses will directly sample the magnetic fields in the polar regions.

Scientists have seen tantalizing and persistent indications that this cycle affects the Earth's climate. For instance, in the 17th century, the sunspots that characterize the solar cycle disappeared for about 70 years (the Maunder Minimum). During this time period, the Earth experienced extremely cold weather, sometimes referred to as the "little ice age." Scientists believe that the solar wind may act as a mechanism by which the solar cycle can affect the Earth's

### The Ulysses Mission and Its Importance

The Ulysses mission is of vital importance for a variety of reasons, some connected with scientific information gathering in the abstract, others connected with more down-to-earth problems. Since Ulysses will gather information regarding previously unobserved solar regions (the poles), it is an essential part of gathering a meaningful understanding of how the Sun, and the solar climate, works. One would not, after all, expect to understand the earth's climate without understanding what goes on at the poles; indeed, most climatological theories today suggest that many important climatic processes take place only at the poles. Similarly, an understanding of what goes on at the Sun's poles is vital to understanding the solar climate, and Ulysses provides an essential first step.

Such understanding has importance from a purely scientific standpoint, of course. Solar scientists have a lot to learn, and the understanding that they achieve will also be of use in understanding other stars as well: the Sun, after all, is the only star we are currently able to observe at close range. In addition, understanding the solar climate will have important ramifications for our understanding of solar-driven events that spread throughout the solar system: the solar wind, various magnetic and plasma effects, solar flares, and so on.

It is worth stressing, however, that abstract scientific benefits are not the only ones likely from Ulysses. There are also many concrete benefits that will come from such knowledge, benefits with considerable down-to-earth importance. These include:

- Better understanding of the earth's climate: Since the Sun is the earth's primary source of heat, variations in solar output can have dramatic impact on the earth's climate. Existing climatological models are unable to take these into account in any significant way, because the mechanisms of solar variation are, to put it mildly, poorly understood. If we are to understand matters such as global warming and other forms of climatic change, we must have more information concerning the solar climate, of the sort that Ulysses can provide.

- Better understanding of the space environment: A

10-1 (Continued)

weather. Evidence suggests that the solar wind influences the Earth's upper atmosphere at an altitude of a hundred kilometers or more. This region then presumably interacts with the region in which weather originates, the troposphere, to produce meteorological phenomena correlated to the solar cycle.

The question of how the variations of the solar cycle influence the solar wind, however, has not been definitively answered. Scientists think that the solar wind, experienced at earth, may originate at high solar latitudes where the little-known polar magnetic field is dominant. It is likely that the solar wind properties, such as its speed, are controlled by the field strength and the area of the magnetic polar cap. Thus, changes in the polar magnetic field with the solar cycle could cause corresponding variations in the solar wind impacting Earth. Knowledge of this potentially important link is vital to investigations of the Sun-weather connections. However, because the Sun's polar magnetic fields and associated solar wind emanate perpendicular to the plane in which the planets revolve, scientists have been unable to make such measurements. Earth-based instruments and existing spacecraft are confined to this plane. Ulysses, however, will venture out of this plane and into a trajectory that will place its instruments in direct line of sight with the fields and wind of interest. Hence, Ulysses may be able to collect data that will be useful to scientists in understanding how the solar cycle, solar wind, and the Earth's atmosphere interact to produce climatic changes.

The second NSS assertion, that Ulysses will yield information relevant to the communication and space exploration hazards posed by solar flares, also seems quite supportable. Solar flares emit very energetic particles that can pose a serious radiation hazard to astronauts as well as to occupants of high-altitude aircraft. These particles also influence the Earth's upper atmosphere, particularly the ozone layer--a layer whose formation and time evolution are now a topic of keen interest.

Ulysses will carry several experiments designed to investigate these solar flare particles. In particular, they will attempt to determine why, after emission from the flare site, the particles can take longer to reach the Earth than is predicted for a direct Sun-Earth trajectory. Scientists believe that this delay results from the particles being trapped by strong solar magnetic fields (magnetic "bottles") until they can drift on to field lines connecting with the solar wind. Since flares tend to occur in the Sun's equatorial region, the detection of solar flare particles by Ulysses at high solar latitudes would indicate the validity of the particle storage and drift concept--knowledge useful in estimating flare particle propagation. Also, a spacecraft at high solar latitudes may, due to the less distorted solar magnetic field in these regions, be able to detect solar flare particles before they reach the Earth, providing an "early warning" capability.

key hazard to manned flight in outer space is excess solar radiation stemming from solar flares. Such flares also pose a hazard to some kinds of spacecraft, and when particularly severe even to earth-based radio communications. A better understanding of the solar climate may lead to an ability to predict solar flares, and to adapt operations to avoid the worst of them. This will be particularly important in the context of space station operations and long-duration manned flights such as the manned Mars mission planned by the President.

- o Better understanding of the earth/space interface: The changing solar cycles interact substantially with the earth's magnetic field and with the highest reaches of the upper atmosphere, at an altitude of 100-300 miles, approximately. Expansion of the upper atmosphere during part of the cycle is an important mechanism for removing debris from low-earth orbits. Better understanding of this process will be important in determining ways of addressing the orbital debris problem, which as recent Congressional hearings made clear is of considerable importance already.

Of course, by stressing these concrete benefits NSS does not mean to suggest that abstract scientific knowledge is not important. Such "abstract" knowledge always turns out to have important concrete uses in the end, though often those uses are entirely unforeseeable at the time the knowledge is arrived at.

10-1 (Continued)

**Adequacy of the Ulysses EIS**

In General

Having reviewed the draft Ulysses Environmental Impact Statement, NSS is of the opinion that it is entirely adequate. NASA has reviewed and considered all relevant factors of importance, and in particular has examined the possibility of catastrophic failure resulting in release of radioactive material from the onboard Radiothermal Generators with considerable thoroughness.

Such examinations are of necessity imprecise and subject to dispute; if risks were entirely clear, and all possible modes of failure obvious, we would live in a very different world indeed. And any authoritative

10-2





The third and final NSS assertion, that Ulysses may contribute to a better understanding of the Sun's effect on the earth's outer atmosphere as related to space debris, is also noted. The orbital lifetimes of both satellites and space debris are highly dependent upon upper atmospheric drag. This drag tends to depend on the extent to which the Sun's ultraviolet rays and x-rays heat the Earth's upper atmosphere. Ulysses will investigate how electrons accelerated in the solar flare process generate such x-rays. By examining solar flares, emanating from the Sun's equatorial region, from a polar perspective, Ulysses will be able to occult portions of the flare with the Sun itself. This partial occultation will allow Ulysses to view different parts of the flare until the region of x-ray production can be localized. By understanding the circumstances of solar x-ray production, scientists will be in a better position to predict their effects on upper atmospheric drag.

Response to Comment No. 10-2

Comment noted.

determination is nonetheless open to dispute -- even judicial opinions fail to convince everyone. However, within the limits of the real world, NASA has done a more than adequate job; certainly no one else has the expertise or experience to do better, and the excellent safety record of radiothermal generators in practice suggests that NASA's estimates cannot be too far off base. Some imponderables remain, of course, but that is the nature of risk assessment and it is foolish to pretend otherwise. Given that radiothermal generators are far less risky than nuclear reactors (with which they are often confused by the public) and given the lack of alternatives, NSS believes that the level of risk is acceptable, and that the EIS identifies and correctly analyzes all significant factors which can be determined in advance. 10-2

NSS also agrees that there are no reasonable alternatives to the use of radiothermal generators for the Ulysses mission. As correctly noted in the EIS, available alternative power sources pose unacceptable costs or risks to the mission -- and, in general, simply would not work at the distance from the Sun (that of Jupiter) at which most of the mission's important phases will (and must) take place.

Errors and Inadequacies in the EIS

NSS would, however, like to take issue with NASA's statement (Draft EIS at pp. v, 4-30) that "[t]here are no environmental impacts associated with the no-action alternative." While this statement may be true from the rather artificial perspective that seems inevitable in the context of an Environmental Impact Statement, it is in fact false. Pursuing a "no-action" alternative -- that is, scrubbing the mission -- would in the real world have negative consequences for the environment that could in fact be quite severe, and that NASA should take into account in determining whether to proceed with the mission. 10-3

These consequences would stem from the failure to acquire the information regarding the solar climate, and its interaction with the earth's climate and the earth/space interface, that was described earlier. In the absence of such information, earthbound climatological models will inevitably suffer, understanding of the extent of the (already severe) orbital debris problem will be reduced, and efforts to ameliorate environmental problems on the earth will be





Response to Comment No. 10-3

Comment noted; text revised.

The environmental impact statement addresses the direct and indirect impacts on the physical environment. It is acknowledged that the no action alternative would result in loss of the opportunity to acquire more information. We conclude that there would be no physical, chemical, or biological impact on the physical environment from the no action alternative; but there would be a significant loss to the scientific community, and an adverse impact to the Nation's solar exploration program.

handicapped, perhaps severely. There are no planned missions duplicating (even in part) Ulysses' functions. Given the long lead-times present for Solar System Exploration, this means that a cancellation of Ulysses would result in a major and long-lasting gap in our knowledge of these important topics.

Furthermore, cancellation of Ulysses would result in a squandering of human and intellectual capital, and in very significant demoralization costs among the planetary science community. Leaving aside the specific benefits that Ulysses itself will provide, no one would disagree that space exploration and planetary science have been of enormous benefit to our understanding of the earth environment -- and, in fact, have been an enormous source of consciousness-raising regarding the importance of environmental issues in general. It is no accident that the first Earth Day took place shortly after the first pictures of the earth from the Moon became available (futurist Arthur C. Clarke predicted that such photos would have just such an impact as early as 1959), or that the environmental movement has adopted just those photos as an important symbol. Furthermore, knowledge gained by satellite observations -- both of the earth and of other planets -- has had dramatic impact on our understanding of specific problems such as the Antarctic ozone hole. Senator Albert Gore, Jr. recently discussed this issue, see Gore, Outer Space, the Global Environment, and International Law: Into the Next Century, 57 Tenn. L. Rev. 329 (1990), and a number of environmental commentators have made similar points. See, e.g., Hartmann, Space Exploration and Environmental Issues, 6 Environmental Ethics 227 (1984), and Beyond Spaceship Earth: Environmental Ethics and the Solar System (Sierra Club Press, 1986): G. Reynolds & R. Merges, Outer Space: Problems of Law and Policy 195-98 (1989).

10-3 (Continued)

Cancelling the Ulysses mission would have a chilling effect on such enterprises in the future, as scientists would be reluctant to invest years of their time in a mission that might be cancelled at the last moment for environmental reasons. Thus, the losses to the environment from cancelling Ulysses might go far beyond those specific benefits promised by Ulysses itself.

In addition to the loss of these concrete benefits, the abstract knowledge gained from Ulysses would be lost. That is not only a loss to the scientific community, but also a loss of other concrete benefits

(currently unforeseeable but no less important for that) likely to be derived from that knowledge. NSS understands that the nature of EIS drafting, and the assumptions and pressures inherent in the risk assessment process generally tend to lead to a discounting of such unquantifiable benefits (a problem known in the risk-assessment trade as the "dwarfing of soft variables"), but urges that NASA resist these pressures and take account of the substantial potential losses, both immediate and long-term, of adopting a "no action" approach. 10-3 (Continued)

For this reason NSS also believes that Section 4.8.2 of the EIS (Draft EIS at p. 4-31) should be revised. That section currently states:

> A potentially large benefit to be gained from successful completion of this project is a better understanding of Earth through exploration and study of the environments of other planets. 10-4

Obviously, NSS does not disagree with this statement. However, NSS believes that the importance of this aspect of the mission is drastically understated in the EIS and should be more fully reflected along the lines set out above.

**Conclusion and Recommendations**

Environmental Impact Statements, of course, do not make recommendations; their purpose is simply to set out costs and benefits. NSS has already explained why it believes that the Ulysses EIS is adequate in its statement of potential costs and risks, but inadequate in its treatment of the likely benefits of the mission. NSS recommends that the EIS be revised to take these benefits into account. 10-5

Regardless of the extent to which such revisions are made, NSS recommends as well that NASA take the benefits noted in these comments into account in making its decision whether to proceed with the Ulysses mission. It is not the function of an Environmental Impact Statement to determine whether a particular project is "too risky." Its function is solely to ensure that the agency to whom decisionmaking authority has been delegated (here NASA and, because radioactive materials are involved, the President) makes an informed decision after considering all relevant factors.





Response to Comment No. 10-4

The section has been modified to include the points raised in the comment.

Response to Comment No. 10-5

Comment noted.

NSS believes that when all relevant factors are considered, the necessary conclusion is that the Ulysses mission is not only justified, but very important -- and that that importance stems not only from scientific factors, but from the very significant positive impact that Ulysses is likely to have on the earth's environment over the long term. For this reason, NSS supports a decision to go ahead with the Ulysses mission. 10-6

Sincerely,

Glenn Harlan Reynolds
Chairman, NSS Legislative
Committee, For the
National Space Society

Response to Comment No. 10-6

Comment noted.

DEPARTMENT OF HEALTH & HUMAN SERVICES

Public Health Service

Centers for Disease Control
Atlanta GA 30333
April 6, 1990

Mr. Dudley G. McConnell
Office of Space Science and Applications, Code EL
National Aeronautics and Space Administration
Washington, D.C. 20546

Dear Mr. McConnell:

We have completed our review of the Draft Environmental Impact Statement (DEIS) for the Ulysses Mission (Tier 2). We are responding on behalf of the U.S. Public Health Service. Technical assistance for this review was provided by the Center for Devices and Radiological Health, Food and Drug Administration.

We have reviewed this DEIS for radiological protection implications. The only radioactive contamination that could occur would result from an impact of the RTG modules on hard rock or other unyielding surface. The probability of a radioactive release in these circumstances is stated to be about one in 4200. Even if this occurred, the resultant collective population dose would be quite low, barely above "de minimus." Based on the information in the DEIS, the plan appears to be sound from a radiological point of view and adequate to protect human health. 11-1

Thank you for the opportunity to review this draft document. Please insure that we are included on your mailing list for receiving the Final EIS and future DEIS's which are developed under the National Environmental Policy Act (NEPA).

Sincerely yours,

Kenneth W. Holt

Kenneth W. Holt, M.S.E.H.
Environmental Health Scientist
Center for Environmental Health
and Injury Control

CC:
Jeannine T. Lewis

Response to Comment No. 11-1

Comments noted.

SIERRA CLUB

730 Polk Street San Francisco, California 94109 415 · 776 · 2211

Committee on Military Impacts on the Environment

April 8, 1990

Dr. Dudley G. McConnell
Deputy Director, Advanced Studies
Solar System Exploration Division
Office of Space Science and Applications (Code EL)
NASA Headquarters
Washington, D.C. 20546

Dear Dr. McConnell,

We appreciate the opportunity to comment on the draft EIS for NASA's planned Ulysses Mission (Tier 2).

In view of the grave risks to the public involved in launching into space a vehicle containing 24 pounds of plutonium (mostly plutonium 238), we are concerned that there be full compliance with the regulations of the National Environmental Protection Act (NEPA) in planning for this mission and in preparing the Environmental Impact Statement for it. Specifically, we are concerned that too little attention is given to consideration of alternative launching options and of alternative means of powering the vehicle once it is in space. In these respects, we find the draft EIS disappointing and inadequate. 12-1

First, with respect to a launching alternative, no real alternative to the shuttle launch is considered, although we understand that the Titan IV configuration would be considerably safer because the plutonuim would not be at the center of tons of highly explosive rocket fuel, but instead would be at the top of the launch vehicle, with the fuel mainly in the bottom. 12-2

Second, we understand that an alternative means of powering the vehicle, using solar power, is available. Obviously, this would be a far preferable option from the environmental and public safety standpoint. 12-3

We understand further that the reason that the Titan alternative is not seriously considered in the Tier 2 DEIS is that it would entail delaying the mission until 1995 and losing important scientific opportunities. This is hard to understand; is there a shortage of Titan missiles? We also question whether a trajectory that swings no further from the sun than Jupiter's orbit would render the vehicle unable to use solar power, as is implied in the Federal Register notice. The Sierra Club opposes 12-4 12-5 12-6



RESPONSES TO COMMENTS
Commentor No. 12: Sierra Club

Response to Comment No. 12-1

See Response to Comments 2-21 and 4-7.

Launch of the Ulysses spacecraft on-board a Titan IV expendable rocket is not feasible within the timeframe of the proposed action. It should be noted that the proposed action being evaluated in the EIS, is the completion of preparation for, and operation of the Ulysses mission in October of 1990 or in the back-up opportunity in November 1991.

During the preparation of the EIS, a "hard look" was given to alternative launch options and to alternative power systems. Section 2.2.4 of the EIS addresses Power Sources, and Section 2.3 addresses alternative launch options.

Response to Comment No. 12-2

The objective is to launch at the earliest opportunity for the mission. For the next three years, the Shuttle represents the only viable option. The modifications required for both the spacecraft and the Titan IV would require approximately three years from time of decision to change the launch vehicle. In addition, a complete nuclear safety analysis is not currently available for a Titan launch. Therefore, the safety of the Titan IV as compared to the Shuttle cannot be accurately determined. Also, see Response to Comment 2-21.

Response to Comment No. 12-3

With respect to the use of solar power for the spacecraft, Section 2.2.4.2 of the EIS addresses the limitations of this power source for a mission in the 1990-1991 timeframe. The only power source meeting the requirements of the proposed action is the RTG. Also, see Response to Comment 4-7.

Response to Comment No. 12-4

See Response to Comment 2-21.

Response to Comment No. 12-5

The Ulysses mission starts at 1 AU travels to 5.2 AU and then returns back to 1.3 AU. Because the amount of power available from the Sun decreases as the square of the distance from the Sun, the amount of solar array needed at Jupiter is about 25 times that required at Earth. Thus, the solar arrays become very large for a mission to Jupiter. This impact was studied in an ESA study and found to be too massive for the current launch capability. The ESA study also indicated that mission science would be degraded on a solar-powered mission (ESA 1990).

the use in space of nuclear power except for deep-space exploration where solar power would not be sufficient. We are not persuaded that the use of plutonium is necessary for the Ulysses mission. 12-6

We understand also that the design for the Ulysses mission predates such accidents as Three Mile Island, Chernobyl, and the Challenger failure, and the probability of an accident therefore may have been substantially underestimated. Finally, we are concerned that such missions will become a routine activity, thus increasing the risks with multiple launches. 12-7

We feel strongly that it is incumbent on NASA, as a government agency planning a project that carries very serious risks, to address those risks clearly and honestly. In this case, however small the probability of occurrence may be, the downside result could include the exposure of millions of people and a large area of the world to plutonium, with a possibility of entraining tens of thousands of cancers and birth defects. These risks should be clearly balanced against the risks and costs of all feasible alternative actions, and the public -- especially residents of Florida -- should have an opportunity to participate in a full discussion of the choices. We therefore urge NASA to reconsider the Titan launch and solar power options and to develop a full, detailed assessment of the costs of delaying the project vs the risks to the public in the event of an accident that could disperse plutonium over wide areas. 12-8

Thank you for your attention.

Sincerely,

Anne H. Ehrlich

Anne H. Ehrlich, Chair



RESPONSES TO COMMENTS
Commentor No. 12: Sierra Club
(Continued)

Response to Comment No. 12-6

Comment noted.

Response to Comment No. 12-7

The accident probabilities result from U.S. experience with launch vehicles and experience in the design and operation of RTG power systems. The Challenger experience is relevant and taken into account in several elements of the analysis as well and the Titan 34D7 accident just following Challenger. Nuclear risk estimates take account of BEIR IV and BEIR V, the most recent guidance in that regard. Chernobyl and Three Mile Island are not applicable to the safety of the RTG.

Response to Comment No. 12-8

NASA has carefully considered the availability of both alternative launch vehicles and alternative power systems. The only launch vehicle configurations capable of conducting the mission involve the Shuttle and the Titan IV. A Titan IV launch vehicle is not a feasible alternative for the 1990 and 1991 launch opportunities stated in this proposal.

Regarding alternative power sources, see Responses to Comment 4-6 and 4-7.

RESPONSES TO COMMENTS
Commentor No. 13: Florida Coalition for Peace and Justice, Christic Institute, and Foundation for Economic Trends

LAW OFFICES
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April 9, 1990

BY FAX AND U.S. MAIL

Dr. Dudley G. McConnell
Office of Space Science and Applications, Code EL
National Aeronautics and Space Administration
Washington, D.C. 20546

Dear Mr. McConnell:

Enclosed are comments on the Draft Environmental Impact Statement (DEIS) for the Ulysses Mission (Tier 2) dated February 1990 submitted on behalf of the Florida Coalition for Peace and Justice, P. O. Box 2486, Orlando, Florida 32802 (Telephone (407) 422-3479), the Christic Institute, 1324 N. Capitol Street, N.W., Washington, D.C. 20002 (202) 797-8196, and the Foundation on Economic Trends, Suite 630, 1130 Seventeenth Street, N.W., Washington, D.C. 20036 (202) 466-2823.

If you should have any questions whatsoever about any of our comments, please feel free to contact myself or Lanny Sinkin, Esq., at the Christic Institute. Thank you.

Sincerely yours,

Edward Lee Rogers

ELR:CV

Enclosure

E-77

April 9, 1990

BY FAX AND U.S. MAIL

Dr. Dudley G. McConnell
Office of Space Science and Applications, Code EL
National Aeronautics and Space Administration
Washington, D.C. 20546

Dear Mr. McConnell:

These comments on the Draft Environmental Impact Statement (DEIS) for the Ulysses Mission (Tier 2) dated February 1990 are submitted on behalf of the Florida Coalition for Peace and Justice, the Christic Institute, and the Foundation on Economic Trends. These three organizations (organizations) brought suit to enjoin the launching of the Galileo Mission. In that suit, plaintiffs challenged both the Tier 1 Environmental Impact Statement (Galileo and Ulysses) and Tier 2 Environmental Impact Statement (Galileo) that had then been issued by NASA. See Florida Coalition for Peace and Justice, et al. v. George Herbert Walker Bush, et al. (Florida Coalition), Civil Action No. 89-2682-OG (D.D.C.) (plaintiffs' submissions), appeal dismissed, No. 89-5372 (D.C. Cir. Oct. 16, 1989); amended complaint filed January 29, 1990.

The organizations find that the DEIS in question suffers from essentially the same defects as the environmental documentation plaintiffs challenged in Florida Coalition. The National Aeronautics and Space Administration (NASA) is, therefore, put on notice by these comments that the organizations assert that each and every inadequacy of the environmental documentation raised by plaintiffs in that litigation are asserted here with regard to the DEIS in question, excepting only those concerns that could apply only to the Galileo project. Inasmuch as those inadequacies are addressed in great detail, with supporting evidence, in that litigation, the presentations made by plaintiffs in that litigation are hereby incorporated herein by this reference with the same effect as though fully set forth herein. There are also additional inadequacies in the DEIS. 13-1

Some of the issues of major concern are briefly referred to below. Inasmuch as we request documents which should have already been made available to the public, we also request an additional comment period after release and/or development of the documents specified below, including any new environmental documentation, to permit us to evaluate the DEIS and any new or supplemental DEIS in light of the information thus made available to us for the first time. 13-2

1. Risk Assessment. The greatest risk presented by the Ulysses launch is the inadvertent release of plutonium resulting 13-3





Response to Comment No. 13-1

NASA refers commentor to the court decision of October 10, 1989 and to the answer filed by NASA with the court in response to the commentor's allegations.

Response to Comment No. 13-2

The EIS and supporting documents prepared for the EIS have been made publicly available.

Response to Comment No. 13-3

Subpart 1a

The Shuttle Data Book (Revision B), of which the commentor has a copy, contains all current data concerning accident scenarios and environments. The risks of such accidents and release characteristics for the Ulysses mission are addressed in the Ulysses FSAR and this EIS (Tier 2).

Subpart 1b

See Response to Comment 8-8. The Ulysses FSAR, Vol. III, Books 1 and 2 (DOE 1990g) present the methodology and assumptions pertinent to this analysis.

Subpart 1c

See Response to Comment 8-8. The Ulysses FSAR, Vol. II, Book 2, Appendix G (DOE 1990f) summarizes the results of the extensive safety verification testing program which the DOE conducts. Additional data are publicly available in the form of technical reports.

from an accident. NASA has previously provided a wide range of estimates as to those risks. For essentially the same reasons set out by plaintiffs in Florida Coalition, the current risk assessments in the DEIS on the likelihood and consequences of any such release is woefully inadequate. One of the primary purposes of the National Environmental Policy Act is to provide adequate information to decisionmakers, the Congress and the public on environmental impacts, including environmental risks, and to assure public involvement in the NEPA process. Accordingly, a new or supplemental DEIS should be issued reflecting full consideration by NASA of, inter alia, the following documents, and we request that those documents be made available to the public preferably before and not later than the date of issuance of that DEIS and well before the issuance of the final EIS.

a. Appendix B to the Shuttle Data Book, the Addendum thereto, and any other documentation which would help the organizations analyze the methodology, assumptions, and data used by NASA in calculating the risk involved in placing plutonium on the shuttle. NASA has not released adequate information for the organizations to present more informed comments than they have to date on the risk assessment summaries presented by NASA for the Ulysses launch. These risks include the risk of a shuttle accident and the risk that such an accident would result in the release of plutonium. These risks also include estimates of the amount of plutonium which would be released in each type of accident.

b. All documentation available to NASA, but not disclosed to the public regarding the threat to public health and safety from any potential release of plutonium from the Ulysses mission. This documentation would include the methodology and assumptions for calculating human dose effects of plutonium release and the particle size of releases expected in each accident scenario considered. The release of this information would assist the organizations to evaluate in a more informed manner the conclusions reached by NASA regarding the potential health effects of a plutonium release.

c. All documentation of the methodology, assumptions, and data used by NASA to determine that the plutonium canisters in the Ulysses Mission have maintained and will maintain their integrity throughout the period of time in which said mission represents a potential threat to Earth's environment.

d. All documentation on all tests conducted to date on the plutonium canisters on the Galileo Mission conducted prior to launch and on the canisters to be placed on the Ulysses Mission made to determine the state of the plutonium ceramic. NASA represented to the appellate court in Florida Coalition that such tests had been conducted to determine the integrity of selected plutonium sources prior to the launch of the Galileo Mission.





RESPONSES TO COMMENTS
Commentor No. 13: Florida Coalition for Peace and Justice, Christic Institute, and Foundation for Economic Trends
(Continued)

13-3

Subpart 1d

See Response to Comments 8-8 and 8-32. The Ulysses FSAR, Volume I, Appendix A (DOE 1990e) summarizes the results of extensive DOE research and testing on the physical characteristics of the plutonium ceramic. Additional information is presented in Section 4 of this EIS.

e. All studies performed on the susceptibility of the shuttle to electromagnetic radiation, including but not limited to the studies conducted by Morton Thiokol on this matter. This should include documentation of all incidents, including both accidents and precursors to accidents, in which electromagnetic radiation was the cause, suspected cause, or a known or suspected contributing factor. This documentation should also include dissenting views, such as those of Steven Agee who worked at Morton Thiokol. This documentation should also include identification of issues related to this matter for which further study is recommended. Finally, this documentation should include any modifications or planned modifications to shuttle protection against lightning or other sources of electromagnetic radiation which NASA has made or is considering making. These modifications include, but are not limited to, changes in the requirements for conditions at the launch site prior to final launch approval, e.g. the presence or risk of lightning, and the use of materials in the shuttle susceptible to electromagnetic effects, e.g. Kapton. 13-4

2. Environmental Impacts of a Shuttle Launch. NASA has previously evaluated the environmental effects of a shuttle launch, but those studies are dated. In order to assess adequately the environmental effects of launching the shuttle for the Ulysses mission, a supplemental draft and final environmental impact statement of the environmental effects of launching the shuttle should be issued. The last such assessment was made more than ten years ago before extensive knowledge was gained about damage currently being suffered by the Earth's atmosphere. In particular, there is a growing concern that further depletion of the ozone layer, particularly in the stratosphere, will result in (further) severe health effects on humans, environmental damage to food crops, and threats to the viability of the ocean food chain. The contribution of a shuttle launch to ozone destruction is a matter requiring an updated assessment, along with other environmental effects of such launches where more recent scientific information raises concerns not adequately addressed in the prior environmental assessments of such launches. 13-5

3. Alternatives. Essentially, the only alternative considered by NASA to launching the Galileo Mission and the Ulysses Mission was the alternative of not launching. Deferred launchings with other power and heat sources than RTGs were summarily dismissed. Therefore we request the development of a comprehensive assessment of alternatives to the use of plutonium for deep space exploratory missions, such as Galileo and Ulysses, and future planned missions. NASA is already on notice of various studies and reports developed that we received after the launch of the Galileo Mission concluding that concentrated solar arrays are a viable alternative to plutonium for such missions. NASA is also on notice that we received copies of a letter sent 13-6





RESPONSES TO COMMENTS
Commentor No. 13: Florida Coalition for Peace and Justice, Christic Institute, and Foundation for Economic Trends
(Continued)

Response to Comment No. 13-4

The robustness of the Shuttle and the spacecraft are addressed in Section 2.2.7.2, and in the Responses to Comments 9-1 through 9-16.

Response to Comment No. 13-5

It should be noted that this EIS relates to the Ulysses mission. The Shuttle effects are discussed only in the context of it as the launch vehicle. The air quality impacts associated with the Shuttle's launch cloud were addressed in the FEIS for the Space Shuttle Program EIS of 1978. They were updated in the Galileo Mission FEIS (Tier 2) dated May 1989 with the results of contemporary studies as noted. The updated discussions in the Galileo Mission Tier 2 EIS were incorporated by reference and summarized for the Ulysses Mission EIS (Tier 2). Section 4.1.2, page 4-1, has however, been further updated to reflect the results of the most recent studies.

The potential impacts of the Shuttle launch on ozone were treated similarly, and were summarized and referenced in the Ulysses DEIS in accordance with 40 CFR 1502.21. Section 4.1.2, page 4-1, has however, been further updated to reflect a recent study on ozone depletion associated with space launches.

Response to Comment No. 13-6

See Response to Comments 8-13 and 8-19 on further delay; and Response to Comments 4-7 and 4-8 on alternative power systems.

to Congress misrepresenting the viability of the use of solar energy on the Ulysses Mission. Adequate and truthful information regarding the feasibility of solar arrays or other alternatives to a plutonium-based system must be fully presented in the NEPA documentation.

That assessment must, therefore, also answer specifically the question as to when particular alternatives could become operational if adequate resources were to be made available, and provide a detailed assessment of a delay alternative incorporating the use of such an alternative. Any such assessment of alternatives to plutonium should also answer the questions set forth in the petition submitted by one of the organizations to NASA prior to the launch of the Galileo Mission. 13-6

4. Timely NEPA Process. The DEIS is only one part of the NEPA process. The DEIS and the final EIS should each be issued in a timely manner, well before any proposed launch date, to assure adequate opportunity for informed review and consideration by decisionmakers, the Congress, and interested members of the public, in accord with the purposes of NEPA. These objectives were seriously compromised in the launching of the Galileo Mission, where final approval was issued only about one month before the proposed launch date.

Applicable NEPA regulations generally require, as a minimum, that no administrative action take place prior to 90 days after issuance of a draft EIS or 30 days after issuance of a final EIS. 40 C.F.R. § 1506.10. The Ulysses project, however, like Galileo, is a much more complex project, with far greater potential adverse public health impacts, by many magnitudes, than most actions subject to the NEPA process. Its complexity and its risks dictate that adequate time be provided for public review and consideration of agency findings and decisions well before final administrative action is taken. The minimum periods required by regulation are inadequate for a decision of such great significance. Accordingly, the launch date should be scheduled, as necessary, to assure adequate opportunity for the full dissemination and consideration of the studies and information discussed above, not previously made available to the public, as well as the agency's findings and rationale in the final EIS. 13-7

Sincerely yours,

Florida Coalition for Peace and Justice, the Christic Institute, and the Foundation on Economic Trends

By: Edward Lee Rogers, Counsel
Lanny Sinkin
Litigation Director
The Christic Institute







Response to Comment No. 13-7

NASA scrupulously follows all applicable NEPA laws and regulations. The FEIS (Tier 1) was issued in November 1988. More than 90 days have already elapsed since the issuance of the draft EIS. NASA will allow at least 30 days between the issuance of the final EIS (Tier 2) and the filing of NASA's Record of Decision. In addition, the Commentor appears to have confused the NEPA process with the Presidential nuclear launch safety approval process, which is independent from and not subject to the procedural requirements of NEPA.

*The Committee for Risk Analysis in Regulation*
*5104 Baum Boulevard #2*
*Pittsburgh, Pennsylvania 15224*
*(412) 681 - 5314*

April 9, 1990

Dr. Dudley G. McConnell
Code EL
National Astronautics and Space Administration
Washington, D.C. 20546

Re: Draft Environmental Impact Statement for the Ulysses Mission (Tier 2), February, 1990

Dear Dr. McConnell:

Please find enclosed our comments on the Draft EIS for the Ulysses Mission.

Very truly yours,

Anand P. Patwardhan (Chair)

Jon F. Merz

enc.

**Comments on the Draft Environmental Impact Statement for the Ulysses Mission**

These comments include specific as well as somewhat more general, methodological issues associated with the Draft Environmental Impact Statement (DEIS).

1. The Final Safety Analysis Report (FSAR) has not been completed, and therefore has not been published for public comment along with the DEIS. Does NASA intend to issue the FSAR as a Supplemental DEIS when completed? If not, will the Final Environmental Impact Statement, which will incorporate the FSAR, be issued for public comment pursuant to *42 C.F.R. §1503.1 (b)* ? — 14-1

2. The calculation presented on page 4-11, last paragraph, which appropriately drops the *de minimis* consideration, appears to be an improper conversion from individual risk to total risk. Specifically, risk per person *times* the number of people at risk yields total risk, not division. Further, the basis for and uncertainty in the number of people at risk (5000) is not presented. Is there any reason why the number of people at risk in this calculation is the inverse of the conditional probability of fatal cancer given in the release (0.0002)? Is there any double counting in this calculation? — 14-2

3. On page 4-1, it is stated that "there are no environmental consequences associated with" the activities preceding the launch. This statement seems in direct conflict with studies made for previous missions like Galileo. Specifically, the FSAR on Galileo presents an estimate of the risk during phase 0, T-8 hours to T+2 seconds. — 14-3

4. Can the results of the mission risk be presented as a distribution of fatalities versus their probabilities, as presented in WASH-1400, the Reactor Safety Study? — 14-4

5. The manner of dealing with uncertainty in the risk calculations is not clear. What are the underlying assumptions about probability distributions for failures of systems, source term generation, environmental dispersion and dose-response? Further, what is the relative contribution — 14-5



RESPONSES TO COMMENTS
Commentor No. 14: Committee for Risk Analysis in Regulation
(Continued)

Response to Comment No. 14-1

The information in the FSAR, together with updated probabilities for accident initiation were used in preparing Sections 4.1.4.3 and 4.3 and Appendix C of this EIS. A complete text of the "Update of Ulysses FSAR Results using Updated NASA Probabilities" is provided in Appendix G for your convenience.

Response to Comment No. 14-2

The paragraph represents a calculation of the average individual risk from the total risk (not vice versa). In other words, the total risk value ($4.5 \times 10^{-8}$) is the product of the total collective dose (0.53 person-rem) received by the 5,000 persons exposed (person-rem) times the cancer risk per person-rem ($3.5 \times 10^{-4}$) times the probability of the accident occurring ($2.4 \times 10^{-4}$). In order to calculate average risk among the 5,000 persons, the total risk is correctly divided by the 5,000 persons to estimate the risk per person ($9 \times 10^{-12}$). There is no double counting involved. The basis for the 5,000 persons at risk is presented in the Ulysses FSAR.

Response to Comment No. 14-3

The statement referred to in this comment was meant to apply to the prelaunch activities of developing the spacecraft, not of the launch itself. The text has been revised to clarify this.

It is true that the Galileo FSAR addressed accident risks during the prelaunch Phase 0. Over the period since the release of the Galileo FSAR, DOE has continued to refine its analyses and analytical techniques. A review of Section 3.3.2 of the Ulysses FSAR Volume II, Book 1 (Accident Model Document) indicates that DOE evaluated Phase 0 accidents for the Ulysses mission, specifically an on-pad fire and explosion involving the external tank, and an inadvertent Range Safety System destruct, with the on-pad fire/explosion dominating the risk, (see Section 3.4.4, Ibid). The FSAR analyses (Section 3.4.4.1 and 3.4.4.2) indicate that these prelaunch accidents do not result in environments severe enough to cause a release of plutonium fuel from the RTG. See Vol. II, Book 1, Section 3 of the FSAR.

Response to Comment No. 14-4

This has now been done in the FSAR and reflected in the FEIS.

Response to Comment No. 14-5

The effect of uncertainties in the risk analysis was undertaken in the Safety Status Report. The critical aspect of this analysis was to identify areas of variability and uncertainty, establish the range of each parameter value, and the distribution within the range. Two types of probability distributions were commonly used. If all values within the range were considered equally probable, then a uniform distribution was chosen. If a best estimate value had been determined, the range of uncertainty was represented as a normal or log normal with a best estimate treated as a mean or geometric mean, respectively.

With respect to system failure probabilities, due to the nature of a nuclear risk assessment, conservative failure probabilities were generated by NASA. The probability estimates were derived from a review of all pertinent studies and historic data from both solid and liquid rocket failures. As a result, STS accident probabilities were provided as decade ranges by phase and by Shuttle major element. Although several options were considered, the geometric mean accident probabilities determined from these ranges were used in the Failure Abort Sequence Trees (FAST). The geometric mean was selected (alternates included the algebraic and harmonic means) because it tends to give equal weight to both the upper distribution, which is often used with uncertainty ranges of an order of magnitude or more where specific distribution data is not available. The algebraic and harmonic means were considered less desirable because they are dominated by the upper and lower probability bounds, respectively. The updated analysis in this EIS used arithmetic means for the initiating accident probabilities. SPASM, a general purpose Monte Carlo simulation program, was used to propagate these uncertainties in the risk analysis.

Also see Response to Comment 1-1.

of the uncertainty in each of these areas to the overall uncertainty estimate of the risk? How have the uncertainties been propagated through the overall risk assessment?
With more specificity, on page 4-11, first paragraph, the dose-response to Pu-238 is said to "range from $3.2 \times 10^{-4}$ to $3.5 \times 10^{-4}$ excess cancer fatalities per person-rem." What is the meaning of this "range"? If this is a confidence interval, at what confidence level? 14-6

6. The discussion of the source term ignores the contribution of the Pu-238 inventory of the Radioisotope Heater Units (R.H.U.'s) on board Ulysses. Why? Note that *14 C.F.R. §1216.905(c)(3)* only exempts R.H.U. on a space vehicle as a *reason for the preparation* of an EIS. Once the EIS is required for other reasons, the R.H.U. inventory should be included in the assessment. 14-7

7. Shuttle systems are understood to be highly redundant. How are common cause failures modeled in the systems failure analyses? Do common cause failures dominate the failure cutsets? If not, why not? 14-8

8. Have the computer models used for simulating failure events been subjected to an independent peer review? If not, what are the contractor's internal quality assurance procedures? 14-9





RESPONSES TO COMMENTS
Commentor No. 14: Committee for Risk Analysis in Regulation
(Continued)

Response to Comment No. 14-6

This range reflects the variability in the biological response to radiation exposure as well as the uncertainty in the dose response relationship. It is not a confidence interval.

Response to Comment No. 14-7

The Ulysses spacecraft does not require the use of RHUs, therefore, none are on board.

Response to Comment No. 14-8

The probability of a specific representative accident scenario occurring is dependent on the initiating failure probabilities. The initiating system level failure probabilities (for Launch Support Equipment, Orbiter, External Tank, Space Shuttle Main Engine, Solid Rocket Rooster, Range Safety System and Payload) provided by NASA, in support of the DEIS were derived from a review of all pertinent reports and historical Eastern Space and Missile Center (ESMC) data of solid and liquid booster failures and not from a detailed analysis at the component level. These probability estimates were intended to be conservative engineering values, recognizing that their sole purpose was to facilitate the nuclear risk assessments for the Galileo and Ulysses missions. Thus, to the extent that similar common cause failures were exhibited in the data for these systems, these failures are reflected in the system level failure probabilities.

Response to Comment No. 14-9

LASEP 3, the primary accident modeling tool utilized by DOE, has been subjected to a three-step verification and validation procedure:

(1) Module Verification
(2) Program Verification
(3) Program Validation.

This is described in Volume II, Book 2 of the FSAR in Section D.4, pages D-85 through D-88.

Each module, subroutine, and group of subroutines was verified, in the Module Verification step, independent of the balance of the program, using test driver programs to check for the correctness of inputs and outputs.

Program verification was undertaken using four compiler options (bounds check, list file check, Debug, and Implicit One). This step ensured that all the parameters passed in subroutine and function calls were checked, and that each module, subroutine, and group of subroutines behaved the same way within the main program as they did in the Module Verification tests.

Program validation was accomplished in several ways to ensure that program output was reasonable. Subroutine and program outputs were validated using: a third party software program; a separate independent software program prepared by DOE's contractor; and graphically, by hand calculations or against test results.

For further details refer to the FSAR as noted above.

The principal risk analysis tool, EMERGE, is proprietary software developed by DOE's risk analysis consultant. EMERGE is described in detail in FSAR Volume III, Book 2, Section A.2.1 beginning on page A-5. EMERGE uses a three-dimensional, variable trajectory, Gaussian puff model to simulate the atmospheric transport and diffusion of an accidental release of RTG fuel, accounting for meteorological conditions which vary in 15 minute steps.

The atmospheric transport and dispersion submodels of the EMERGE model grew out of several other NUS developed computer codes: NUSPUF and AQPUF. The AQPUF model was validated through SF6 tracer studies in complex terrain.

EMERGE has been evaluated against four other atmospheric dispersion models for selected release cases:

1. The ATMOS model developed
2. The PFPI model developed by Savannah River Laboratory
3. The ARAC MATHEW/ADPIC model developed by Lawrence Livermore Laboratory
4. Sandia National Laboratories DIFOUT model.

The evaluation indicated good comparability in results, with any differences explainable.

See also Response to Comment No. 2-7.

National Aeronautics and
Space Administration

Washington, D.C.
20546

Attachment 1

Reply to Attn of SL

May 11, 1990

Mr. Daniel Hirsch
President
Committee to Bridge the Gap
1637 Butler Avenue #203
Los Angeles, CA 90025

Dear Mr. Hirsch:

This letter responds to yours of April 24, 1990 (received on April 30, 1990) which stated your concerns regarding NASA providing you documents cited as references in the draft environmental impact statement for the Ulysses mission (Tier-2).

In order of the points you raised:

1. The Final Safety Analysis Report (FSAR) for the Ulysses mission was published by the Department of Energy (DoE) on March 14, 1990. You may obtain a copy by contacting Dr. A. T. Clark, Operations Manager, Office of Special Applications (NE-53) at DoE Headquarters or by calling (301) 353-4021. Dr. Clark will provide copies as long as his supply will permit. The FSAR is also available from the National Technical Information Service (NTIS) which is the public source of record for such government reports.

   The DoE has distributed the FSAR to many repositories. In particular, it will be available for review at all of the NASA sites at which the Ulysses Final Environmental Impact Statement (FEIS) will be available.

2. The NASA regulation at 14 CFR 1216.310(b) provides for making available to the public the draft and final EIS and the key underlying documents on which the EIS is based. In the case of the Ulysses mission DEIS (Tier-2), the key underlying document was the DoE's Safety Status Report. That document was available at information locations, such as NASA field Centers, NASA Headquarters, and the Jet Propulsion Laboratory. Similarly, the FSAR will be available at those installations along with the FEIS.

Further the regulation provides that supporting documentation shall be available for public review and copying in the office of the responsible Headquarters official or a suitable designee. While we are still in the process of preparing the FEIS, the complete set of references to which you allude is in the hands of our consultants, Science Applications International Corporation (SAIC), at Tysons Corners, Virginia. A complete set of those references will be forwarded to my office and available for review when the FEIS is completed. Requests for any specific non-NASA document cited in the references should be directed to the agency or entity that originated the document. Requests for a specific NASA document may be directed to my office.

The NASA regulation is based upon the CEQ regulations which require a concise, clear, and to the point EIS, which need not be encyclopedic (see 40 CFR 1502.7); and the EIS's efficient and economic distribution (see 40 CFR 1502.19). Nothing in the NASA or CEQ regulations require that all references cited in a reference appendix (which is comparable to a bibliography) be made available by NASA.

3. NASA would face an impractical and undue burden in seeking to assist all parties, such as your organization, to obtain all of the documents cited in the DEIS reference appendix beyond those key documents (such as the Safety Status Report) which are provided for inspection along with the DEIS. NASA mails out dozens of copies of its DEIS to agencies, organizations, and individuals that we have reason to believe would be interested in receiving the DEIS. It is not appropriate or practical to assist all such recipients to obtain all of the cited reference documents listed in the reference appendix. If we assisted one, we would have to offer the same assistance to all. This would obviously be contrary to the efficient and economical administration of the EIS process. Rather NASA will make publicly available a complete set of references as stated above.

4. As indicated above, the FSAR is available now for your review -- for instance, at the Jet Propulsion Laboratory. The DEIS indicated that it was based on the Safety Status Report (SSR) and that the FEIS would be based on the FSAR. The DEIS was based upon the most current information available at the time of its publication. Upon completion of the FEIS there will be a 30 day waiting period,

following public notice of the availability of the FEIS, prior to NASA's reaching its decision and filing the record of decision. I believe that you will find that the FEIS takes account of all of your concerns, and, of course, you are welcome to comment on the FEIS during the 30-day period.

Thank you very much for your interest in the Ulysses mission.

Sincerely,

Dudley G. McConnell
Deputy Director (Advanced Programs)

cc:
DoE NE-53/Dr. A. T. Clark, Jr.

# APPENDIX D

# DEVELOPMENT OF PHASE 1 SOURCE TERMS FOR RISK ASSESSMENT

# APPENDIX D

## DEVELOPMENT OF PHASE 1 SOURCE TERMS FOR RISK ASSESSMENT

The purpose of this appendix is to explain the detailed derivation of the source terms presented in the Ulysses FSAR Vol. II. The Accident Model Document of the FSAR (DOE 1990f, Book 1) presents the Phase I source terms and associated release probabilities in two different ways. The aim here is to trace the relationship between the two forms of presentation. Table 2-1 on page 2-6 presents the average source terms for each of the five subphases. These average source terms are presented for each of three release locations that affect the transport pathways to people and the environment:

- Releases in the fireball (possible only in the 0-10 sec. subphase)
- Releases at ground-level (outside the fireball)
- Releases at some altitude above the Earth.

The average source terms in Table 2-1 are the averages taken over all of the Monte Carlo trials for each subphase, where a release occurs. For example, in the 0-10 sec. subphase, 230 trials resulted in a release (see Table D-15, p. D-99 of Vol. II, Book 2), thus the average fireball and ground-level source terms presented for these two release locations in Table 2-1 were derived by dividing the sum of all fireball releases by 230, and the sum of all ground-level releases not in the fireball by 230. The source terms presented in Table 2-1 are the average source terms carried over into the Nuclear Risk Analysis Document, Vol. III, Book 1 (see Table 3-1).

From Table D-15, it can be determined that the average source terms for the remaining subphases were based upon:

| | |
|---|---|
| 11 - 20 sec.: | 233 trials with a release |
| 21 - 70 sec.: | 66 trials with a release |
| 71 - 104 sec.: | 176 trials with a release |
| 105 - 120 sec.: | 1,328 trials with a release |

The probability of release presented in Table 2-1 for each subphase is the product of the accident (SRB Case Rupture) probability ($1.02 \times 10^{-3}$) found on Figure 3-11 on page 3-60, times the conditional probability (i.e., weighting factor) that the case rupture, if it occurred, would occur in that particular subphase (see Table 3-6 for the conditional probabilities by subphase), times the probability of a release, if such an accident occurs, as determined by the subphase LASEP3 run. Again, using the 0-10 sec. subphase as an example:

- SRB Case Rupture = $1.02 \times 10^{-3}$
- Conditional probability that a case rupture, if it occurred, would occur in the 0-10 sec. subphase = 0.5

- Probability of Release from the 0-10 sec. LASEP3 run = 230 trials with releases out of 100,000 trials, or 230 / 100,000 = 0.0023.

The release probability for the 0-10 sec subphase is thus:

$[1.02 \times 10^{-3}] \times 0.5 \times 0.0023 = 1.17 \times 10^{-6}$ or $1.2 \times 10^{-6}$ rounded

The average source terms and the subphase probabilities thus derived for Table 2-1, are those found in the Nuclear Risk Analysis Document (Vol. III, Book 1) in Table 3-1 as "Conditional Probabilities."

The second way average source terms and release probabilities are presented in Vol. II, Book 1 can be found in Tables 3-6 and 3-7 on pages 3-62 and 3-63. These average source terms are the source terms by release mechanism as opposed to location. There are 7 possible release mechanisms:

- SRB fragment impact; release in air
- impact of GPHS on: steel, concrete, sand
- impact of Fueled Clad on: steel, concrete, sand.

The averages for each of these 7 possible mechanisms were computed (where they occurred) on the basis of only the number of trials within a Monte Carlo run where a release occurred for the given mechanism. For example, within the 230 trials showing a release for the 0-10 sec. subphase, a release in air occurred in 114 of those trials. The average air release shown in Table 3-6 was thus based on dividing the sum of all air releases by 114.

The probabilities for each average source term presented in Tables 3-6 and 3-7 were developed by multiplying the initiating probability for a SRB Case Rupture accident ($1.02 \times 10^{-3}$; see Figure 3-11 on page 3-60) times the conditional probability (i.e., the weighting factor) of a release within each subphase (see Table 3-6, page 3-62), time the probability of release by the given mechanism as determined from the LASEP3 run. For example, to develop the release probability found in Table 3-6 for an air release in the 0-10 sec. subphase:

$[1.02 \times 10^{-3}] \times 0.5 \times [114 / 100,000] = 5.8 \times 10^{-7}$

EXAMPLE:

To develop the fireball source term for the 0-10 sec. subphase found in Table 2-1, the following process can be followed.

a. Refer to Table 3-6 for the 0-10 sec. average air release. All air releases in the first 10 seconds of Phase I are assumed to occur in the fireball.

b. Refer to Table 3-7 for the remaining 0-10 sec. average releases that occur in the fireball. (Note that under "Fueled Clad Impacts", the 0-10 sec. impact on steel should be coded as within the fireball. This is a

typographical error.) All of the components of the 0-10 sec. average fireball release thus become:

- Air: 5.64 Ci (114 trials)
- GPHS (Steel): 1,340 Ci ( 7 trials)
- FC (Steel): 1,510 Ci ( 3 trials)
- FC (Concrete): 0.843 Ci ( 8 trials)
- FC (Sand): 0.0217 Ci ( 1 trial)

c. Refer to Table D-15 for the total number of trials with a release for the 0-10 sec. subphase (i.e., 230 trials showed a release).

d. Reconstruct the sum on which each of the average fireball source term components is based as follows:

5.64 Ci x 114 trials = 642.96 Ci Sum

1,340 Ci x 7 trials = 9,380 Ci Sum

1,510 Ci x 3 trials = 4,530 Ci Sum

0.842 Ci x 8 trials = 6.74 Ci Sum

0.0217 Ci x 1 trial = 0.0217 Ci Sum

e. Add the reconstructed sums and divide by the total number of trials for the 0-10 sec. subphase in which a release occurred.

14,559.72 Ci Total Sum / 230 trials = 63.4 Ci Average Fireball Release

# APPENDIX F

# STATE AND FEDERAL COORDINATION

# APPENDIX F

## STATE AND FEDERAL COORDINATION

Appendix F documents NASA's Federal and State coordination regarding the environmental analysis of the Ulysses mission. This coordination particularly involves the State of Florida, site of the action, the U.S. Environmental Protection Agency (EPA), which oversees Federal environmental analyses, and the U.S. Air Force which operates the Eastern Test Range at which Shuttle launches occur. Thus, these communications are distinct from the general comment activity.

STATE OF FLORIDA

# Office of the Governor

THE CAPITOL
TALLAHASSEE, FLORIDA 32399-0001

BOB MARTINEZ
GOVERNOR

May 14, 1990

Dr. Dudley G. McConnell
Deputy Director (Advanced Programs)
National Aeronautics and Space
Administration Headquarters
Code EL
Washington, D.C. 20546

RE: Draft Environmental Impact Statement for the Ulysses Mission (Tier 2)

SAI: FL9004201284C

Dear Dr. McConnell:

The Florida State Clearinghouse, pursuant to Presidential Executive Order 12372, Gubernatorial Executive Order 83-150, the Coastal Zone Management Act and the National Environmental Policy Act, has coordinated a review of the above referenced project.

Pursuant to Presidential Executive Order 12372, the project is in accord with State plans, programs, procedures and objectives.

The State has reviewed your federal consistency determination for the above referenced project. There were no comments from our reviewing agencies, therefore, the State agrees that the proposed project is consistent with the Florida Coastal Management Program.

This letter reflects your compliance with Presidential Executive Order 12372.

Please call Beth Lines or Don Henningsen at (904)488-8114 should you have further questions.

Sincerely,

Karen K. MacFarland

Karen K. MacFarland, Director
State Clearinghouse

KKM/rt

F-2

Comments noted.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IV

345 COURTLAND STREET, N.E.
ATLANTA, GEORGIA 30365

APR 14 1990

Dr. Dudley G. McConnell
NASA Headquarters
Code EL
Washington, DC 20546

Subject: Draft Environmental Impact Statement (EIS) for the Preparation and Operation of the Ulysses Spacecraft

Dear Dr. Dudley:

Pursuant to Section 309 of the Clean Air Act and Section 102 (2)(C) of the National Environmental Policy Act, EPA, Region IV has reviewed the document's discussion of the flight mission to observe the polar regions of the Sun. The mission's objectives are to conduct studies of the Sun and the heliosphere. In our recent comments on a similar generic undertaking, viz., the Galileo Mission Project, we had a number of environmental concerns about certain procedural aspects of the emergency response and clean-up measures associated with the consequences of a launch vehicle abort and re-entry. As a result of additional information provided by NASA together with attendance of EPA technical staff at the actual Galileo launch, these concerns were satisfactorily addressed. This notwithstanding, the environmental impacts of an accidental release of the plutonium dioxide used in the power system is currently underway. Preliminary results indicate small health or environmental risks. However, a final Safety Analysis Report which will render a definitive conclusion will be available prior to publication of the Final EIS.

Our remaining environmental interest in this and similar launch actions centers on the short- and long-term air quality impacts associated with the combustion products of the solid rocket motor. There is a growing awareness among elements of the scientific community that these products could have greater effects than were initially supposed in previous evaluations. These concerns were expressed in the attached letter which we recently sent to the U.S. Air Force's Titan IV upgrades (See Attached). NASA is already aware of these concerns and is in the process of specifically responding to them in its supplemental analysis to the rocket motor testing program at the Stennis Space Center. When this study is completed it should provide answers as to whether the air emissions associated with the solid rocket motor engines pose a real/significant environmental risk.

On the basis of our review a rating of EC-2 was assigned. That is, we have a degree of environmental concern about the potential air quality effects resulting from the rocket motor exhaust and will need to evaluate the results of work which is currently in progress to make a final determination.

F-3

This EIS is primarily concerned with the impacts of the Ulysses mission, a Shuttle payload. The impacts addressed in the EPA letter are attendant to every Shuttle launch, and have been addressed extensively in earlier NEPA documentation. The near field area around the launch site was acquired by NASA for the express purpose of conducting launch activities. The impacts are an unavoidable element of Shuttle launch operations. They are, however, judged to be short term because there was notable recovery during the pause in Shuttle flights following STS 51-L. Ground water is systematically monitored in test wells near the perimeter of KSC to assess migration of possible contaminants.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IV

345 COURTLAND STREET, N.E.
ATLANTA, GEORGIA 30365

MAR 2 8 1990

Captain Anthony E. Fontana, III
Environmental Planning Division
Regional Civil Engineer, Eastern Region
Department of the Air Force
77 Forsyth Street, S.W.
Atlanta, GA 30335

Subject: Environmental Assessment (EA) and Finding of No Significant Impact (FONSI) for the Proposed Titan IV Upgrade Program (Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC), FL

Dear Captain Fontana:

Pursuant to Section 309 of the Clean Air Act, EPA, Region IV has reviewed the subject document in which the U.S. Air Force examines the ramifications of increasing KSC's launch rate capability for Titan IV vehicles and improving the payload capacity of the system by the use of a larger solid rocket motor (SRM). Existing support facilities are not capable of processing solid rocket motors at the rate which could sustain the higher launch frequencies; therefore, a number of new facilities will have to be constructed to meet the anticipated demand. On the basis of the information provided we do not have any immediate, significant concerns regarding the latter element of this proposal, i.e., physical facilities; however, we do have some concerns about some aspects of the larger SRMs and the environmental consequences of certain elements of the air emissions associated with the upgraded launch program .

The focus of our environmental concerns about the SRM is the anticipated increase in combustion products of the larger engines coupled with the potential long-term ecosystem consequences of these emissions. In addition, there is the issue of incremental effects of upgraded frequencies of other launch vehicle systems/programs at KSC, i.e., Delta and Atlas rockets and Space Station Freedom. A procedural corollary to this would be the fact that each of the programs is examining impacts in their NEPA documents without fully considering the cumulative/synergistic consequences of the others. Specifically, we believe that it is important to know the long-term impacts of the combustion products from the various vehicles on the local biota (KSC/Brevard County) through acid rain deposition and related pH changes to the soil column and surface waters.

In order to estimate the concentrations of the combustion products in the "ground cloud", the Rocket Effluent Exhaust Dispersion Model (REEDM) was used in the assessment of launch impacts. However, it

is our understanding that this model has been withdrawn from use by the USAF in order to incorporate some modifications/recalculations. If this is the case, we need verification that the most current model was used in this document. If not, the section on air quality impacts needs to be updated with the results of the new model calculations.

To date there has been relatively little research into the secondary effects of rocket emissions on the environment. NASA is in the process of addressing this omission at its Stennis facility in Mississippi via a supplement to a recently prepared environmental impact statement (EIS). The results of this investigation would have immediately applicability to the situation at KSC. Since the engines which are tested at Stennis will ultimately be used at KSC, we suggest that a monitoring program be established to develop site specific data on the degree/type of edaphic/biotic changes at KSC and at selected mainland sites which are occuring response to the rocket motor emissions. The details/protocol of this program would be worked among the interested parties during subsequent coordination.

This notwithstanding, results of existing research in related topics suggest that the impacts on the local biota from the combustion products of the SRM may not be as benign as the stated conclusions in the EA. The document could be improved if it summarized the studies (by reference or in text in an appendix) which formed the basis of the conclusions that no significant adverse impacts can be anticipated. A number of references about the effects/interaction/relationship of the major components of the exhaust emissions, viz.,aluminum and HCl (pH) which we have discovered are included for your review. It should be noted that certain of these studies tend to diverge in perspective from the assumptions used in the EA. For example, aluminum oxide, a major by-product of motor combustion is noted to be insoluble; hence, not available to the environment. This is correct at or above neutral pH, but at lower pHs the solubility/availability increases. If the soils in the local area on the mainland tend to naturally be acidic, deposition of acidified aluminum oxide could pose a long-term problem. Even though KSC is located immediately adjacent to the ocean and launches would generally occur during periods of offshore winds, the winds aloft are often variable in term of direction. This may pose a problem over time and bears examination to determine its significance.

We suggest that the final document would be improved by additional discussion as to why the less powerful and less polluting engine configurations/types can not meet the Air Force's objectives. We understand from conversations with USAF technical staff that the larger lifting capacity of the larger motors is deemed desirable. However, since the Titan program has been in operation for a number of years, a practical alternative could be argued to exist in the existing motors. Moreover, it would seem that improved technologies,e.g., miniaturization, would lessen to some degree the need for the increased throw capabilities being demonstrated by the new SRMs.

Thank you for the opportunity to comment on this action. If we can be of further assistance, Gerald Miller (404-347-3776) will serve as initial point of contact.

Sincerely yours

Heinz Mueller

Heinz J. Mueller, Chief
Environmental Policy Section
Federal Activities Branch

SPECIFIC REFERENCES

- Acidification of soils reduces the availability of phosphorous to plants and increases the solubility of other elements, some of which may be toxic. Aluminum is of most interest in this case as it is a by-product of motor operation and is already one of the most abundant toxic element in many forest and agricultural soils. Increasing soil acidity leads to greatly increased solubility and toxicity of aluminum to many crop and forest plants ("A Status Report on Acid Precipitation and Its Biological Consequences", In: Acid Precipitation: Effects on Ecological Systems, 1982).

- The potential for the alteration of soil microbial activity by acid precipitation by mechanisms other than decreased soil pH are also of interest and should be considered. The net consumption of $H^+$ by mineral species usually involves the solubilization and mobilization of aluminum species. However, the potential for toxic effects on soil microbes and plants is not yet fully understood. (Direct and Indirect Effects of Acidic Deposition on Vegetation, 1984).

In addition to the possible adverse effects of soil acidification and various mineral activities on plants, the potential for deleterious effects on aquatic life should also be considered.

- Aluminum is a ph-sensitive element that can cause acute toxicity in some organisms at aqueous activities of 10uM or less. (CRC Critical Reviews, 1, Haug, 1984).

- Environmental scientists have reported a potentially harmful biogeochemical link between acidic deposition onto forest soils and aluminum toxicity in forest and aquatic communities of northeastern North America and northern Europe (Cronan et al., 1986).

- Although aluminum has been considered relatively innocuous, recent studies have shown aluminum to be toxic to aquatic life in some acid waters. When soils become acid, as may occur with acid precipitation, aluminum is mobilized and may leach into streams and lakes. The information available on toxicity of aluminum to aquatic organisms is limited; however, it has been established that when the pH of the water is 5.5 or below, aluminum can be toxic to fish. (U.S. Fish and Wildlife Service, Research Information Bulletin, No. 83-48, 1983).

- Atlantic salmon fry, exposed to aluminum at intermediate pH in a laboratory toxicity test developed significant abnormalities in gill structure. Gill abnormalities were observed in fish exposed to 75 ppb or greater aluminum. These gill abnormalities could result in delayed mortality in older life stages. (U.S. Fish and Wildlife Information Bulletin, No. 87-118, 1987).

- Aluminum concentrations of 0.1 mg/l for white suckers and 0.2 mg/l for brook trout resulted in measurable reductions in survival and growth of larvae and postlarval at pH levels ranging from 4.2 to 5.6. The simultaneous increase in aluminum concentration with elevated acidity must be considered to accurately assess the potential effect of acidification of surface waters on survival of fish populations. ("Aluminum Toxicity to Fish in Acidic Waters, Baker & Schofield, Water, Air, and Soil Pollution, 1987).

- The concentrations of aluminum reported to be toxic in laboratory experimentation varies greatly - ranging from physiologic alterations in rats at levels as low as 37 mg/kg given intragastric to no reported effects at 8000 mg/kg in the diet. (Mineral Tolerance of Domestic Animals, National Academy of Sciences, 1984).

The references provided above suggest that the concerns of combined aluminum and acid wastes should not be ignored. The noted studies certainly do not prove that a problem may eventuate at the ASRM, but they do point out the need for further investigation on the part of the involved parties before any definitive conclusions can be reached regarding the long-term environmental ramifications of this action.

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON, D.C. 20330

Dr. Dudley G. McConnell
Office of Space Science and Applications, Code EL
National Aeronautics and Space Administration
Washington, D.C. 20546

Dear Dr. McConnell

The draft Environmental Impact Statement (EIS), TIER 2, for the Ulysses Mission has been reviewed and comments are attached for your consideration to include into the EIS. Our action officer is Maj J. R. Williams at (202) 697-9886.

Sincerely

RANDLE K. BUNNER, LT COL, USAF
Chief, Environmental Planning Office
Environmental Quality Division

1 Atch
Review Comments

cc: SAF/MIQ
AF/LEEV

Review Comments

Draft Environmental Impact Statement for the Ulysses Mission

1. As a matter of format and discussion, Chapters 3 and 4 environmental analysis require a similarity of tracking in that, areas covered in the affected environment (i.e. physical, biological, social and economic factors) are also covered in the environmental consequences (effects) section, thus providing a clear scientific and analytic basis for the reader to compare what the environmental impacts of the alternatives including the proposed action are. However in Chapter 4, a disclaimer stating that certain environmental components have been analyzed, but that they are not described here because they are associated with limited or no impacts may be appropriate. — AF-1

2. Provide scales and directional arrows for all referenced location and site maps in the document. — AF-2

Response to Comment No. AF-1

A suitable revision has been made to the text of Section 4.1.2.

The impact discussions in Section 4.1 of the Ulysses EIS have been expanded to discuss recent information on air quality and ozone impacts of Shuttle launches.

Response to Comment No. AF-2

Scales and directional arrows have been added where appropriate.

# APPENDIX G

# UPDATE OF ULYSSES FSAR RESULTS

Update of Ulysses FSAR Results
Using Updated NASA Probabilities

## 1.0 Introduction

The mission risk results reported in the Ulysses FSAR issued on March 14, 1990, were based on initiating accident probabilities the National Aeronautics and Space Administration (NASA) provided to the Department of Energy (DOE) on July 13, 1988. These probabilities were provided in terms of ranges; the geometric mean of these ranges were used in the development and presentation of the results in the FSAR for source terms, radiological consequences and risks.

Subsequent to the issuance of the FSAR, DOE received a revised set of probabilities from NASA. These probabilities were presented in terms of distributions for each initiating accident and characterized by a mean and cumulative percentile values. NASA recommended that DOE use the updated probabilities to update the Ulysses FSAR results. Accordingly, at the request of DOE this letter report has been prepared to evaluate the changes in the Ulysses FSAR results when the updated mean probabilities are used.

## 2.0 Initiating Accident and Total Fuel Release Probabilities

A comparison of the two sets of initiating accident probabilities for all accident scenarios considered in the FSAR is presented in Table 1. The accident analysis in the FSAR determined that only a subset of the scenarios would lead to source terms. For this subset of accident scenarios, the total fuel release probabilities by mission phase and sub-phase are shown in Table 2. As in the FSAR, the Range Safety Destruct scenario has not been included due to its low probability and small contribution to risk.

It should be noted that aside from the total fuel release probabilities, the base case source terms and radiological consequences reported in the FSAR (Executive Summary, Tables 3-2 and 3-3, and Volume III, Book 1, Tables 3-1 and 3-2) remain unchanged.

## 3.0 Risk Analysis Results

The FSAR analyses produced probability distributions of radiological consequences for accident scenarios leading to source terms. These results were presented by figures displaying complementary cumulative distributions functions (CCDFs) of consequences. (See the FSAR, Executive Summary, page 3-9, and Volume III, Book 1, Figures 4-1 through 4-9.) The plotted results of the CCDFs show the total probability (including initiating accident and conditional fuel release probabilities) that consequences (calculated health effects) would be equal to or greater than the indicated value.

The CCDFs have been regenerated taking into account the updated NASA mean probabilities. Figures 1 through 5 show the CCDF for subphases of Mission Phase 1. Figures 6 through 8 show the CCDFs for Mission Phases 2, 3, and 4, respectively. Figure 10 shows all the phase and sub-phase revised mean value CCDFs plotted together. A comparison of the overall mission CCDF based on the mean values for the FSAR and revised probabilities is shown in Figure 10.

The total risk associated with each of the mission phases or sub-phases is equal to the product of total release probability and the mean value of calculated health effects. Table 3 shows these values using both sets of probabilities.

## 4.0 Conclusions

The conclusion of this evaluation is that the mean value of the overall mission risk increases by a factor of 3.4 when the updated rather than the FSAR probabilities are used. This is due primarily to the increase in the SRB case rupture probability. However, the resulting risk is still well within the bounds of normally acceptable risks.

Table 1

Ulysses Mission Accident Probabilities

| | Mean Accident Probabilities FSAR | Updated |
|---|---|---|
| **Phase 0** | | |
| Pad Fire/Explosion | $1.79 \times 10^{-4}$ | $2.91 \times 10^{-3}$ |
| **Phase 1** | | |
| Tower Impact | $2.06 \times 10^{-4}$ | $1.89 \times 10^{-4}$ |
| SRB Loss of Thrust | $2.49 \times 10^{-3}$ | $2.17 \times 10^{-3}$ |
| SRB No Ignitition | $7.59 \times 10^{-5}$ | $8.65 \times 10^{-5}$ |
| SRB Case Burst | $1.02 \times 10^{-3}$ | $2.92 \times 10^{-3}$ |
| Range Destruct | $1.51 \times 10^{-6}$ | $1.70 \times 10^{-6}$ |
| Aft. Compartment Explosion | $3.95 \times 10^{-4}$ | $3.54 \times 10^{-3}$ |
| Vehicle Breakup | $8.98 \times 10^{-5}$ | $2.20 \times 10^{-4}$ |
| Crash Landing | $3.79 \times 10^{-6}$ | $3.79 \times 10^{-6}$ |
| Ocean Ditch | $7.21 \times 10^{-5}$ | $7.21 \times 10^{-5}$ |
| **Phase 2** | | |
| Vehicle Breakup | $1.51 \times 10^{-3}$ | $5.65 \times 10^{-3}$ |
| Crash Landing | $8.85 \times 10^{-6}$ | $8.0 \times 10^{-6}$ |
| Ocean Ditch | $1.68 \times 10^{-4}$ | $1.59 \times 10^{-4}$ |
| **Phase 3** | | |
| On Orbit Failure | $1.58 \times 10^{-4}$ | $5.75 \times 10^{-4}$ |
| **Phase 4** | | |
| Reentry | $6.16 \times 10^{-3}$ | **$6.16 \times 10^{-3}$** |

## Table 2

## Total Fuel Release Probabilities

| Phase | Time Period, s | Probability | | | | |
|---|---|---|---|---|---|---|
| | | Initiating | | | Total | |
| | | FSAR | Updated | Conditional | FSAR | Updated |
| 1[a] | 0-10 | $5.10 \times 10^{-4}$ | $1.46 \times 10^{-3}$ | $2.30 \times 10^{-3}$ | $1.17 \times 10^{-6}$ | $3.36 \times 10^{-6}$ |
| | 11-20 | $1.28 \times 10^{-4}$ | $3.65 \times 10^{-4}$ | $2.32 \times 10^{-3}$ | $2.97 \times 10^{-7}$ | $8.47 \times 10^{-7}$ |
| | 21-70 | $2.41 \times 10^{-4}$ | $6.62 \times 10^{-4}$ | $6.60 \times 10^{-4}$ | $1.59 \times 10^{-7}$ | $4.37 \times 10^{-7}$ |
| | 70-104 | $9.91 \times 10^{-5}$ | $2.60 \times 10^{-4}$ | $1.76 \times 10^{-3}$ | $1.74 \times 10^{-7}$ | $4.58 \times 10^{-7}$ |
| | 105-120 | $4.25 \times 10^{-5}$ | $1.71 \times 10^{-4}$ | $1.33 \times 10^{-2}$ | $5.65 \times 10^{-7}$ | $2.27 \times 10^{-6}$ |
| 2[b,c] | - | $1.51 \times 10^{-3}$ | $5.65 \times 10^{-3}$ | $1.09 \times 10^{-2}$ | $1.65 \times 10^{-5}$ | $6.16 \times 10^{-5}$ |
| 3[c,d] | - | $1.58 \times 10^{-4}$ | $5.75 \times 10^{-4}$ | $2.69 \times 10^{-1}$ | $4.25 \times 10^{-5}$ | $1.55 \times 10^{-4}$ |
| 4[c,d] | - | $6.16 \times 10^{-3}$ | $6.17 \times 10^{-3}$ | $2.69 \times 10^{-1}$ | $1.66 \times 10^{-3}$ | $1.66 \times 10^{-3}$ |



a. SRB case rupture

b. Vehicle breakup

c. Conditional and total probabilities for phases 2, 3, and 4 are for land impact. Associated source terms are expectation values given a land impact.

d. Uncontrolled Orbiter reentry

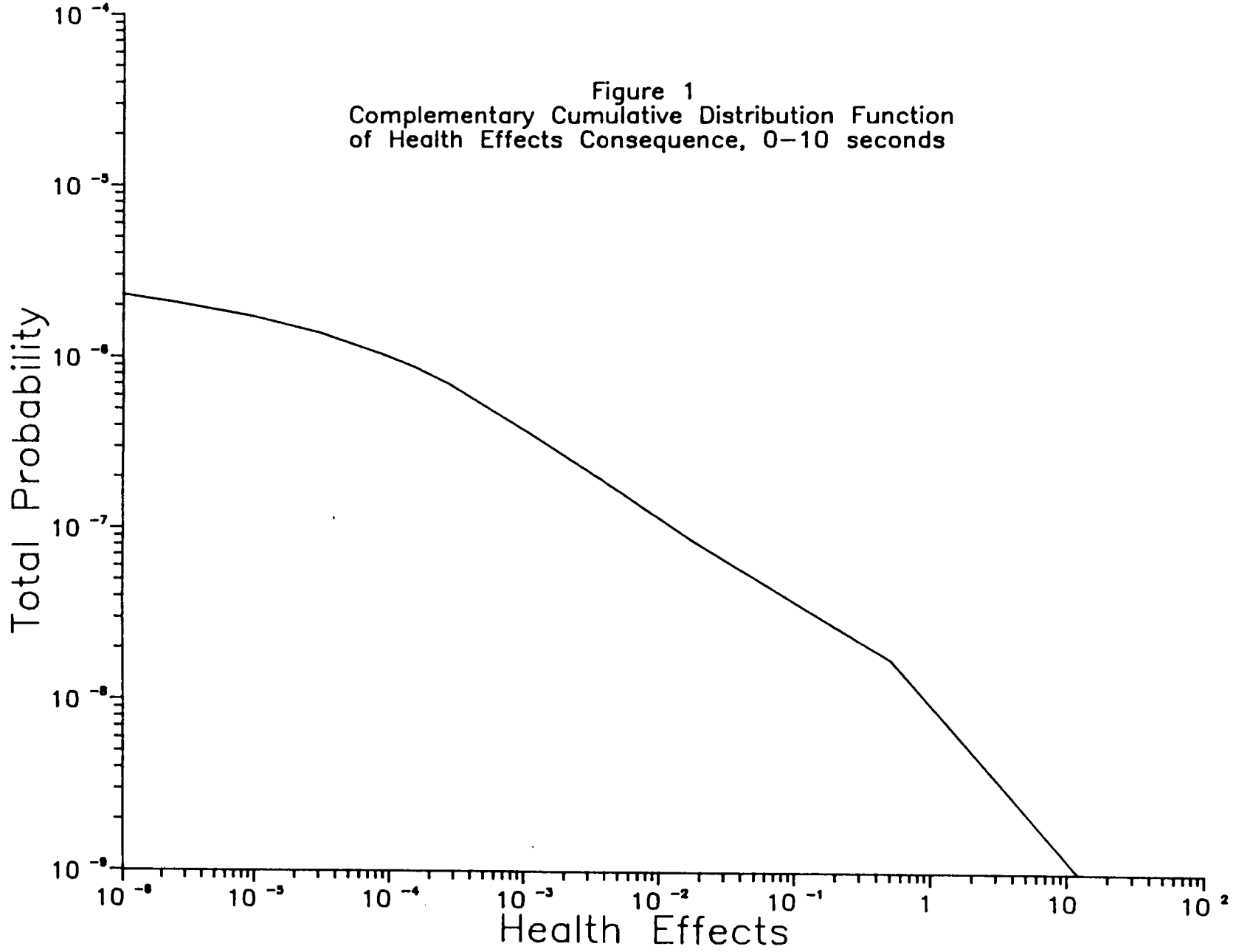



Figure 1
Complementary Cumulative Distribution Function
of Health Effects Consequence, 0–10 seconds

Figure 2
Complementary Cumulative Distribution Function
of Health Effects Consequence, 11–20 seconds

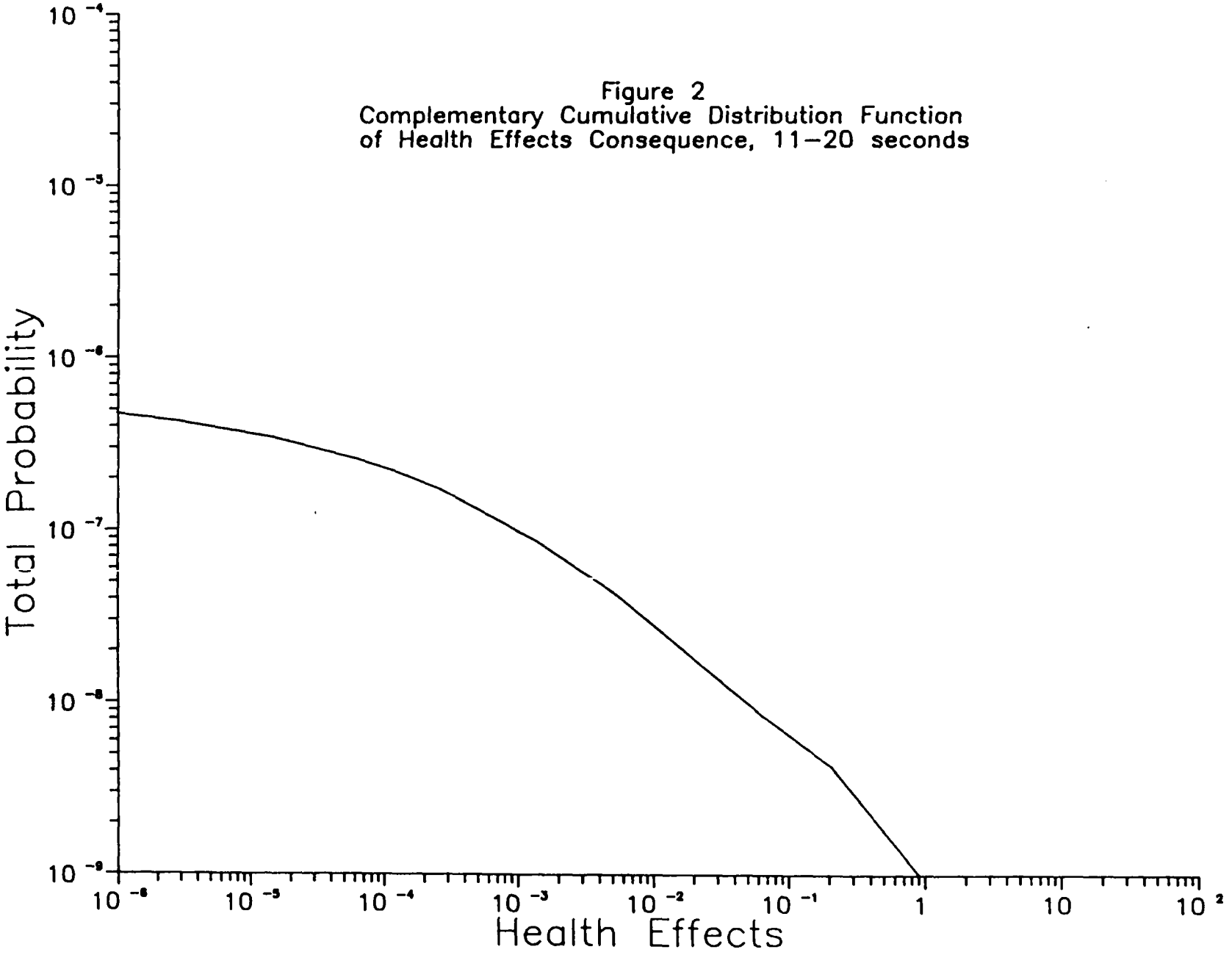


Figure 3
Complementary Cumulative Distribution Function
of Health Effects Consequence, 21–70 seconds

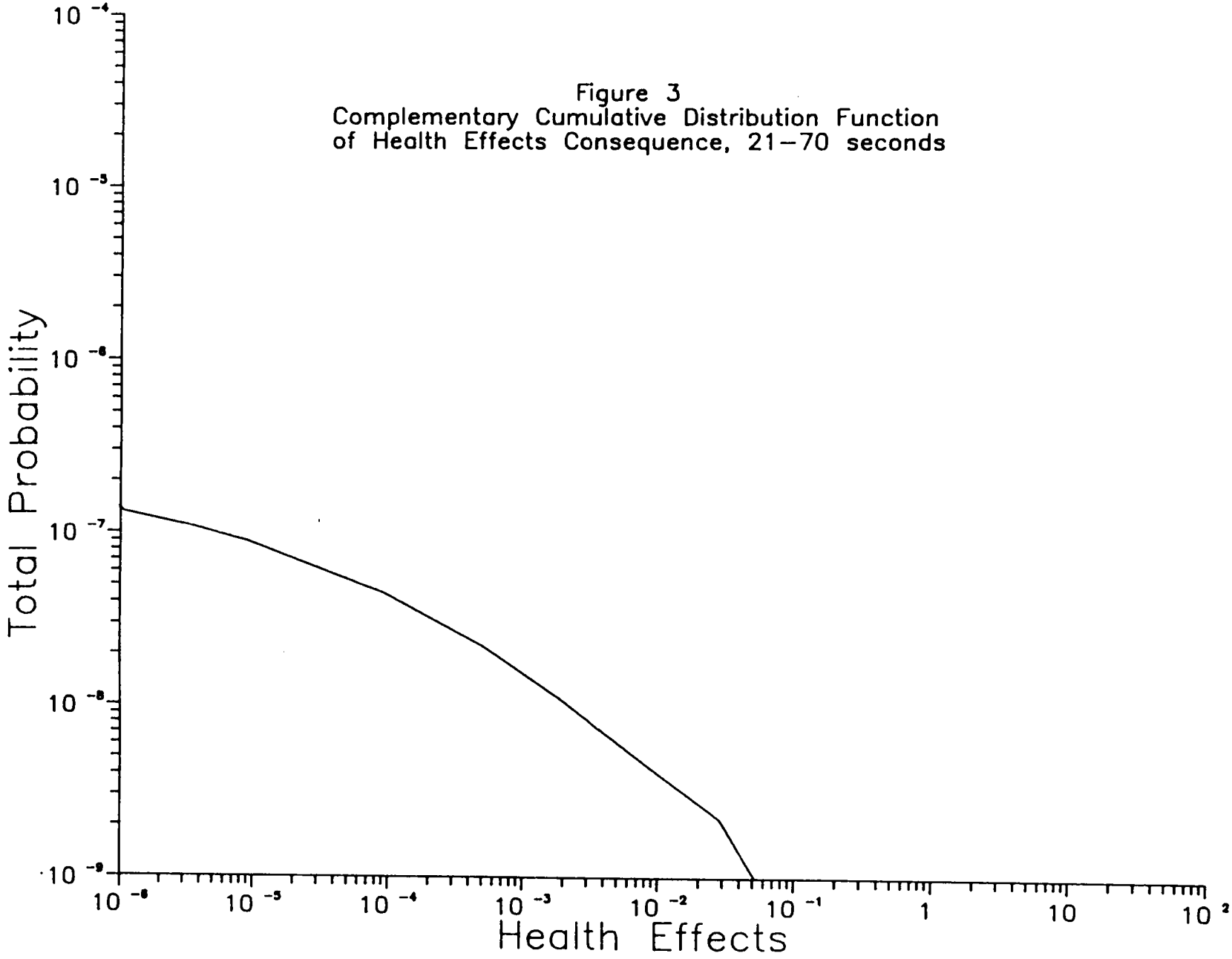
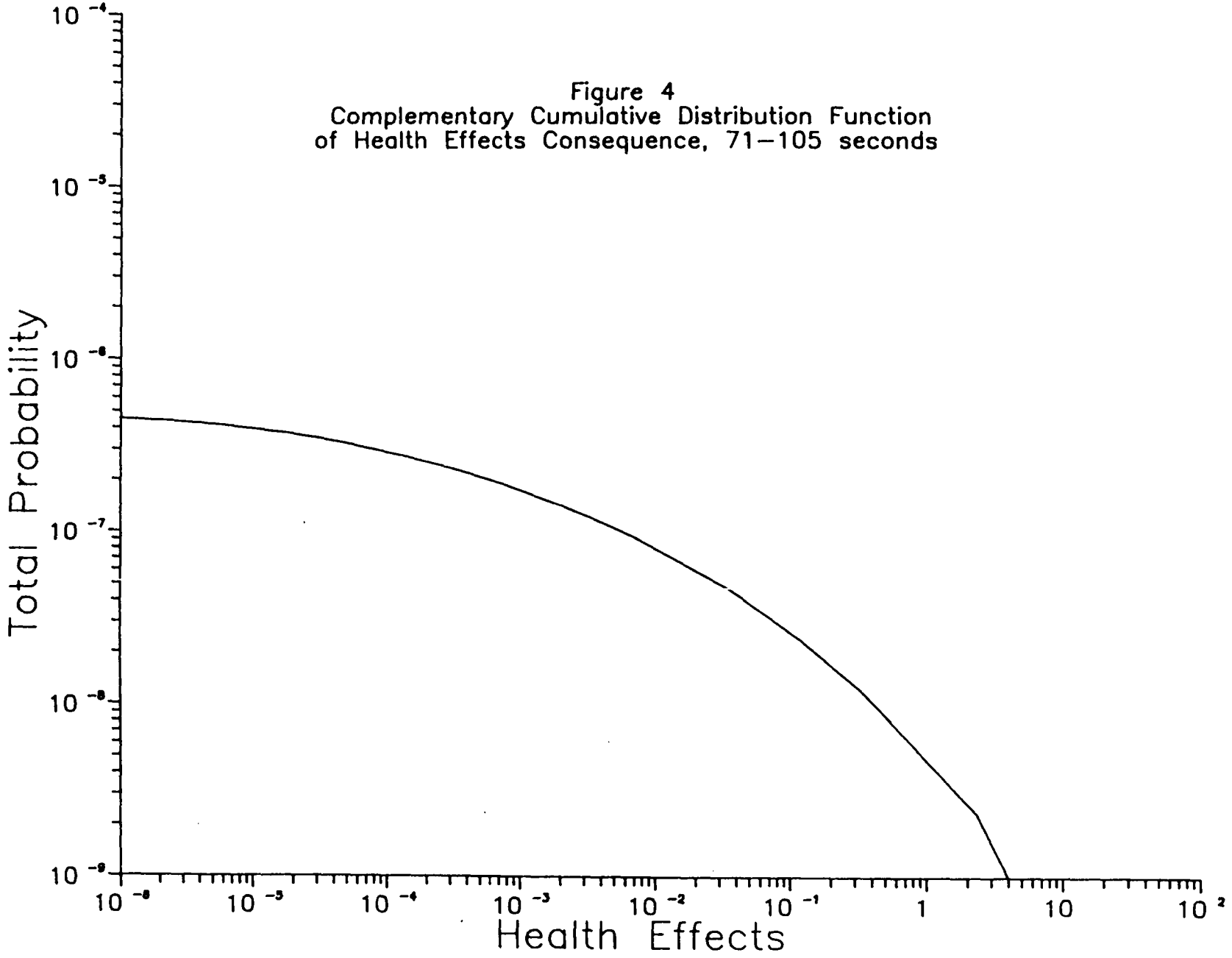


Figure 4
Complementary Cumulative Distribution Function
of Health Effects Consequence, 71–105 seconds



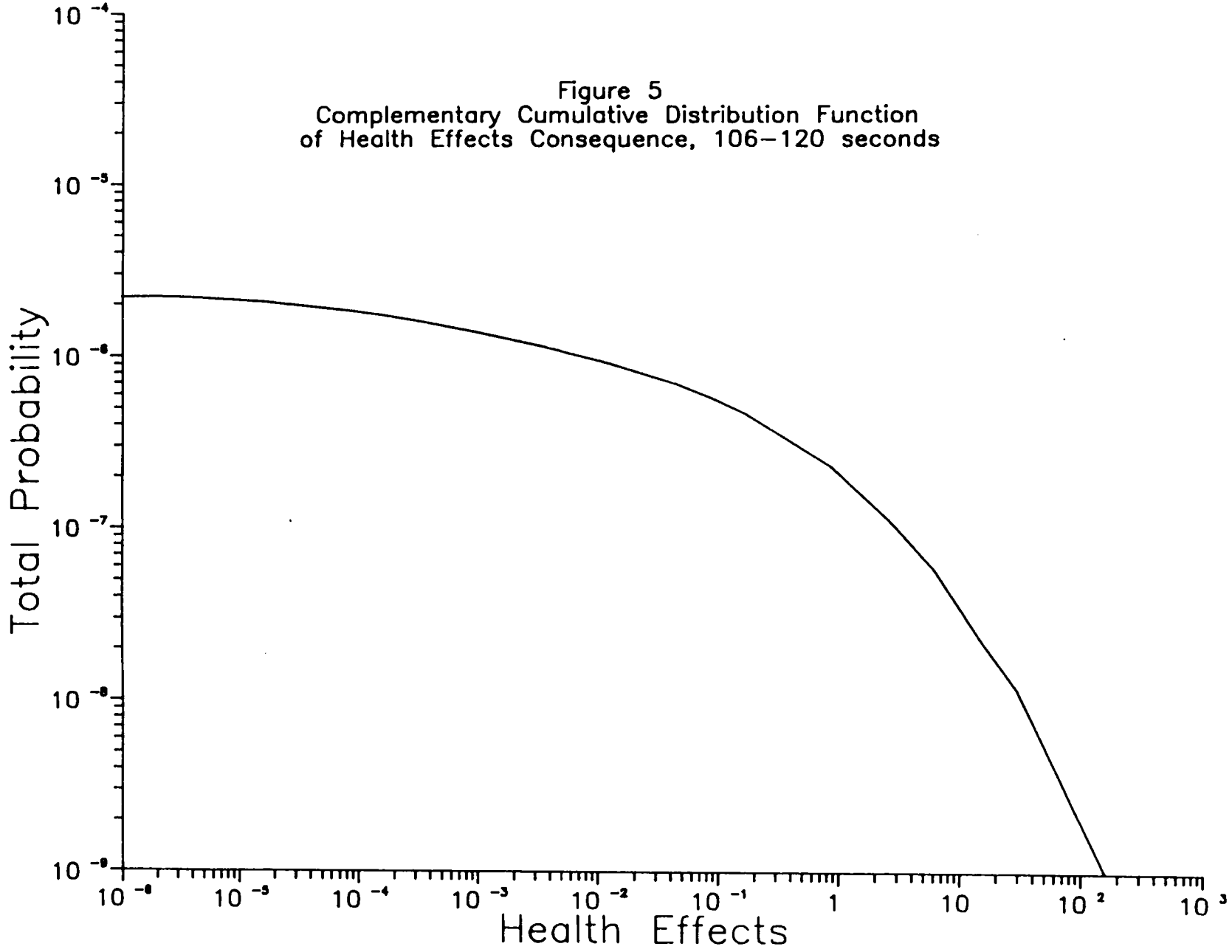
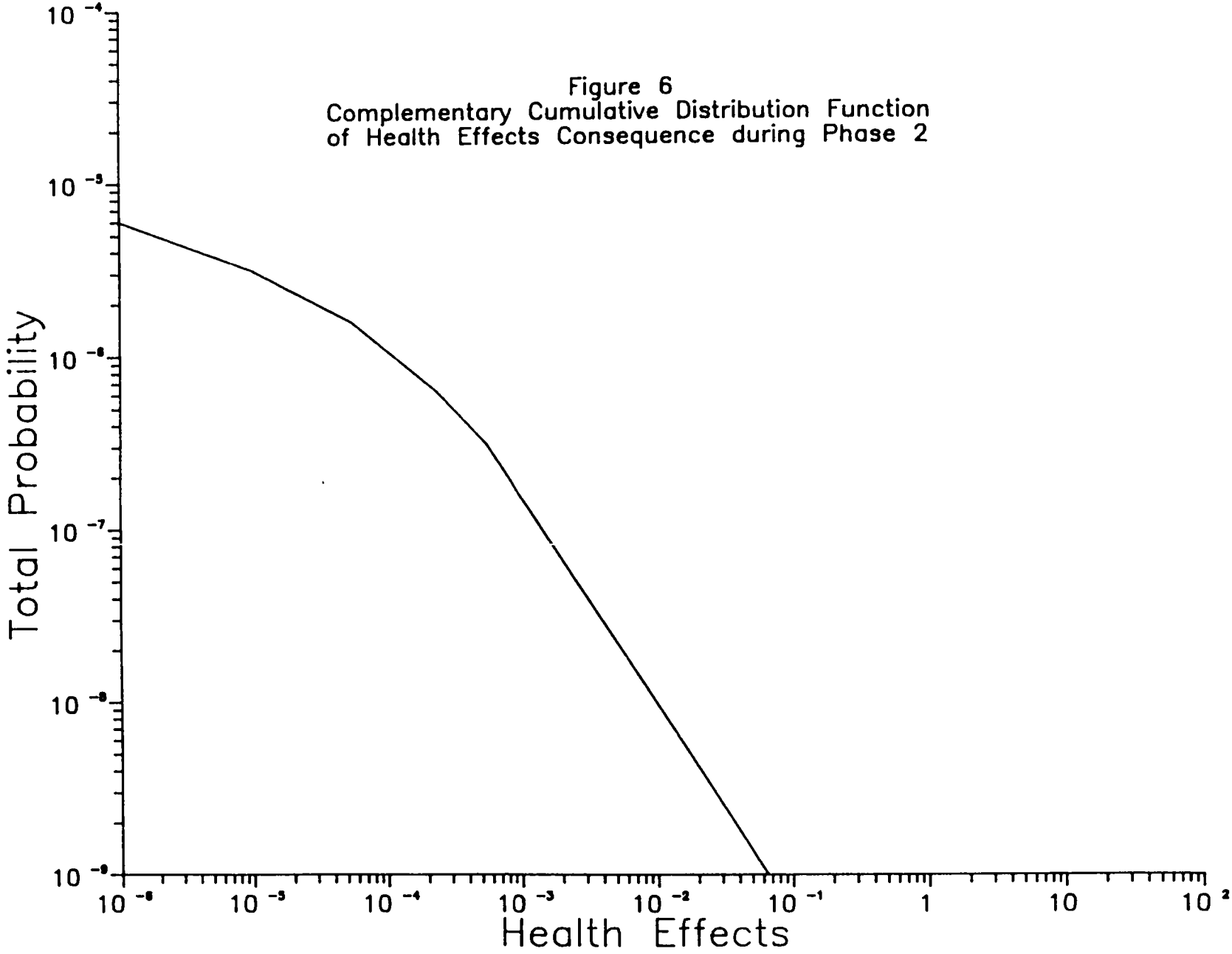



Figure 5
Complementary Cumulative Distribution Function
of Health Effects Consequence, 106–120 seconds

Figure 6
Complementary Cumulative Distribution Function
of Health Effects Consequence during Phase 2



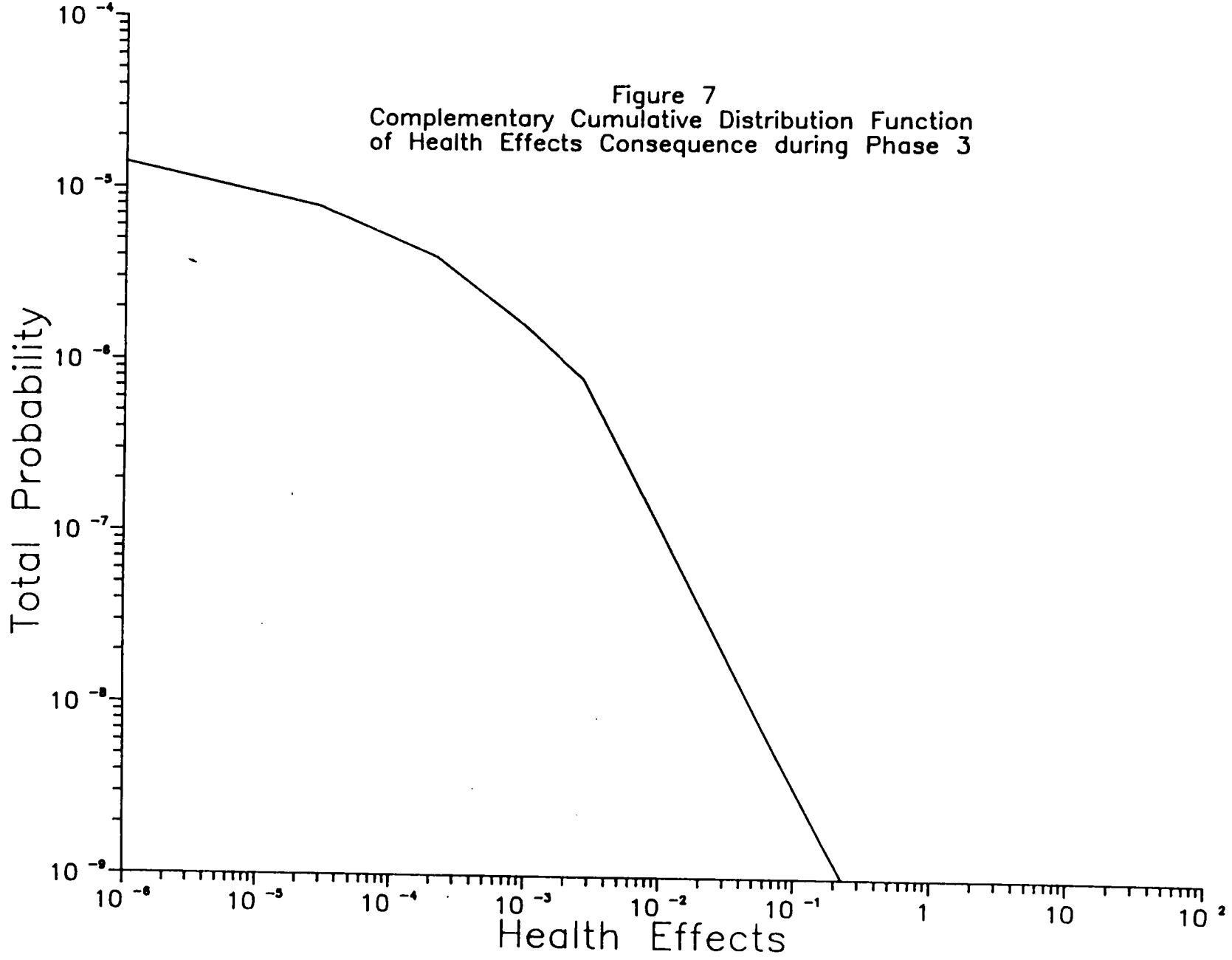



Figure 7
Complementary Cumulative Distribution Function
of Health Effects Consequence during Phase 3

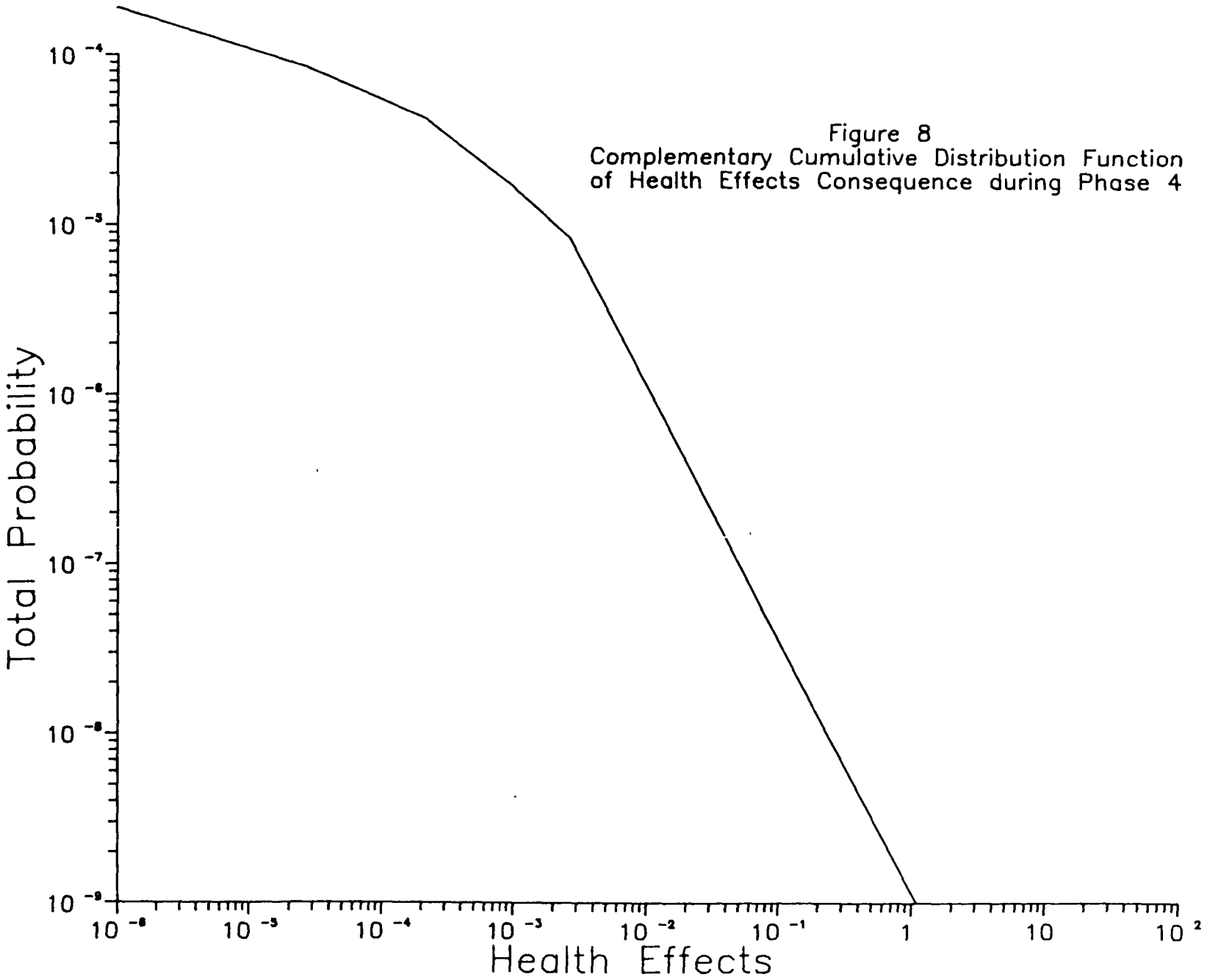



Figure 8
Complementary Cumulative Distribution Function
of Health Effects Consequence during Phase 4

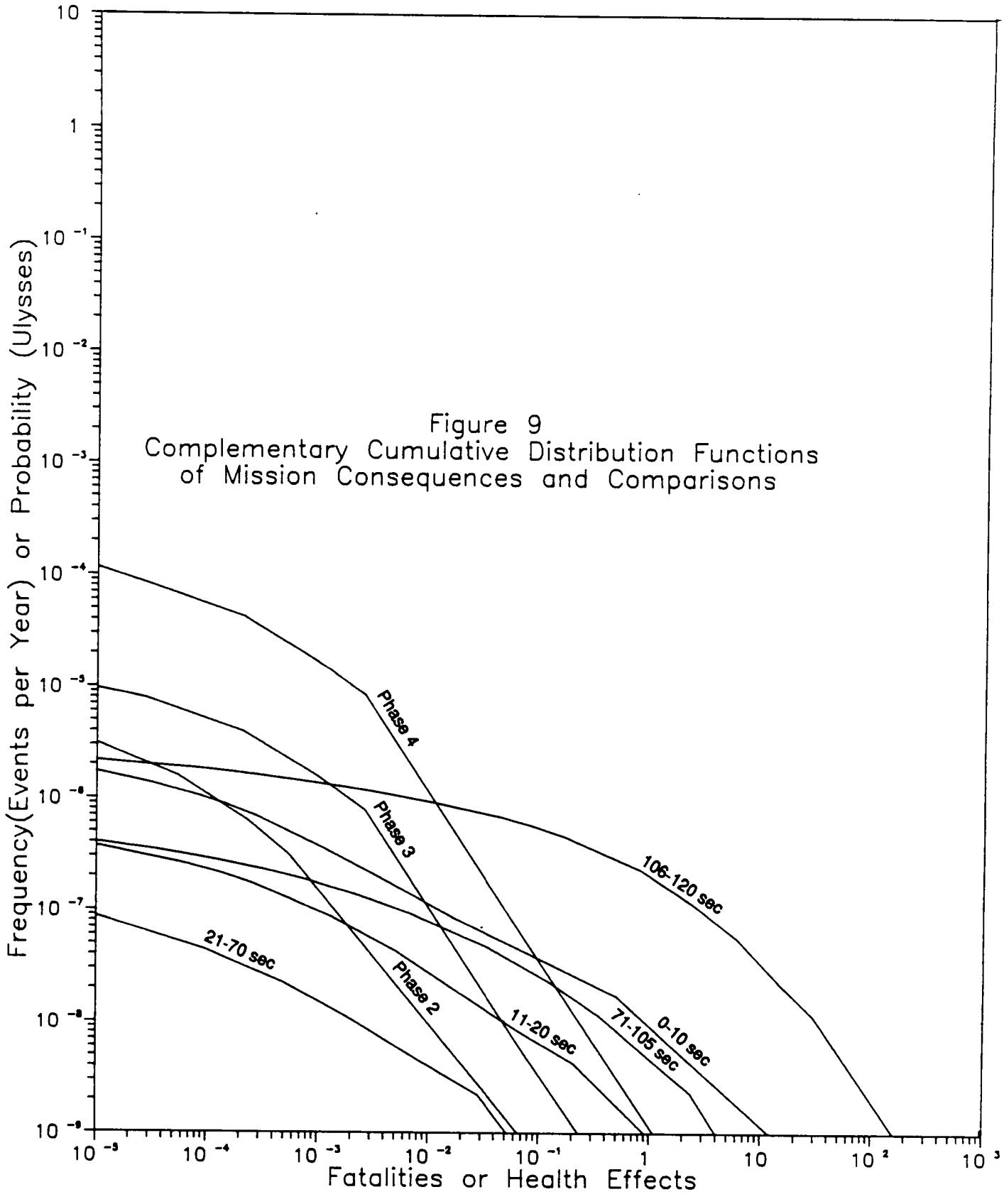



Figure 9
Complementary Cumulative Distribution Functions
of Mission Consequences and Comparisons

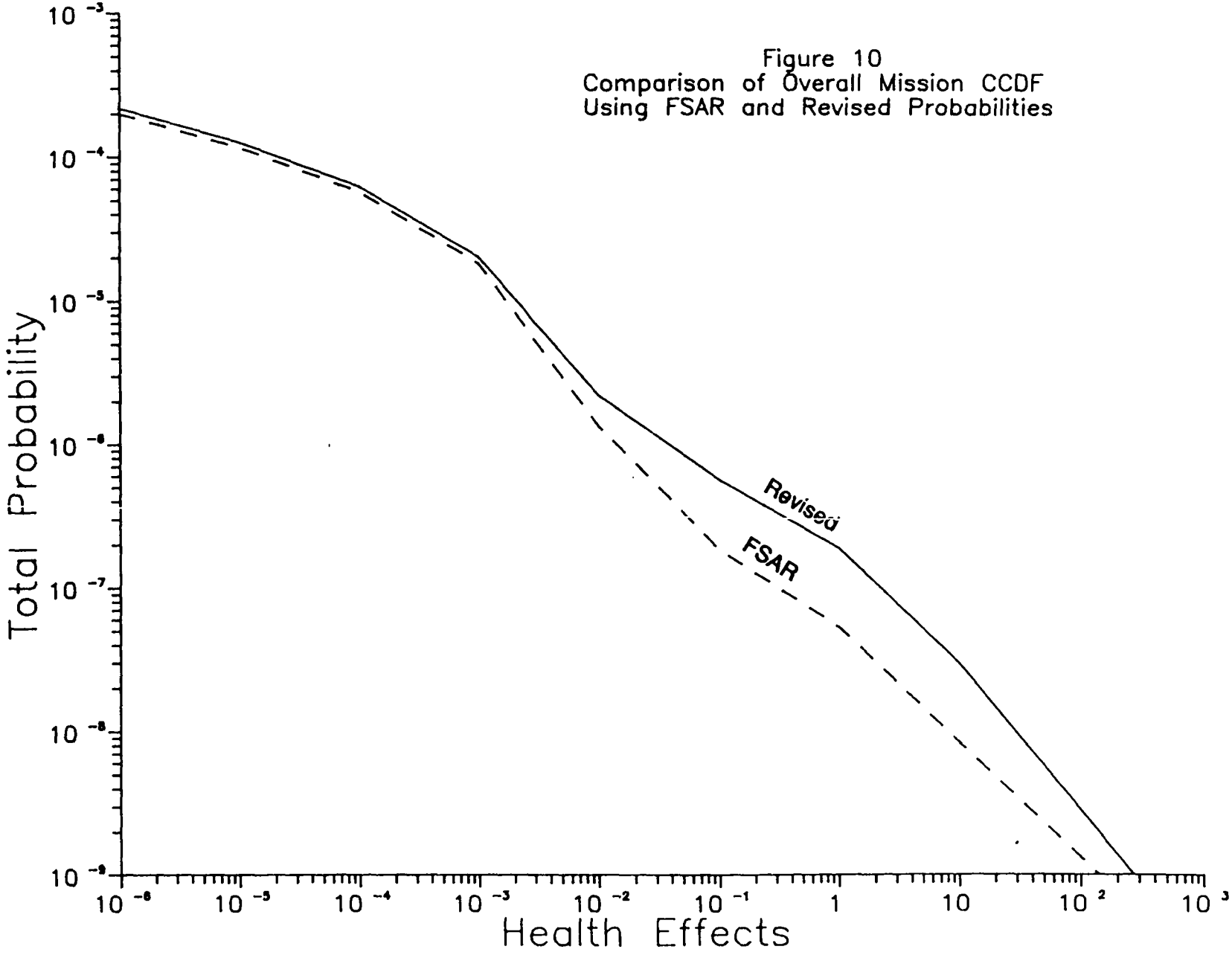



Figure 10
Comparison of Overall Mission CCDF
Using FSAR and Revised Probabilities

Table 3

Comparison of Mission Risks Based on FSAR and Revised Probabilities

| Phase | Time Period, s | Total Probability | | Mean Value of Health Effects | Mean Value of Risk | |
|---|---|---|---|---|---|---|
| | | FSAR | Updated | | FSAR | Updated |
| 1 | 0-10 | $1.17\times10^{-6}$ | $3.36\times10^{-6}$ | $3.69\times10^{-2}$ | $4.32\times10^{-8}$ | $1.24\times10^{-7}$ |
| | 11-20 | $2.97\times10^{-7}$ | $8.47\times10^{-7}$ | $9.35\times10^{-3}$ | $2.78\times10^{-9}$ | $7.92\times10^{-9}$ |
| | 21-70 | $1.59\times10^{-7}$ | $4.37\times10^{-7}$ | $1.14\times10^{-3}$ | $1.81\times10^{-10}$ | $4.98\times10^{-10}$ |
| | 70-104 | $1.74\times10^{-7}$ | $4.58\times10^{-7}$ | $6.38\times10^{-2}$ | $1.11\times10^{-8}$ | $2.98\times10^{-8}$ |
| | 105-120 | $5.65\times10^{-7}$ | $2.27\times10^{-6}$ | $8.61\times10^{-1}$ | $4.86\times10^{-7}$ | $1.95\times10^{-6}$ |
| 2 | - | $1.65\times10^{-5}$ | $6.16\times10^{-5}$ | $1.56\times10^{-5}$ | $2.57\times10^{-10}$ | $9.61\times10^{-10}$ |
| 3 | - | $4.25\times10^{-5}$ | $1.55\times10^{-4}$ | $7.54\times10^{-5}$ | $3.20\times10^{-9}$ | $1.17\times10^{-8}$ |
| 4 | - | $1.66\times10^{-3}$ | $1.66\times10^{-3}$ | $7.54\times10^{-5}$ | $1.25\times10^{-7}$ | $1.25\times10^{-7}$ |
| | | | | Total[a] | $6.71\times10^{-7}$ | $2.25\times10^{-6}$ |

a. Mean value of overall mission risk, representing the expectation value of health effects given the mission