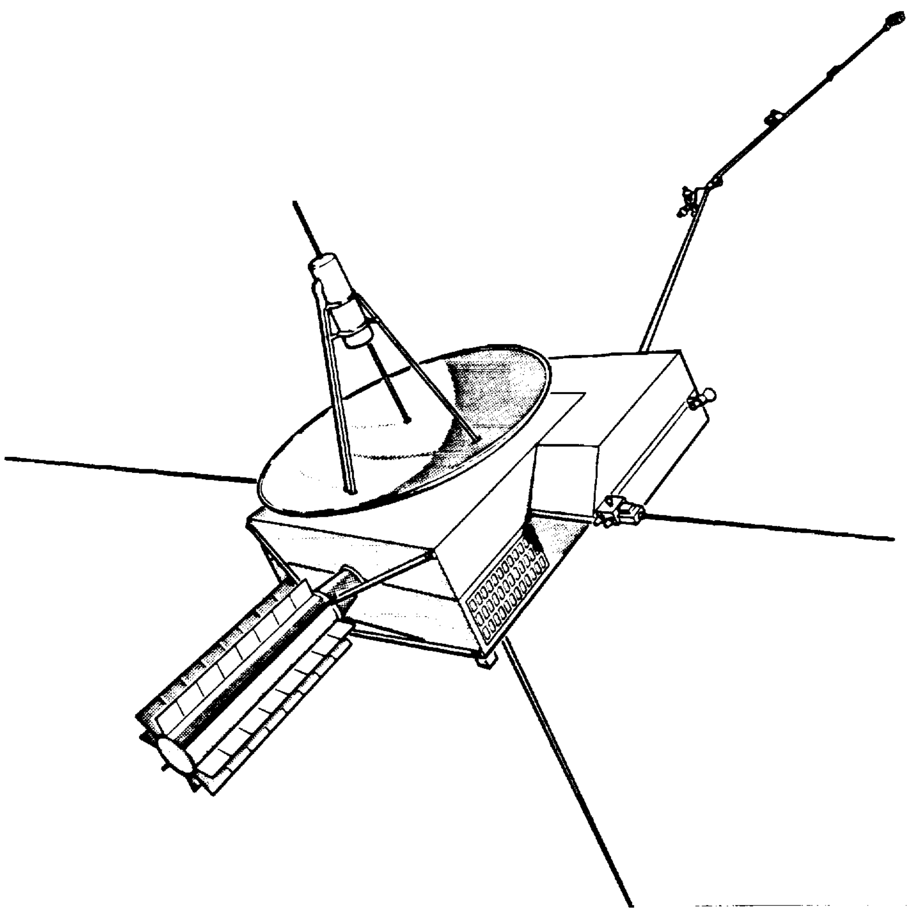
National Aeronautics and
Space Administration

February 1990

Draft Environmental Impact Statement for the Ulysses Mission (Tier 2)



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Draft Environmental Impact Statement for the Ulysses Mission (Tier 2)

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

February 1990

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ABSTRACT

LEAD AGENCY:	National Aeronautics and Space Administration Washington, DC 20546
COOPERATING AGENCY:	U.S. Department of Energy Washington, DC 20585
FOR INFORMATION CONTACT:	Dr. Dudley G. McConnell NASA Headquarters Code EL Washington, DC 20546 (202) 453-1587
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This Draft Environmental Impact Statement (DEIS) addresses the environmental impacts which may be caused by the implementation of a space flight mission to observe the polar regions of the Sun. The proposed action is completing the preparation and operation of the Ulysses spacecraft, including its planned launch on the Space Transportation System (STS) Shuttle in October 1990 or in the backup opportunity in November 1991, and the alternative of 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. However, 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.

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. Consequently, NASA terminated all mission planning for the Titan IV as a backup launch vehicle.

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. 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 are 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.

Environmental impacts are possible from mission accidents that could release some percentage of the plutonium dioxide used in the Ulysses power system. Intensive analysis of the possible accidents associated with the proposed action are currently underway and preliminary results indicate small health or environmental risks. A Final Safety Analysis Report will be available prior to publication of the Final EIS; therefore, the results of that analysis will be available for inclusion in the Final EIS. There are no adverse environmental impacts in the no-action alternative; however, the U.S. Government and the European Space Agency would incur adverse fiscal and programmatic impacts if this alternative were implemented.

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 by the Space Transportation System (STS)/Inertial Upper Stage (IUS)/Payload Assist Module-Special (PAM-S), 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) Draft Environmental Impact Statement (DEIS) is the completion of preparation and operation of the Ulysses mission, including its launch 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 planetary plane and into a polar orbit of the Sun.

The alternative to the proposed action is no-action; that is, cancelling 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. However, in November 1988, the U.S. Air Force, which procures the Titan IV, 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 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. In addition, delay of the mission beyond the earliest opportunities would threaten the viability of key scientific teams, threaten the acquisition of key scientific data, and require an additional expenditure of public funds.

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.

In the event of (1) an accident during launch, or (2) reentry of the spacecraft from Earth orbit, there are potential 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 using a base case as summarized below.

The Base Case predicted average releases developed in the risk assessment (DOE 1990c) based upon extensive safety tests on the RTG and its components, combined with statistically rigorous modeling of accident sequences and environments that can cause sufficient damage to the RTG to result in a release of some percentage of the plutonium dioxide fuel. The average source term for each phase or subphase were then utilized in atmospheric transport and deposition calculations. These calculations for the first stage ascent phase used 40 meteorological data sets from the local KSC area climatology for the period of the launch opportunity (October 5 through October 23). The median consequence of the 40 trials is defined as the base case result for the first stage ascent phase. For each of the subsequent phases, the average source term was utilized along with average population densities and worldwide meteorology representative of median conditions for the affected areas. This defines the base case for each of the remaining mission phases. The radiological consequences are reported in terms of maximum individual dose to an exposed individual, total collective (population) dose to all members of the exposed population, and in terms of land and ocean areas contaminated.

The total collective dose was reported both with and without _de minimis_ (1 mrem/yr). The _de minimis_ dose used was based upon U.S. Department of Energy (DOE) and Nuclear Regulatory Commission (NRC) considerations, and documentation from the National Council on Radiation Protection and Measurement. More complete discussions of _de minimis_ and its use in this DEIS are provided in Section 4 and Appendix C.

For the mission as a whole, the accident with the highest probability of a resultant release is an IUS failure (Phase 4) during deployment which leads to spacecraft break-up, reentry of the RTG modules, and impact of the modules on water, in which case there would be no release of RTG fuel. In the unlikely event the modules impact on hard rock, a release is predicted to occur. The probability of release is 2.40×10^{-4}, or about 1 in 4,200. The collective population dose over a 50-year period would be 0.53 person-rem (0.16 person-rem above _de minimis_). 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.

For the base case analysis, as a whole, collective doses were found to be very low and indicate no statistical fatalities even in the rare event of an accident leading to release. The analysis indicated there were limited areas, on site at KSC, where deposition from near ground-level releases exceeded the U.S. Environmental Protection Agency (EPA) screening levels.

The overall risks associated with the mission are expected to be less than those for the Galileo mission. The Ulysses mission has only one RTG instead of two and has no Earth flyby.

There are no environmental impacts associated with the no-action alternative. There are, however, severe adverse fiscal and programmatic impacts inherent in the no-action alternative. No further action would render the to-date expenditures on the mission a "sunk cost" and entail a larger scientific loss in terms of human resources and efforts and the scientific knowledge that would result from the mission.

This Draft EIS (Tier 2) uses as its primary data source, the safety analysis being conducted by DOE for the Ulysses mission. That safety analysis is in preparation, and therfore, DOE has not published its Final Safety Analysis Report (FSAR) for the Ulysses mission. The analyses of the last three mission phases are complete.

Analyses of the fragment environment in the launch phase are continuing. Based on available information, it is anticipated that the risk of the Ulysses mission will be well below any of the common risk values encountered in everyday life (see Subsection 4.4).

This mission-specific Tier 2 EIS follows a Tier 1 EIS (NASA 1988a) and provides updated and more detailed information regarding the completion of preparation and operation of the Ulysses mission.

In view of the detailed analyses of the STS/IUS configuration (DOE 1988a, DOE 1988b, DOE 1989a, DOE 1989b, DOE 1990a) enough information is available to indicate an envelope of the risks of the Ulysses mission. The Final EIS will incorporate results of the Final Safety Analysis Report when it is available.

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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, provide 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, and an additional complement of scientific investigations.

This Draft (TIER 2) Environmental Impact Statement (DEIS) 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 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 heliogenic 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 and the other planets 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. In order to study the complete range of heliographic latitudes (the third dimension), a spacecraft must leave the ecliptic and traverse the solar poles. Until recently, the same limitation has plagued direct space-based measurements. No launch vehicles have been available with sufficient thrust to send the spacecraft out of the ecliptic. However, Ulysses will overcome these limitations by using Jupiter's immense gravitational field to sling itself 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 mission will end when the spacecraft power level is reduced to a point where the spacecraft instruments no longer function. 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.

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 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 ICE-E and 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.	56	61	69
Pioneer 11	17 deg N.	40	42	50

[a] Ulysses in high solar polar region

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 caps. 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 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/or 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. 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 available launch opportunity is in October 1990. The proposed action is needed to implement the mission at the earliest available launch opportunities.

2. ALTERNATIVES, INCLUDING THE PROPOSED ACTION

2.1 ALTERNATIVES CONSIDERED

This Draft (Tier 2) Environmental Impact Statement (DEIS) 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, are discussed in subsections 2.2.4.2 and 2.3, respectively.

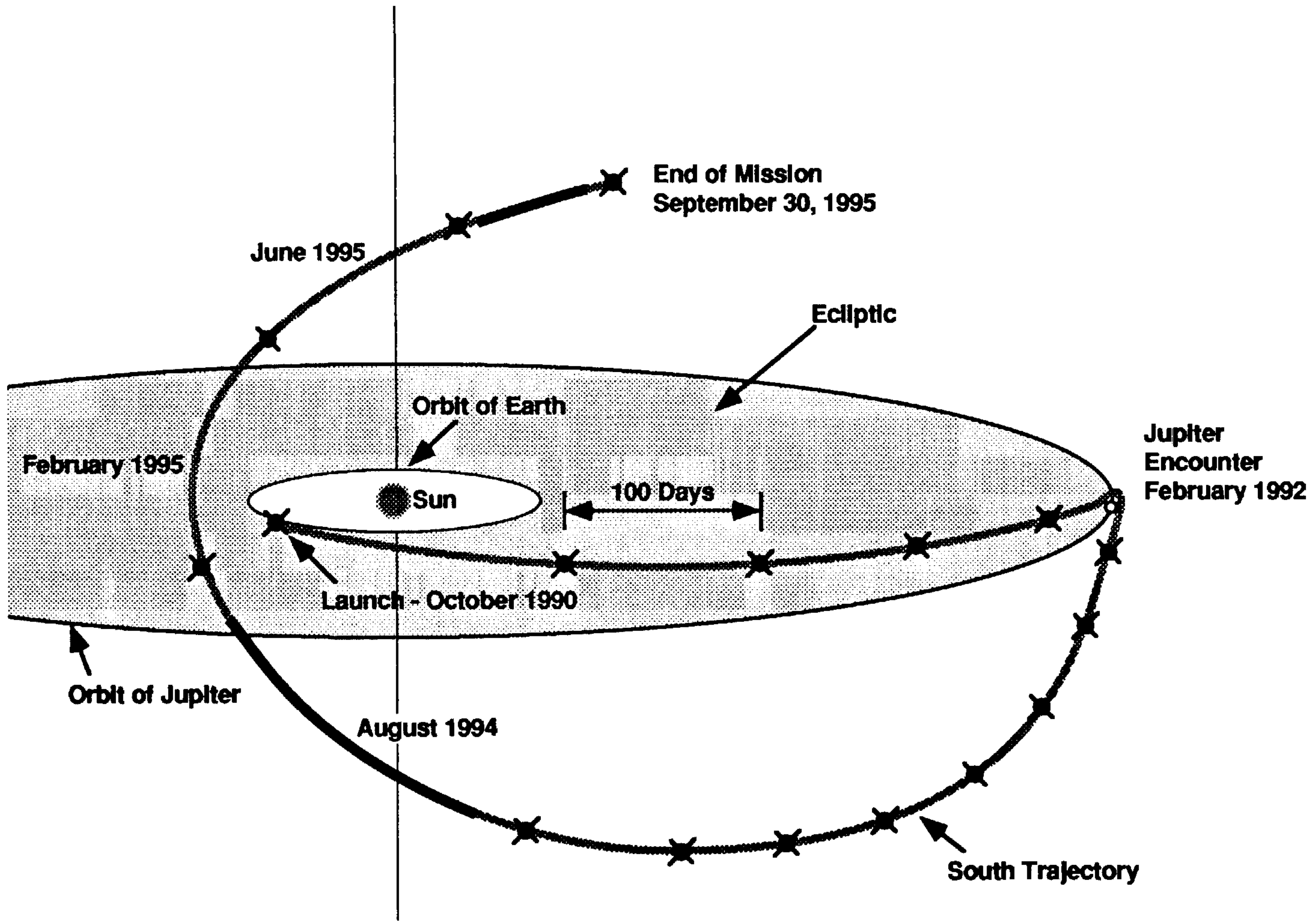
2.2 DESCRIPTION OF THE PROPOSED ACTION TO PROCEED AS PLANNED WITH COMPLETION OF PREPARATIONS AND OPERATION OF THE ULYSSES MISSION, INCLUDING ITS PLANNED LAUNCH ON THE STS IN OCTOBER 1990 OR IN THE BACKUP OPPORTUNITY IN NOVEMBER 1991

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 STS/IUS/PAM-S 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



250 Days Above 70°, Maximum Latitude 85°

FIGURE 2-1. ULYSSES SPACECRAFT TRAJECTORY AND MISSION PROFILE

technical problems with the launch vehicle or the spacecraft, or adverse weather conditions, 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 associated with delaying a mission.

2.2.3 Spacecraft Description

The Ulysses spacecraft weighs approximately 800 pounds and is illustrated in Figure 2-2. The spacecraft is spin-stabilized with an antenna on top, one 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 Source

Alternate power sources include fuel cells, batteries, photovoltaic systems, RTGs, alkali metal thermoelectric converters, and turbine energy conversion. These potential power sources 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

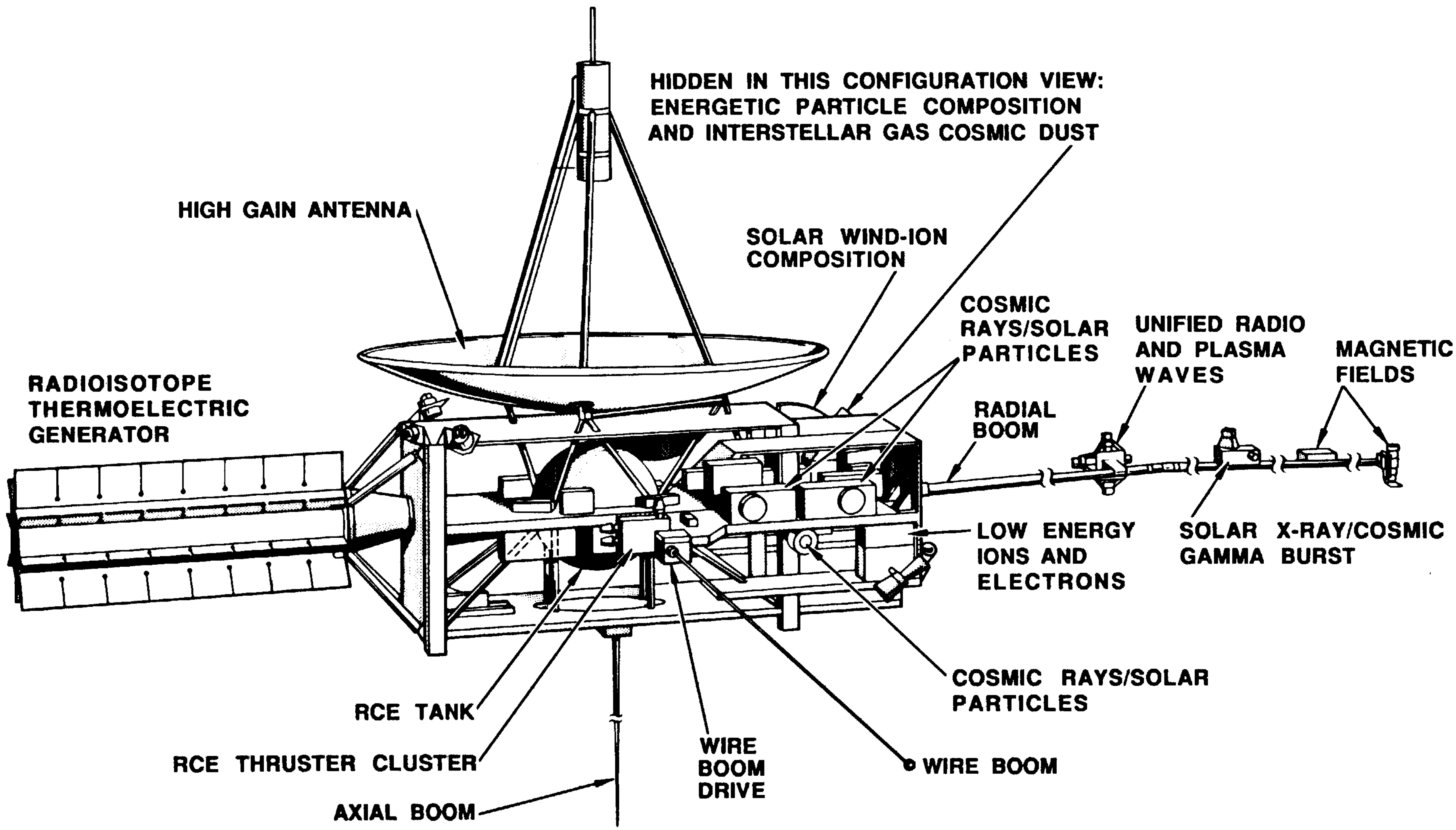


FIGURE 2-2. DIAGRAM OF SPACECRAFT HARDWARE AND SCIENCE INSTRUMENTS

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 Sources

Spacecraft power sources include fuel cells, batteries, photovoltaic power sources, 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 high weight (over 15,000 kg in each ease) 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 with a solar intensity only 10 percent that of Earth, the large solar array for a Ulysses mission would require a complete spacecraft system redesign, including selection of 3-axis control as opposed to the current spin-stabilized approach. A conceptual design study using state-of-the-art array technology indicates that this system would require an increase in the total spacecraft mass of 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, nor has its development been approved or authorized; consequently, this is not a feasible alternative.

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 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

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	Power	73,000	Integration	Non-rechargeable. Too heavy for any available vehicle.
2. Batteries	Now	Power	18,250	Integration	Too heavy for any available launch vehicle.
3. Photovoltaic (Solar)					
a. Rigid Array	Now	Array	250	Configuration, attitude control, and dynamics	Difficult with attitude, difficult to stow and deploy. No array of this size has been flown on a spacecraft. Flown on Magellan, Mars Observer and TOPEX; requires at least Titan/Centaur/kick stage.
b. SAFE	Now	Array	90	Configuration, attitude control, and dynamics	Flown on Shuttle experiment; requires at least Titan/Centaur. Difficult to unfurl.
c. APSA	1995/ 2000	Array	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	Power	15	Configuration attitude control, and dynamics	Conceptual designs. Bulky, plastic.
4. Advanced Solar Dynamics (ASD)	2000	Power	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

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	Power	47	None	Power level decays; proven technology, mission tested, very lightweight.
b. Advanced (MOD-RTG)	1996/ 2000	Power	32	Minimum Modifications	Power level decays; modular design; reduced amount of Plutonium dioxide.
c. Advanced Material RTG	1998/ 2003	Power	16	Minimum Modifications	Will compete with APSA.
2. AMTEC	2000/ 2005	Power	13	Modifications necessary to operate in zero gravity environment	Laboratory scale. Flight experiment in late 1990s.
3. TEC	1997/ 2002	Power	13	Attitude control	Scaling would be an issues. Laboratory scale based on Closed Brayton and Rankine Cycles; component life tests in 1998.

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

flight testing until the mid to late 1990s. The radioisotope-driven TECs are 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.

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.

2.2.4.3 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 23 previous U.S. space missions. These applications have included some of NASA'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). 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 10.754 kg (23.7 lbs) of plutonium dioxide used to manufacture an RTG.

Until the RTG is transported to the KSC, it will be stored at a DOE facility. A few days before launch, the RTG will be installed on the spacecraft.

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

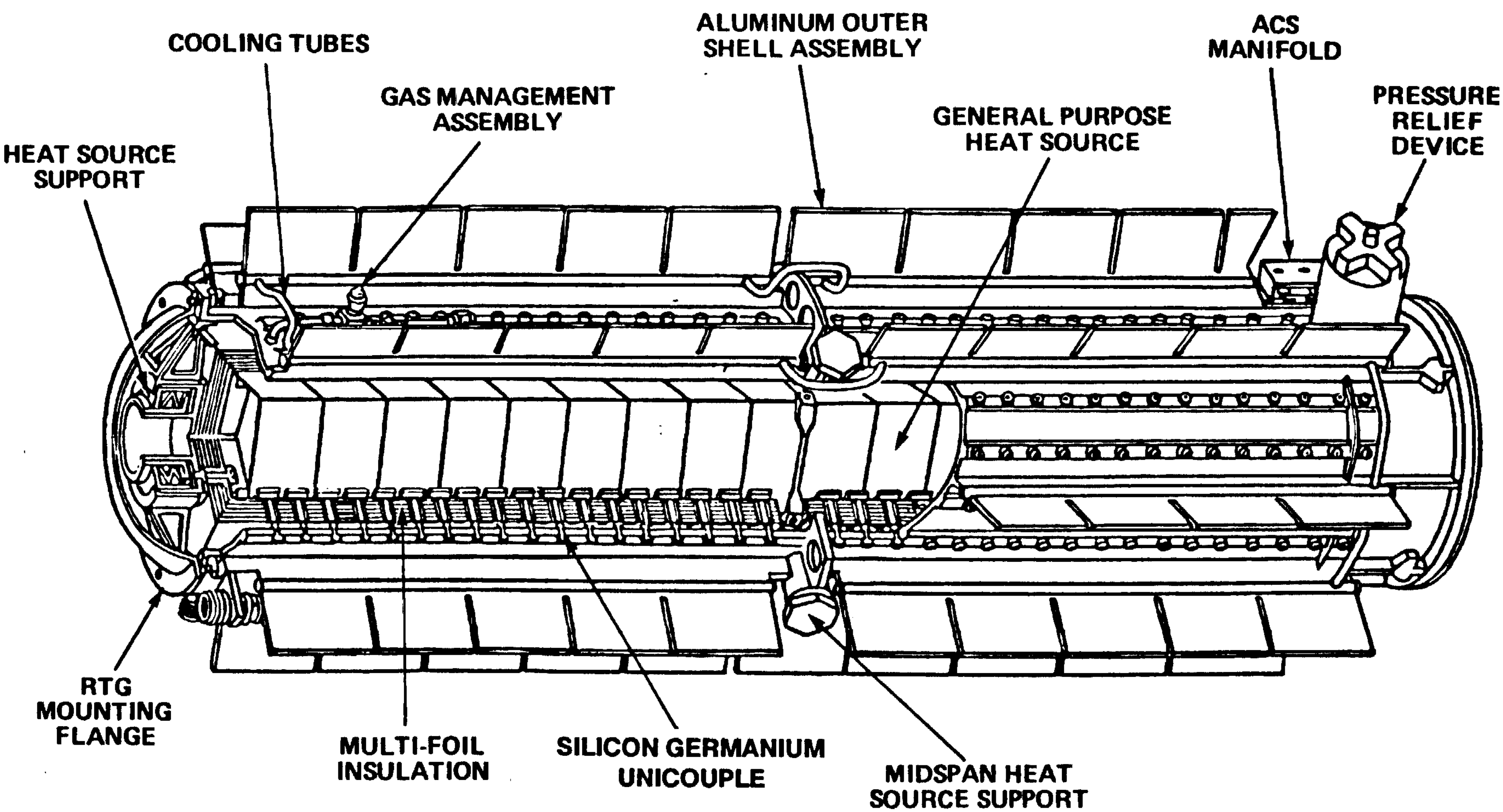


FIGURE 2-3. DIAGRAM OF RTG ASSEMBLY

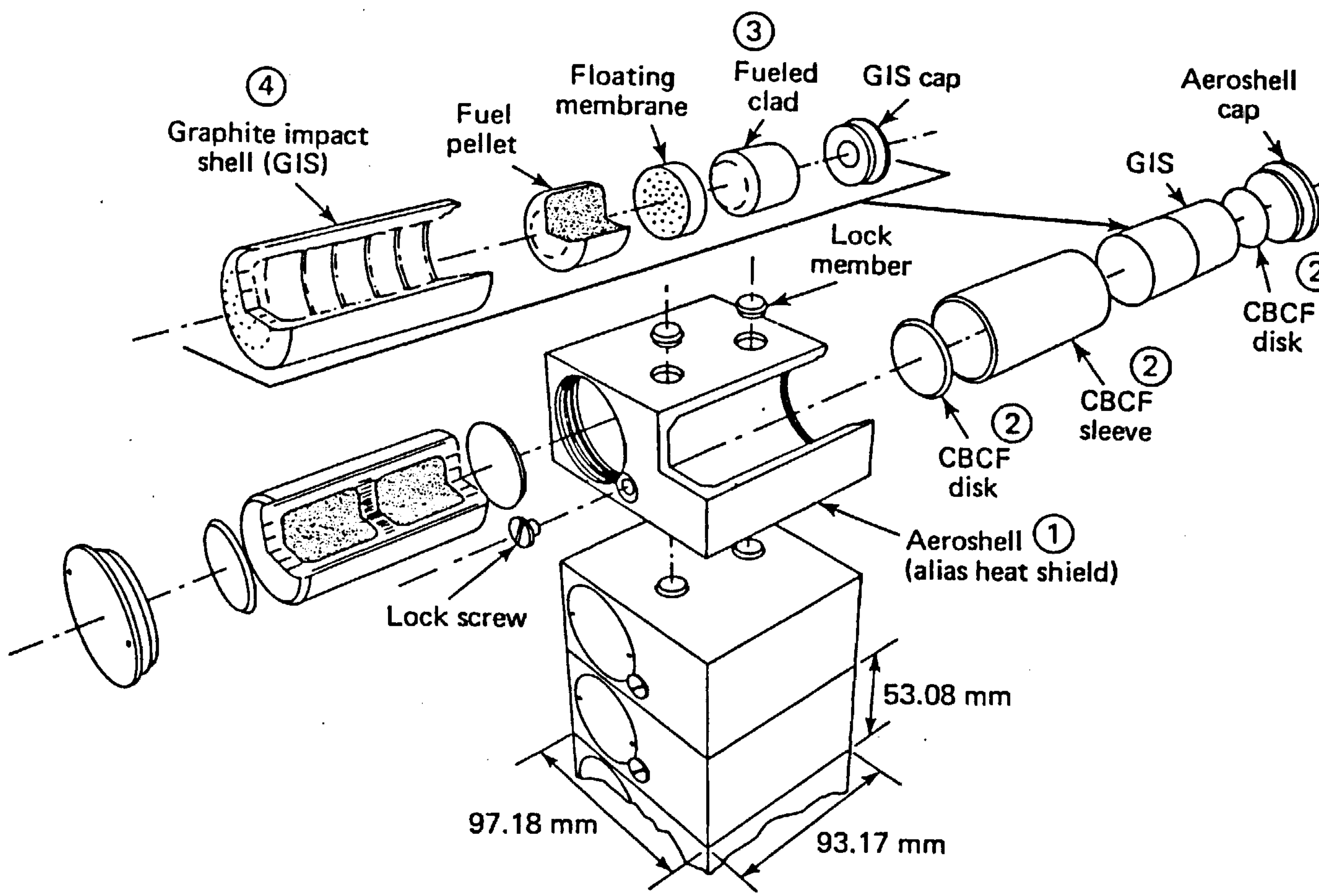


FIGURE 2-4. DIAGRAM OF GENERAL PURPOSE HEAT SOURCE

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	5.27×10^{-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 (F-3) 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).

power generation system. The following is a brief summary (Turi 1989) of relevant safety environments and the GPHS response:

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

- Solid Propellant Fires: Bare fueled clads and clads contained in the Graphite Impact Sheild (GIS) were shown to survive solid propellant fires (i.e., temperature calculated at 3,700°C or 6,690°F), 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.

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 23 previous U.S. space launches.

Three U.S. spacecraft powered by RTGs have failed to achieve their intended mission and 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 entirely 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.

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. 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. There is no evidence of any release of the radioactive material.

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).

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).

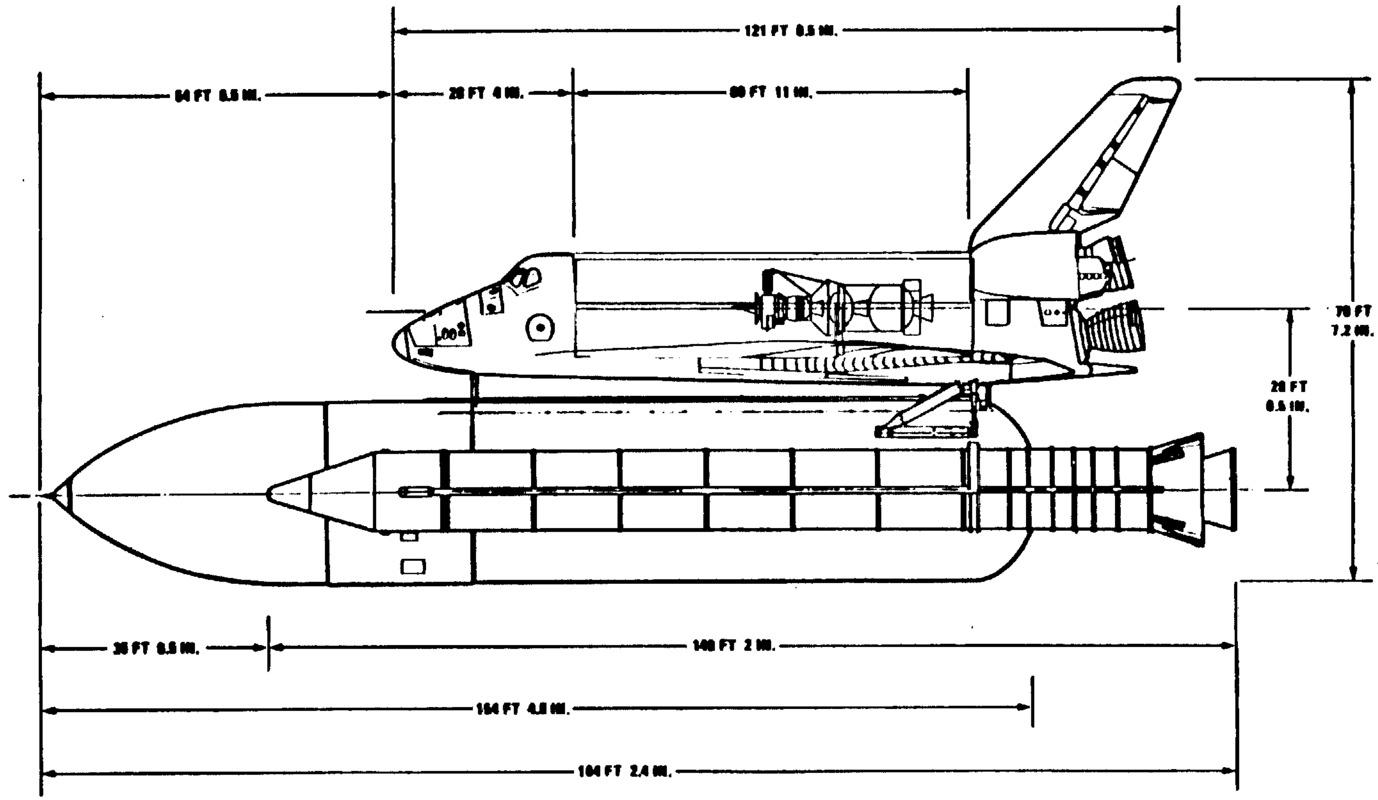


FIGURE 2-5. DIAGRAM SHOWING CONFIGURATION OF ULYSSES SPACECRAFT IN SHUTTLE BAY FOR LAUNCH

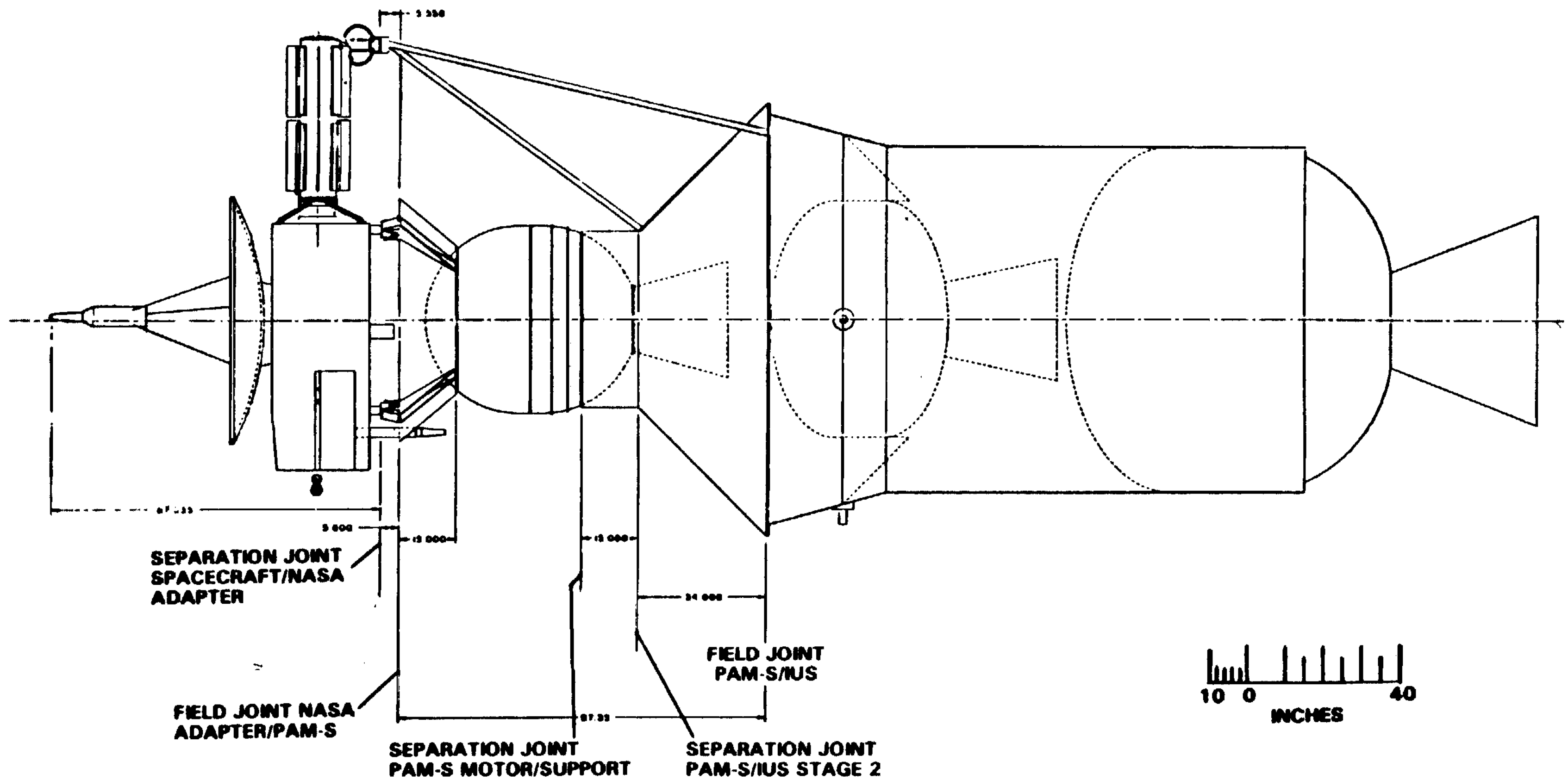


FIGURE 2-6. CONFIGURATION OF ULYSSES SPACECRAFT ASSEMBLED WITH THE IUS/PAM-S

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

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.

2.2.8 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 Alternate - Moron, Spain Banjeel, Gambia Zaragoso, Spain Dakar, Senegal
Abort-Once-Around	Edwards Air Force Base, CA Alternates - White Sands Space Harbour, NM Kennedy Space Center

Abort-From-Orbit	Edwards Air Force Base, CA Alternates - White Sands Space Harbour, NM 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 THE DELAY ALTERNATIVE

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. However, the U.S. Air Force has informed NASA that a Titan IV launch vehicle will not be available 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 and Voyager 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 the further commitment of resources to the mission. 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 COMPARISON OF ALTERNATIVES

The criteria pertinent to a comparison of the proposed action with the no-action alternative are summarized in Table 2-3 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. 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 1988b) and are associated with the routine launch operations of the STS

TABLE 2-3. SUMMARY COMPARISON OF ALTERNATIVES

PROGRAMMATIC CONSIDERATIONS	PROPOSED ACTION STS/IUS/PAM-S IN 1990 (AND 1991 BACKUP)	NO ACTION
LAUNCH OPPORTUNITY		
Vehicle Availability	Firm Commitment	N/A N/A
Launch Period		
- First Possible Launch Date	October 5, 1990	N/A
- Length	19 Days	N/A
Daily Launch Window	60-180 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
• Sonic Boom	No sustained adverse impacts.	No Effect

TABLE 2-3. SUMMARY COMPARISON OF ALTERNATIVES (Continued)

PROGRAMMATIC CONSIDERATIONS	PROPOSED ACTION STS/IUS/PAM-S IN 1990 (AND 1991 BACKUP)	NO ACTION
• 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 expected 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		
- Expectation[a]	388 Ci at 1.77×10^{-7} Probability	None

[a] Expectation of results over Phase 1, determined by probability weighing the base case results for every sub-period in Phase 1.

* Based on preliminary information contained in the Safety Status Report for the Ulysses mission (DOE 1990c).

TABLE 2-3 SUMMARY COMPARISON OF ALTERNATIVES (Continued)

PROGRAMMATIC CONSIDERATIONS	PROPOSED ACTION STS/IUS/PAM-S IN 1990 (AND 1991 BACKUP)	NO ACTION
Lifetime Incremental Collective (Population) Dose in the Event of a Mission Accident-Total Launch Vicinity Accident Causing Release - Base Case		None
• Total Dose (without de minimis	2.42×10^2 person rems	
• Above de minimis	0	
Incremental Cancer Fatalities among Exposed Population in the Event of a Mission Accident Launch Vicinity Accident Causing Release - Base Case		None
• Without de minimis	0.0847 fatalities	
• With de minimis	0	
Inland Area Potentially Affected by Deposition in Event of an Accident Launch Vicinity Accident Causing Release - Base Case (Expectation)	12.3 km^2	None
Inland Area Potentially Requiring Cleanup and Mitigation at Second Year Following Accident (i.e., Annual Dose Rate Exceeding 25 mrem/yr) Launch Vicinity Accident Causing Release - Base Case (Expectation)	0 km^2	None

and Titan IV launch vehicles. The impacts were determined to be localized to designated areas and, therefore, insufficient to preclude Shuttle operations. The following subsections 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.

2.5.1.2 Possible Environmental Impacts of Mission Accidents

Proposed Action

For the proposed action, there is a slight chance of adverse impacts. Analysis indicates that the chance is small of any accident occurring that could release some percentage of the plutonium dioxide fuel (NASA 1988a, NASA 1989a, and Section 4 of this EIS).

The DOE conducts a detailed program of safety verification, testing, and analysis to determine the chances and consequences of releasing plutonium dioxide from the Ulysses 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. A Final Safety Analysis Report will be available prior to the publication of the Final EIS, and therefore the results of that analysis will be available for inclusion in the Final EIS.

For the mission as a whole, the accident with the highest probability of a resultant release is an IUS failure (Phase 4) during deployment which leads to spacecraft break-up, reentry of the RTG modules, and impact of the modules on water, in which case there would be no release of RTG fuel. In the unlikely event the modules impact on hard rock, a release is predicted to occur. The probability of release due to this accident scenario is 2.4 X 10^{-4}, or about 1 in 4,200. The collective population dose over a 50-year period would be 0.53 person-rem (0.16 person-rem above de minimis). 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.

An additional potential concern relates to the non-ionizing effects of electromagnetic fields from radio frequency transmitter/antenna systems upon the liquid and solid fuels (Hazards of Electromagnetic Radiation to Fuels [HERF]). The proper bonding and grounding of fuel systems and their appurtenances (per Military Standard B-5087B) to Space Shuttle structure precludes the potential ignition threats due to arcs created by radiation and triboelectric charging.

Hazards of Electromagnetic Radiation to Ordnance (HERO) have been well studied and tested by NASA, other government agencies, and commercial testing laboratories and have resulted in design and safety margins for ordnance installation, wiring, and pyro-initiator controllers.

Electromagnetic Compatibility (EMC) of telecommunications equipment, electrical equipment and control of Electromagnetic Interference (EMI) is a rigorous on-going activity. This includes the design and installation and usage scenarios of subsystems and line replaceable units in Space Shuttle Systems. The control circuits of the Space Shuttle, payload, and Airborne Support Equipment systems that constitute potential hazards are carefully reviewed for acceptable inhibit control types and redundancy as required by safety standards.

The EMI Safety Margins (EMISM) requirements delineated in Military Standard E-6051D for conducted and radiated emissions versus susceptibility of electric, electronic and ordnance equipment are strictly enforced.

Potential electrostatic charging mechanisms and Electrostatic Discharge (ESD) are carefully accounted for in the design of the Space Shuttle, payloads, experiments, and other Government furnished equipment manifested for flight. Radio frequency bonding, fault bonding, static bonding, hazard bonding, antenna bonding and launch site bonding criteria, lightning protection criteria, and launch commit criteria concerning weather and other considerations are strictly enforced.

Designs and procedures are under continuous review and enhancement. In addition, systems with explosion potential are not armed until the appropriate time, such as launch and other key mission milestones. The Space Shuttle and payloads are designed and/or shielded by enclosures to withstand the launch electromagnetic environment. All Eastern Test Range (ETR) transmitter/antenna systems are controlled by the ETR Range Officer and the Department of Defense.

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.

2.5.3 Launch Preparation and Operation Costs (Mission Only)

The proposed Ulysses mission, with an estimated cost to completion 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, 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 result in releasing a Shuttle launch commitment (and an IUS/PAM-S upper stage booster) in October 1990 for either a NASA or Department of Defense mission. The existing engineering work force would be available to work on other NASA projects. 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.

2.5.6 Summary

The launch of the Ulysses mission in 1990 or 1991 will allow 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.

Later launch windows are December 1992, January 1994, February 1995, March 1996, April 1997, May 1998, and June 1999. 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, and the time that the requisite modifications can be completed to the spacecraft and launch vehicle. In addition, 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.

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. The most promising appears to be the advanced photovoltaic solar array which could be combined with batteries to provide power. Flight testing of this source is currently scheduled for 1993; consequently, the earliest estimate for a possible application would be for a March 1996 mission. Therefore, alternative power sources to replace the use of an RTG are not available before the late 1990s.

In summary, no alternative to the proposed launch vehicle is available before 1995, and no alternative to the RTGs as a power source is available before the late 1990s.

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), and the abrogation of a NASA/ESA international agreement.

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

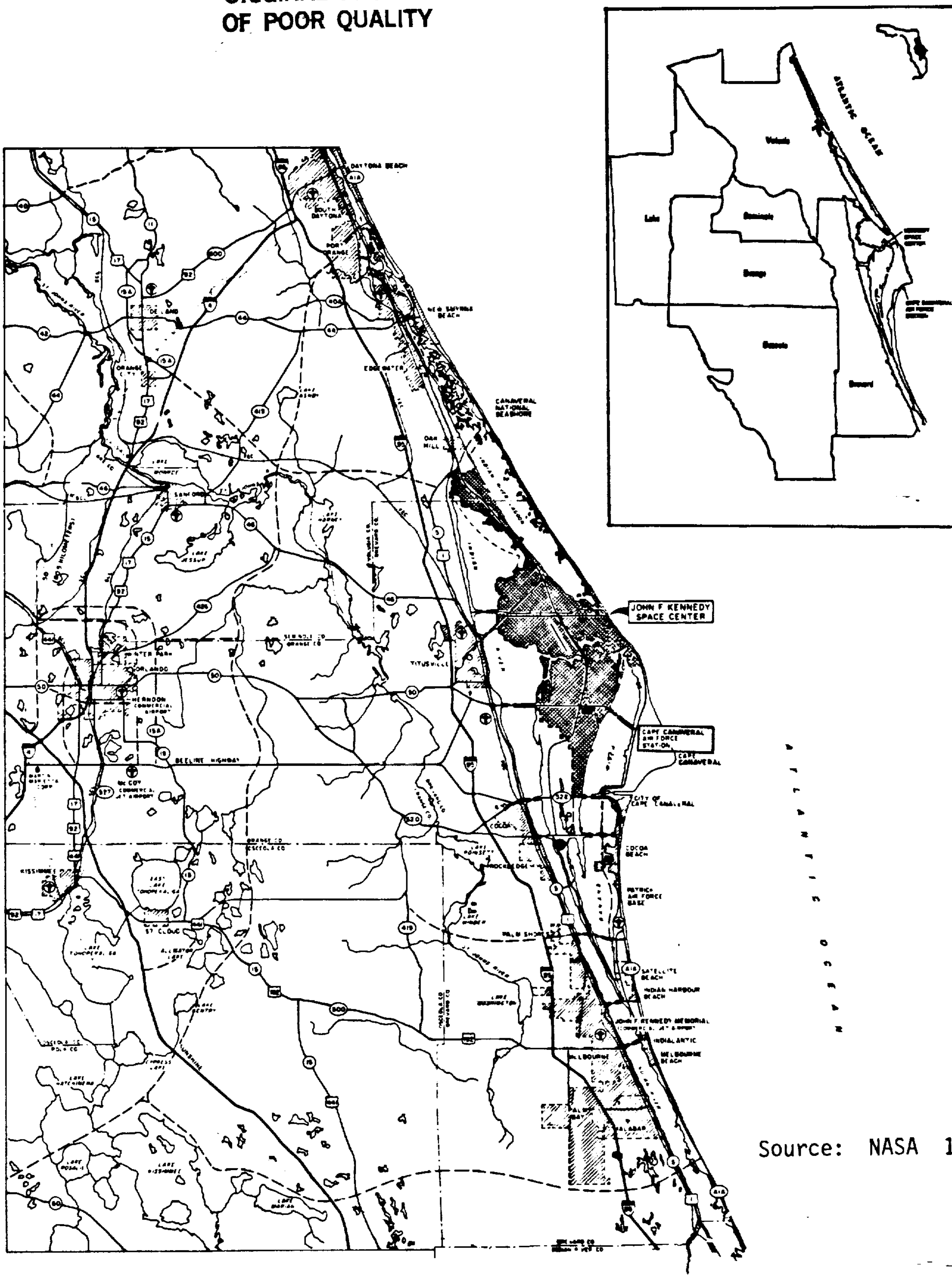
For the purpose of this document, the region is defined as the six county area (Brevard, Volusia, Seminole, Lake, Orange, Osceola counties) which encompasses KSC and CCAFS, as shown in Figure 3-1.

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 has 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.

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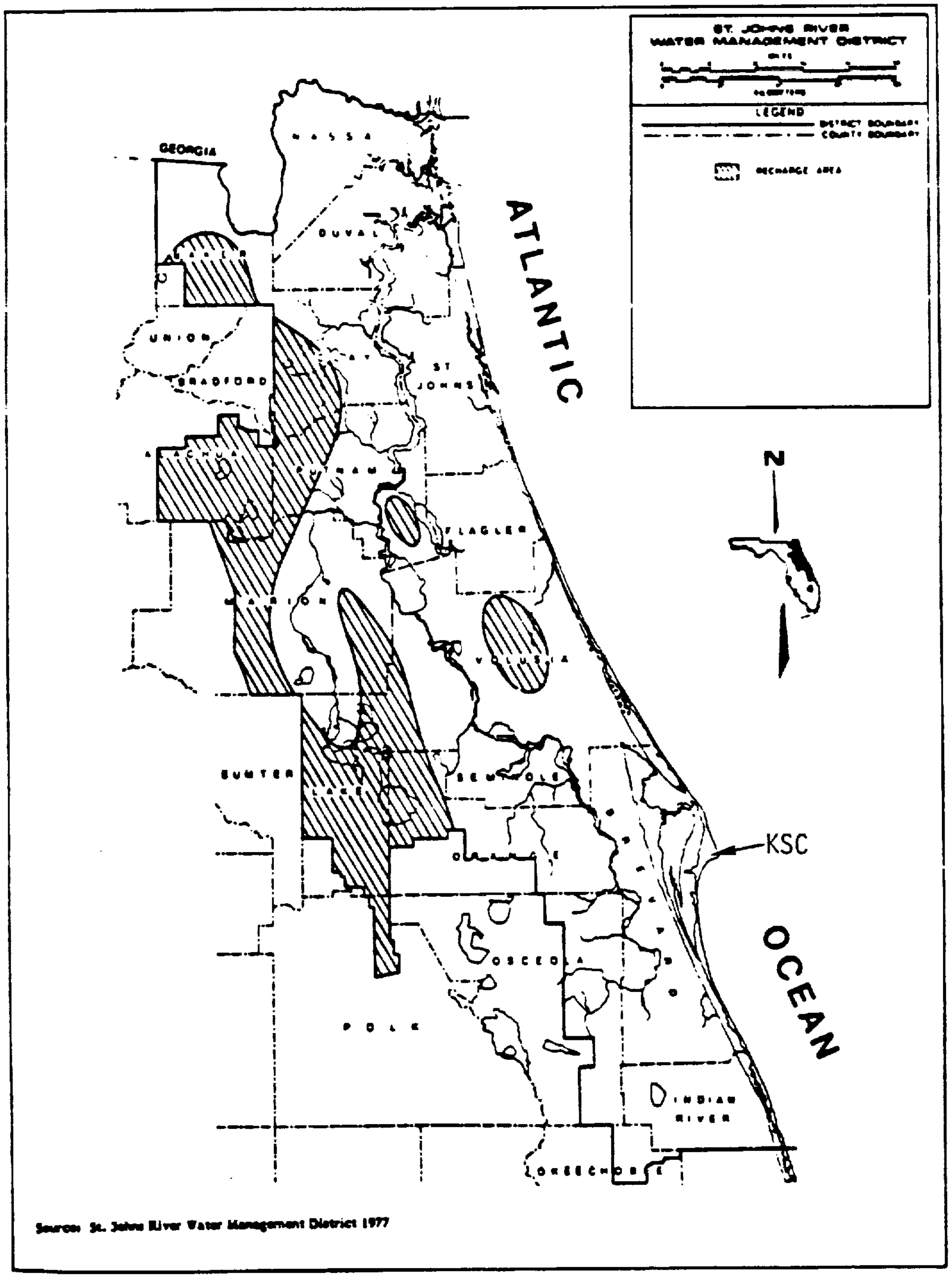


Source: FSU 1984

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).

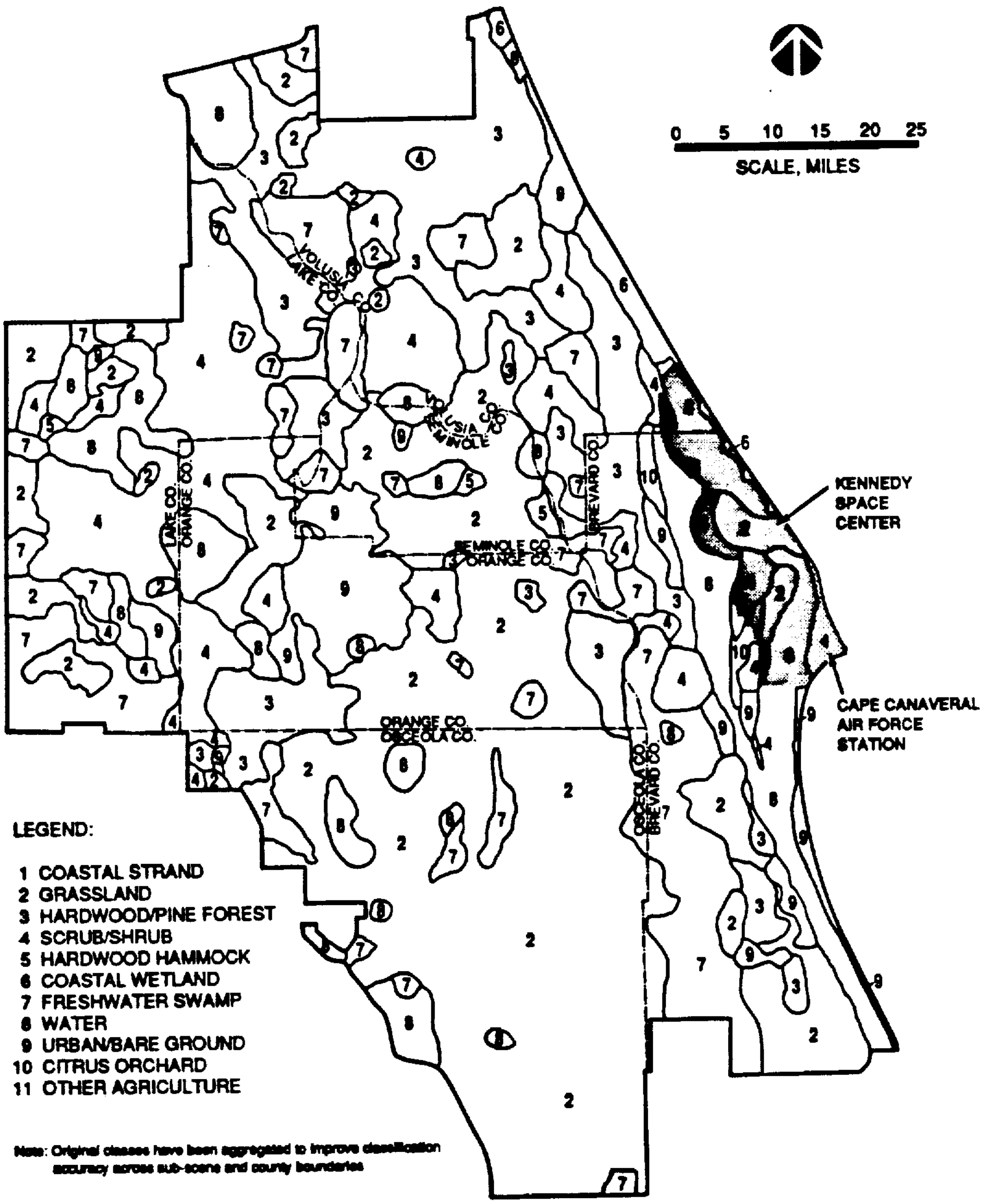
Figure 3-3 provides an overview of land cover types found throughout the six county region, with a county-by-county breakdown provided in Table 3-1. Freshwater and coastal wetlands comprise about 23 percent of the total area of the six county region, followed by xeric grassland (21 percent), scrub and 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.



SOURCE: ECFRPC 1988

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 23,608,458 pounds of finfish, invertebrates (clams, crabs, lobsters, octopus, oysters, scallops, squid, etc.), and shrimp in 1987. Brevard and Volusia ranked fifth and sixth, respectively, among the 12 east coast counties of Florida in total 1987 finfish landings. Brevard led east coast counties in invertebrate landings with about 16 million pounds. Volusia County ranked fifth with about 0.4 million pounds. Brevard also ranked first on the east coast with 1.6 million pounds of shrimp; Volusia was fifth with about 0.3 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.

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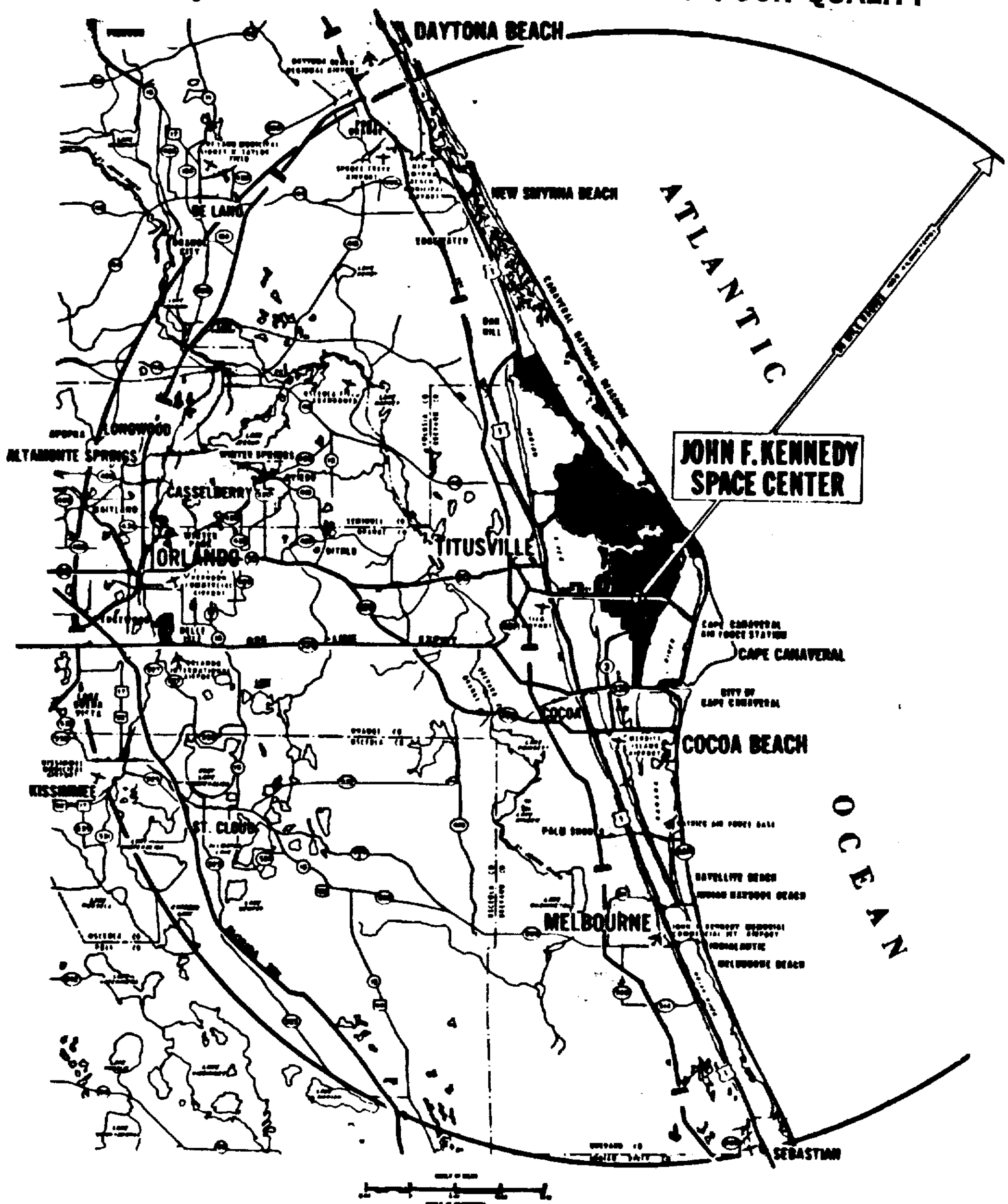

SOURCE: NASA 1986

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

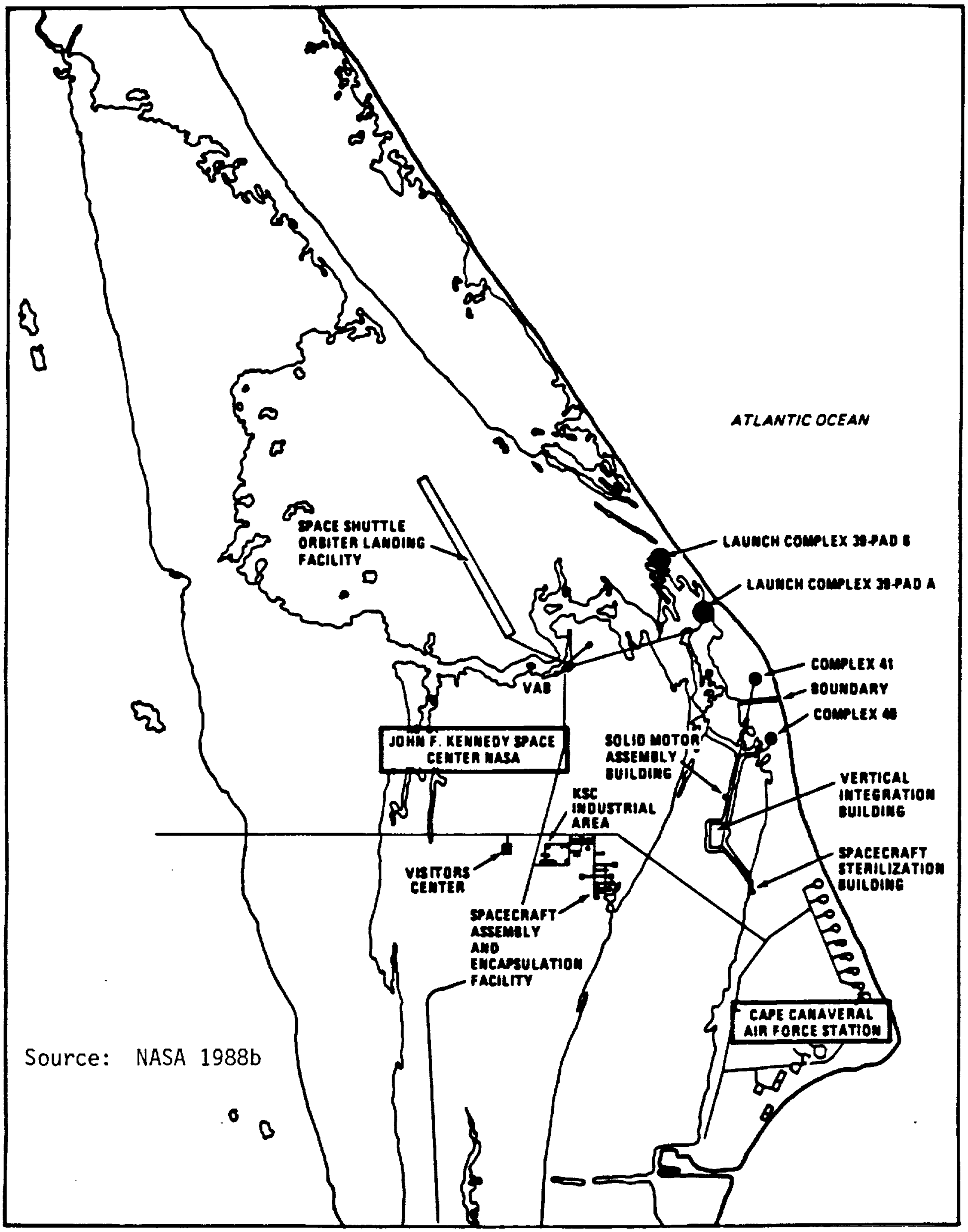

FIGURE 3-5. GENERAL LAND USE AT KENNEDY SPACE CENTER

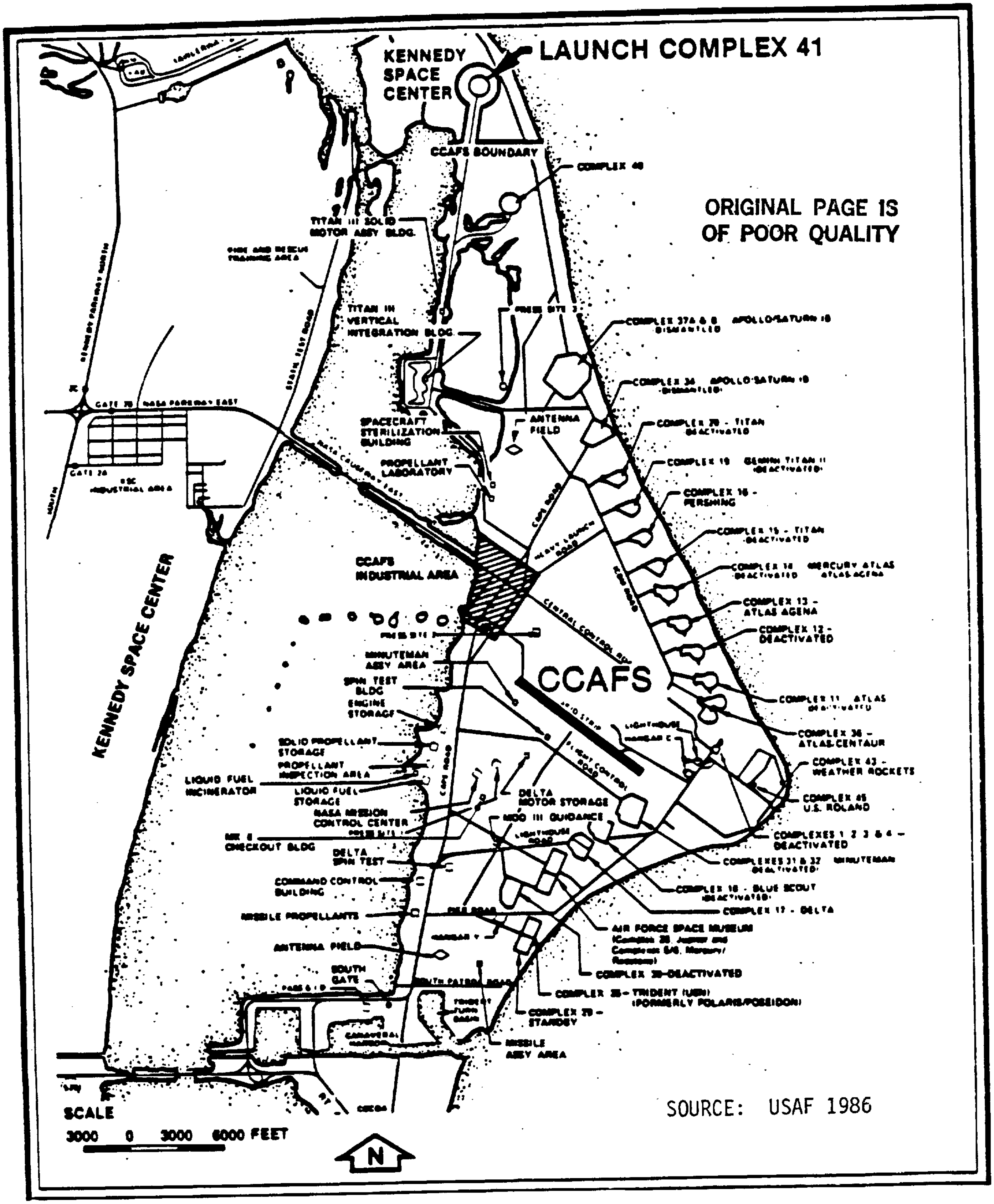

FIGURE 3-6. EXISTING LAND USE AT CCAFS

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.

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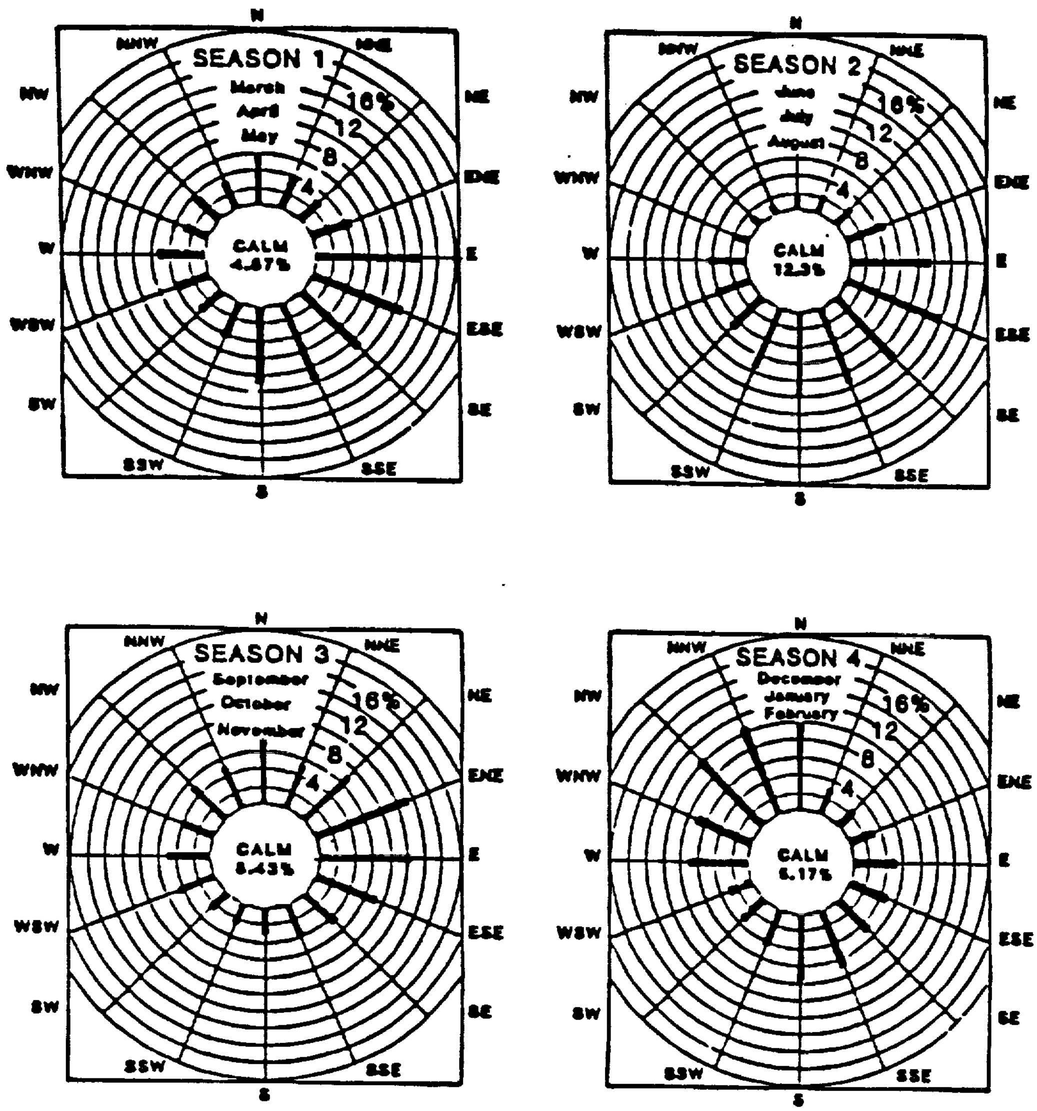

SOURCE: NASA 1986

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).

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 NASA Parkway East.

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

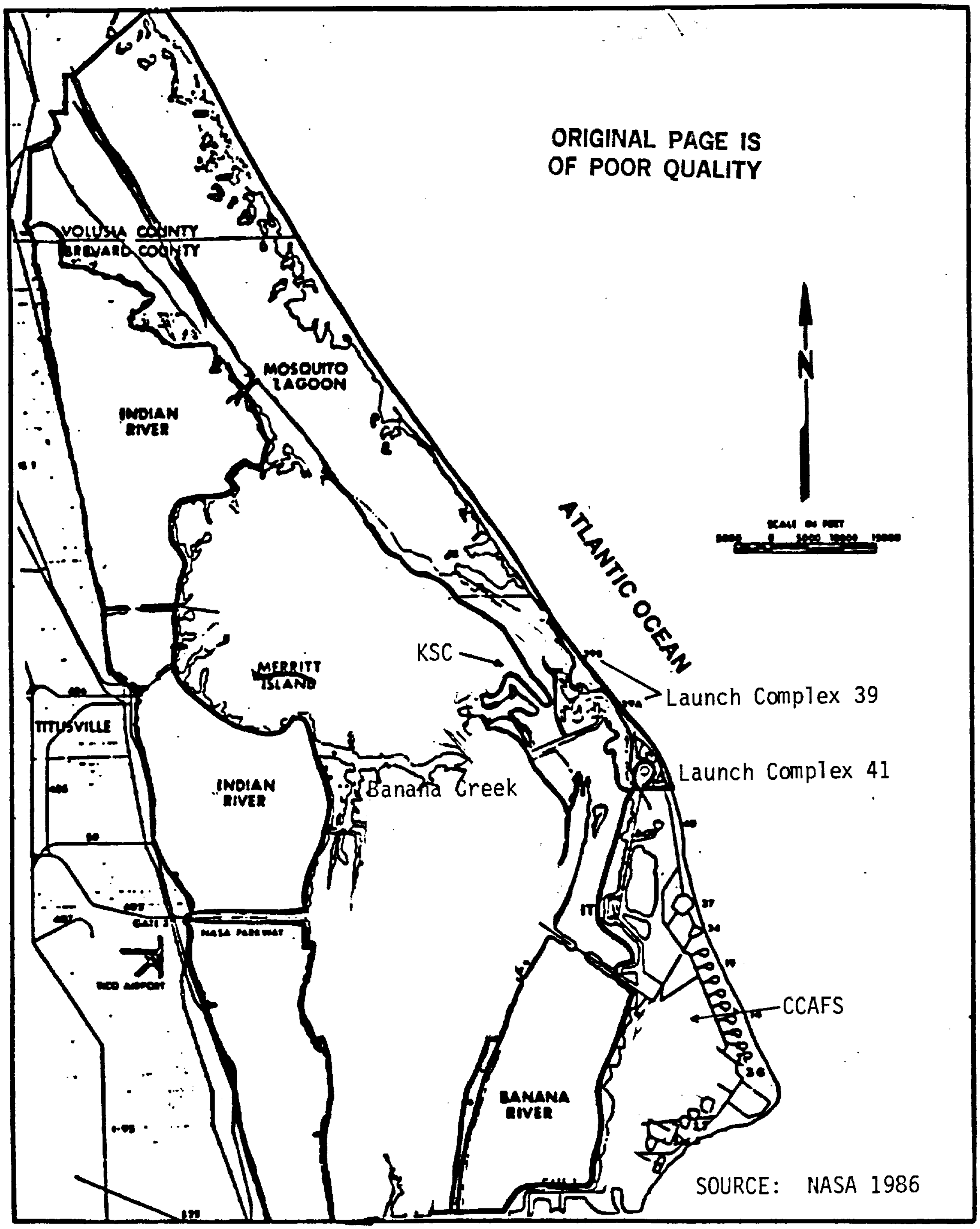

FIGURE 3-8. MAJOR SURFACE WATER BODIES NEAR KSC

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 adjacent to 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).

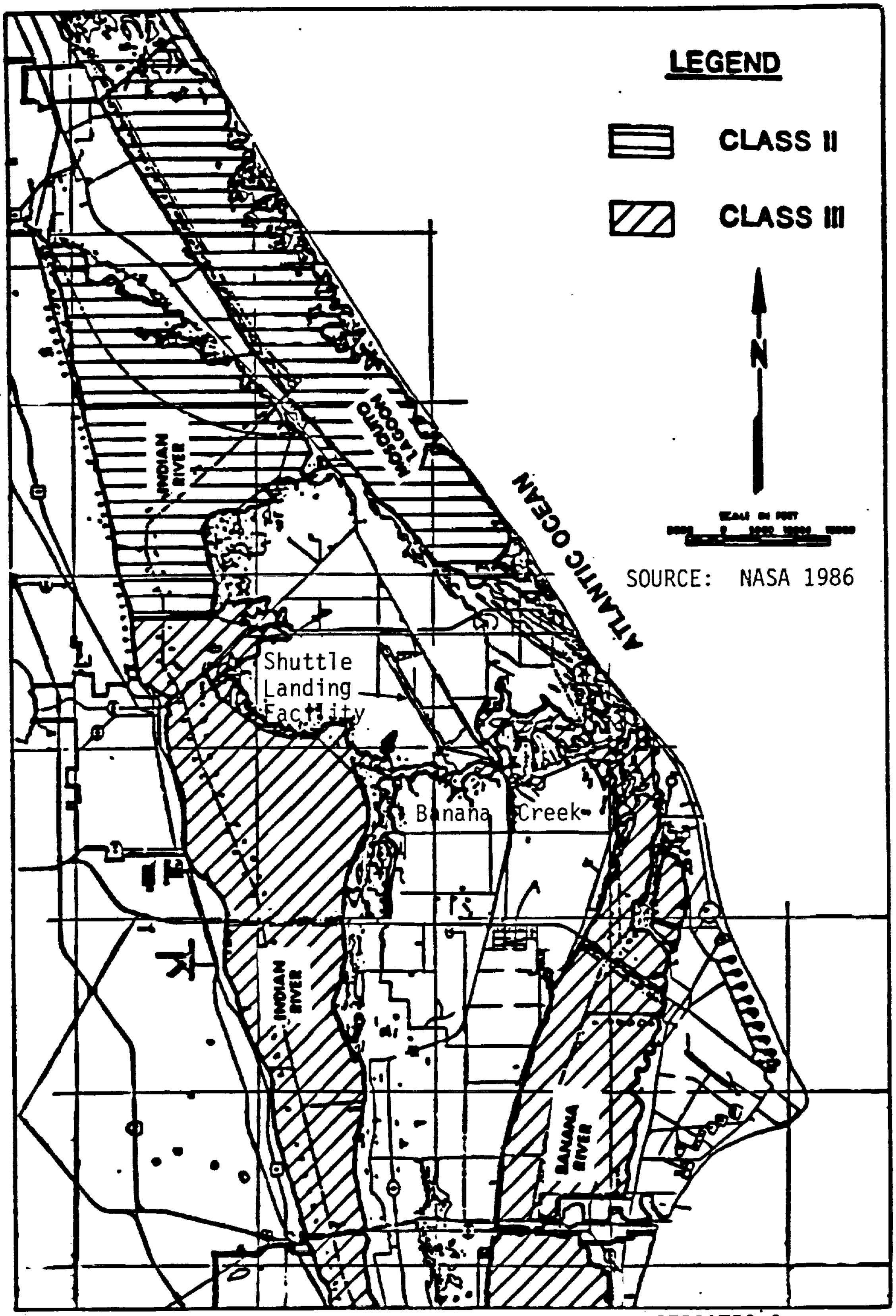

FIGURE 3-9. KSC SURFACE WATER CLASSIFICATIONS

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.

<u>NOTES</u>:
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.

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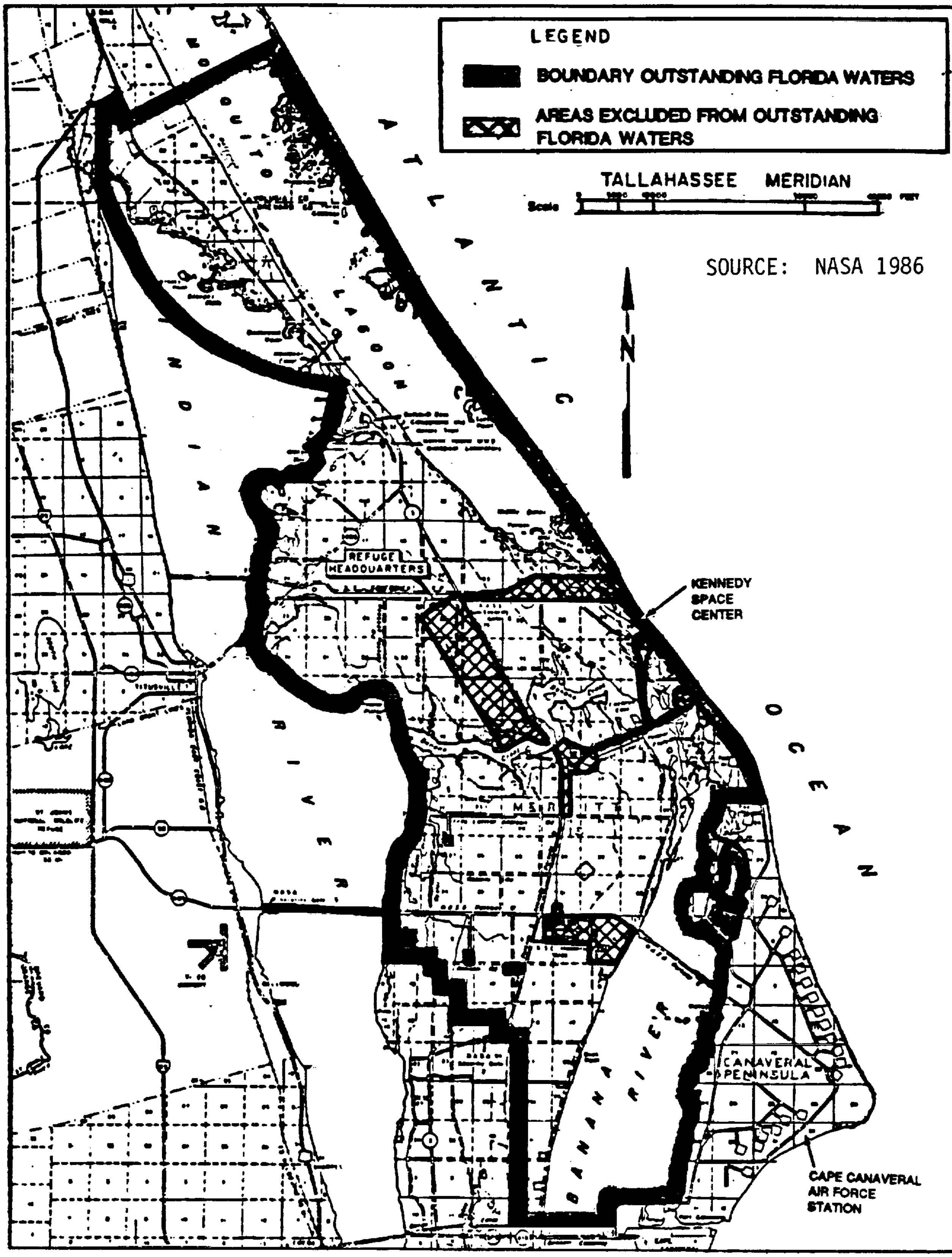


FIGURE 3-10. KSC OUTSTANDING FLORIDA WATERS

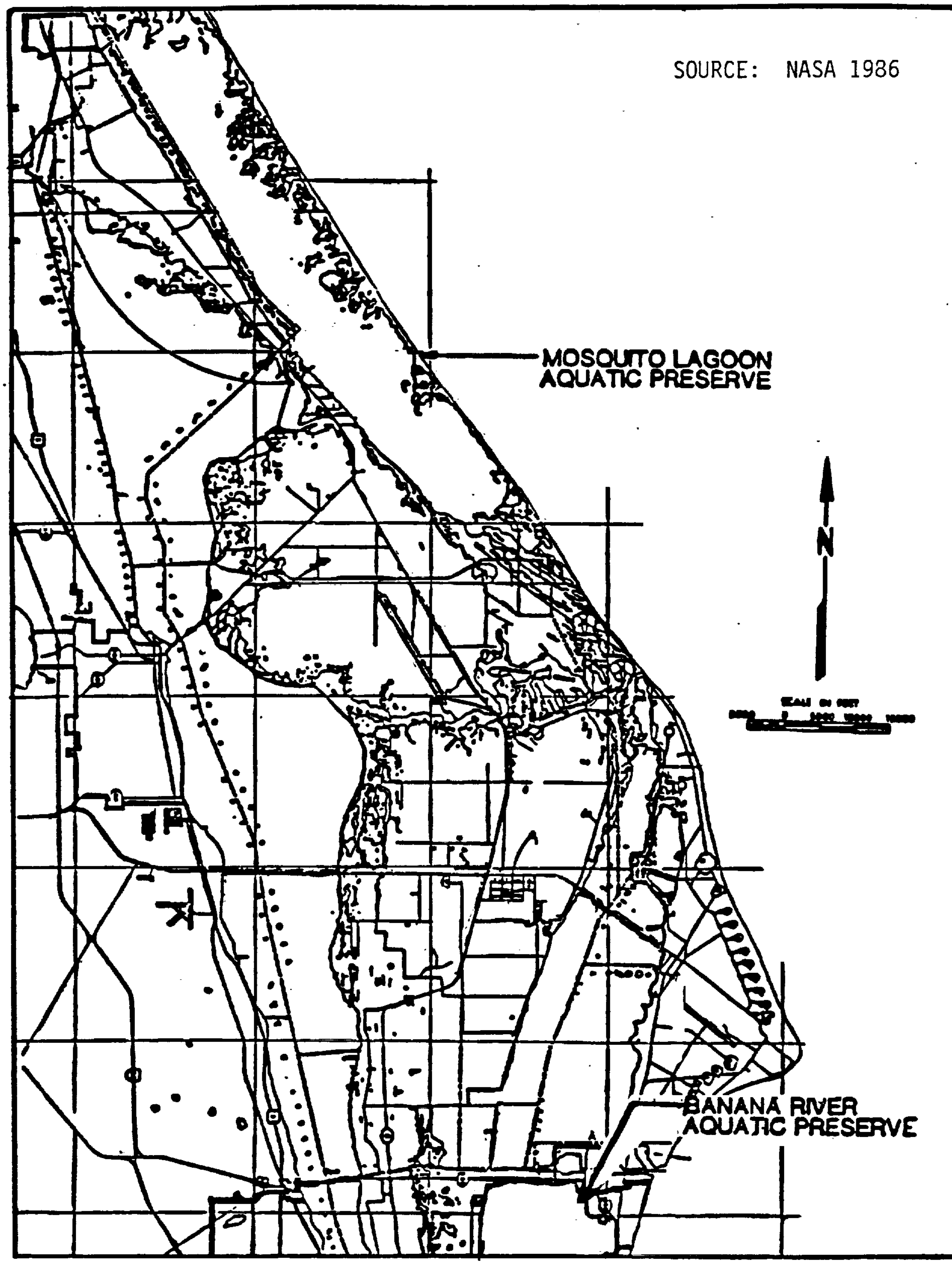


FIGURE 3-11. KSC AREA AQUATIC PRESERVES

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

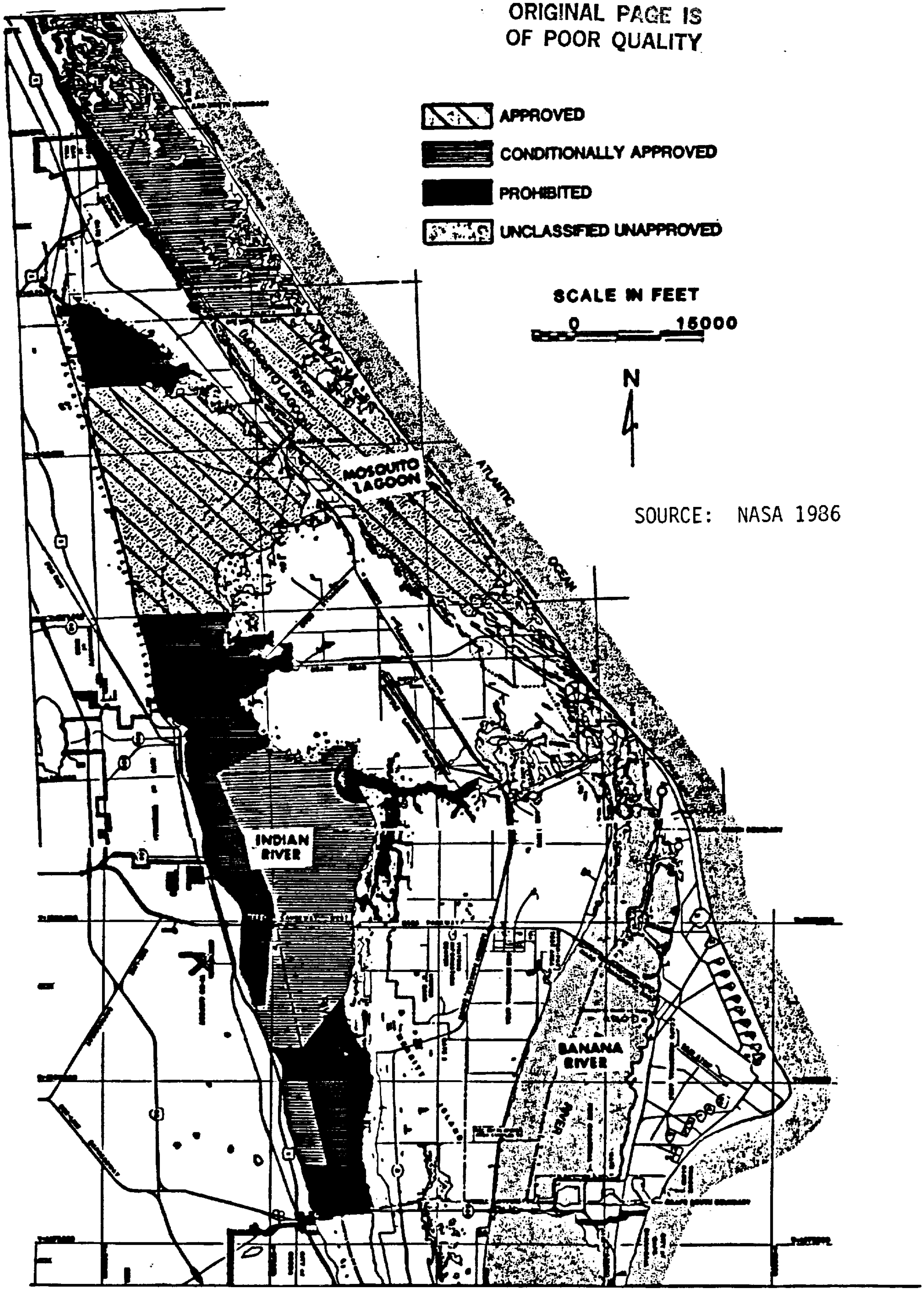


FIGURE 3-12. KSC SHELLFISH HARVESTING AREAS

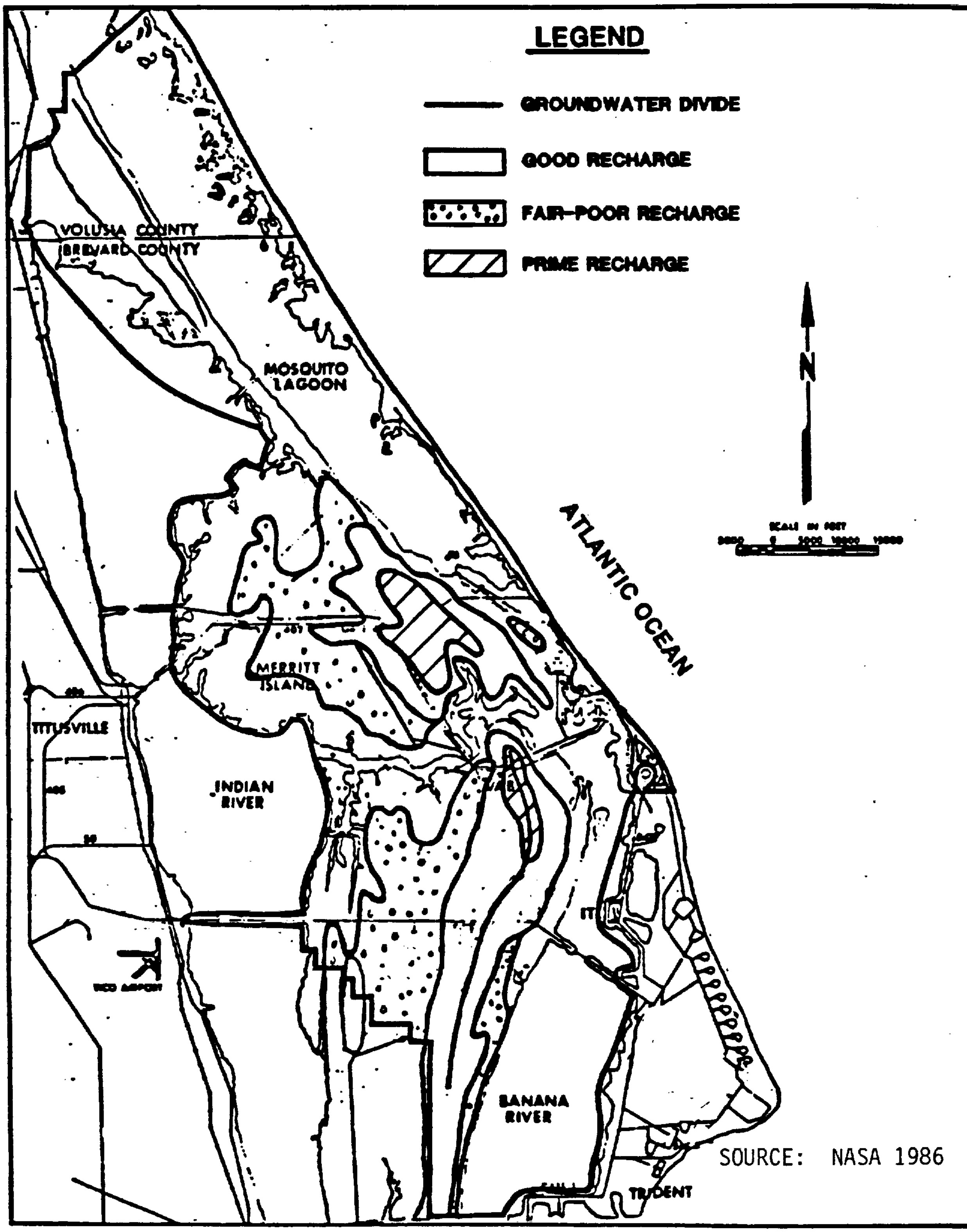


FIGURE 3-13. POTENTIAL RECHARGE FOR SURFICIAL AQUIFER

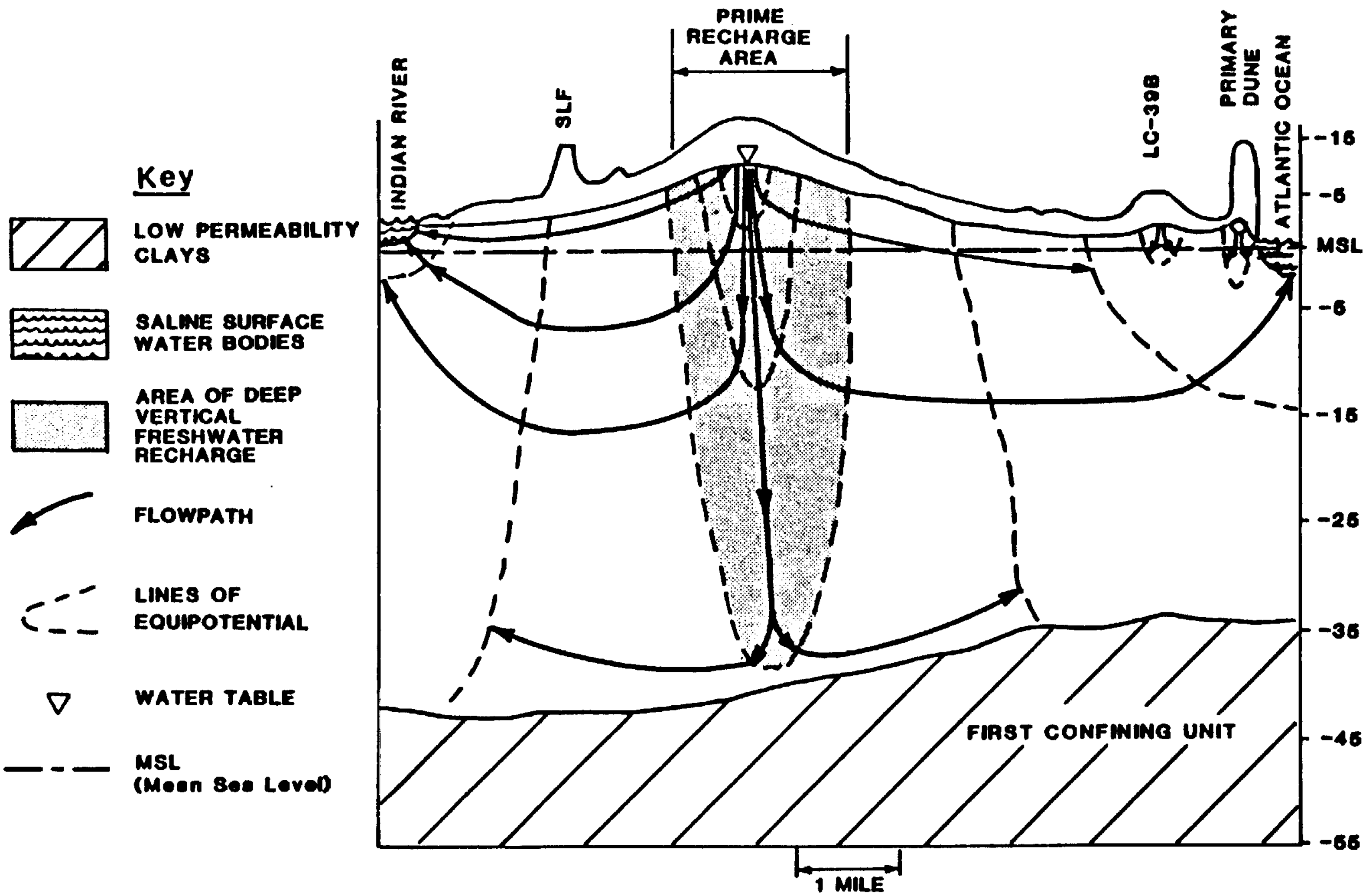


FIGURE 3-14. **QUALITATIVE FLOW NET FOR THE SURFICIAL AQUIFER ILLUSTRATING GROUNDWATER CIRCULATION. NOTE AREAS OF DEEP VERTICAL RECHARGE.**

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.

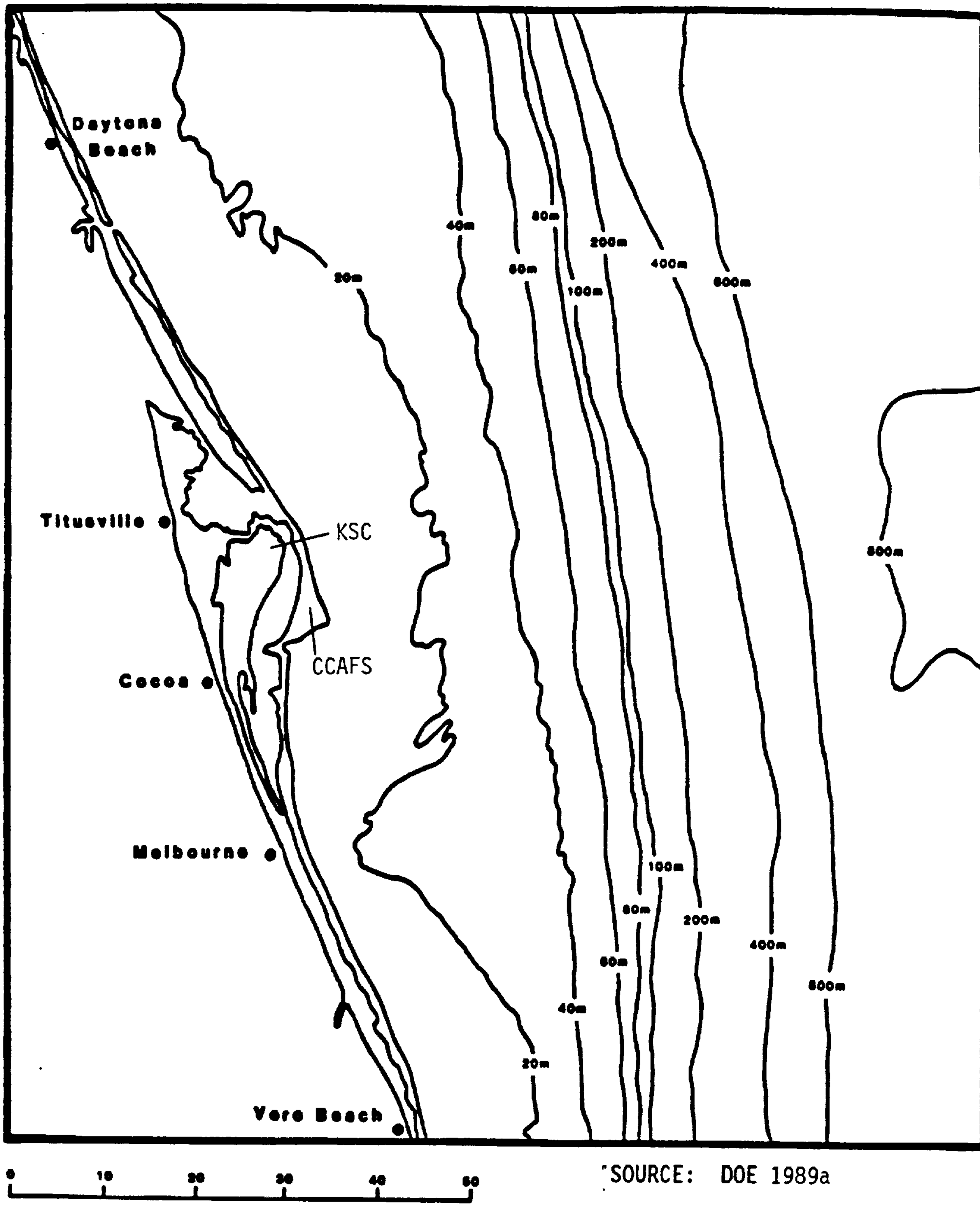
Preliminary data for the Secondary Semi-Confined Aquifer show that some of these aquifers may be marginal water sources; however, it appears that they are not capable of sustaining large scale development.

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.

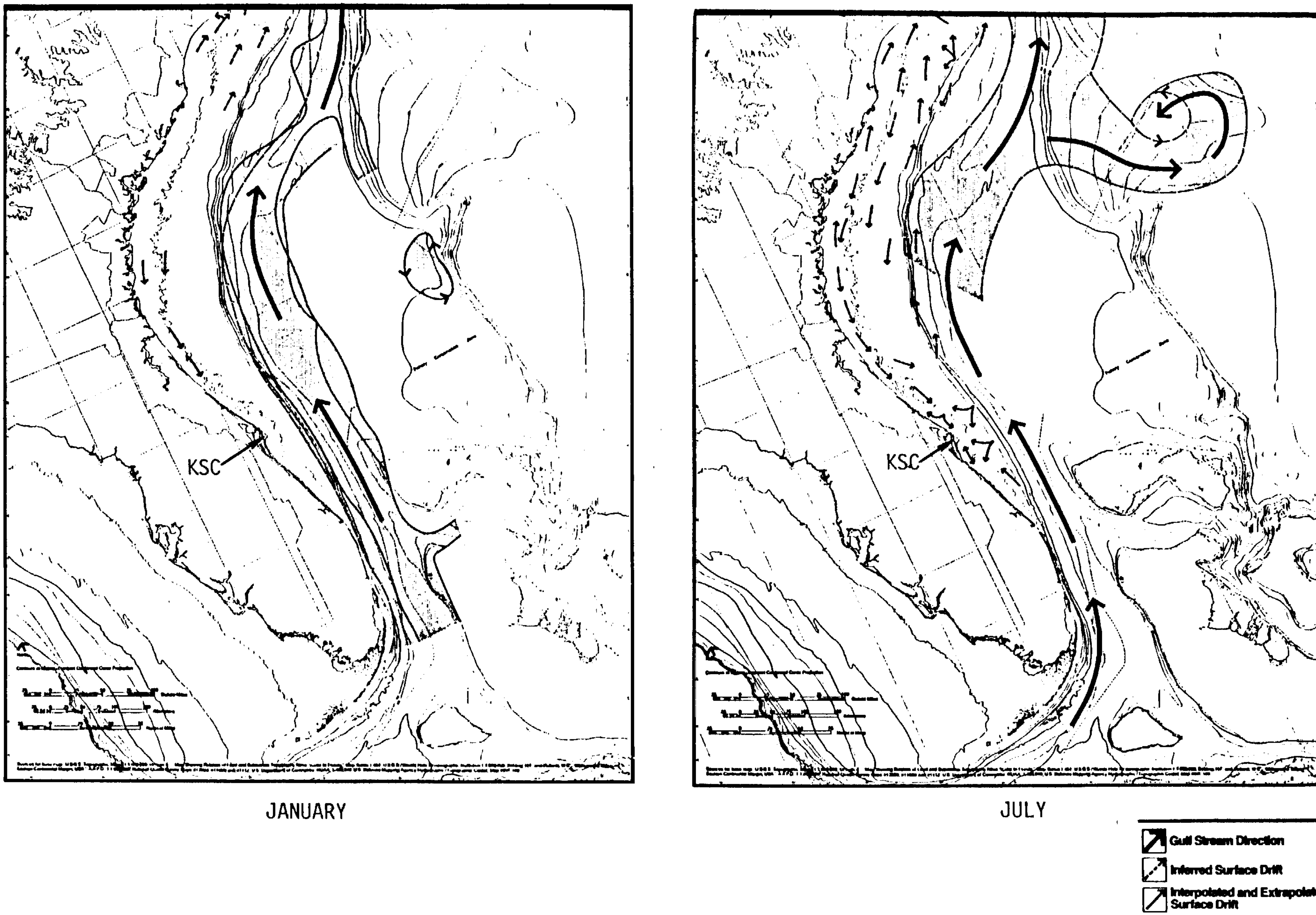
Out to depths of about 60 feet, sandy shoals dominate the underwater topography. The bottom continues seaward at about the same slope out to about 34 miles where the bank slopes down to depths of 2,400 to 3,000 feet to the Blake Plateau. The Blake Plateau extends out to about 230 miles from the shore 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. 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).



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

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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

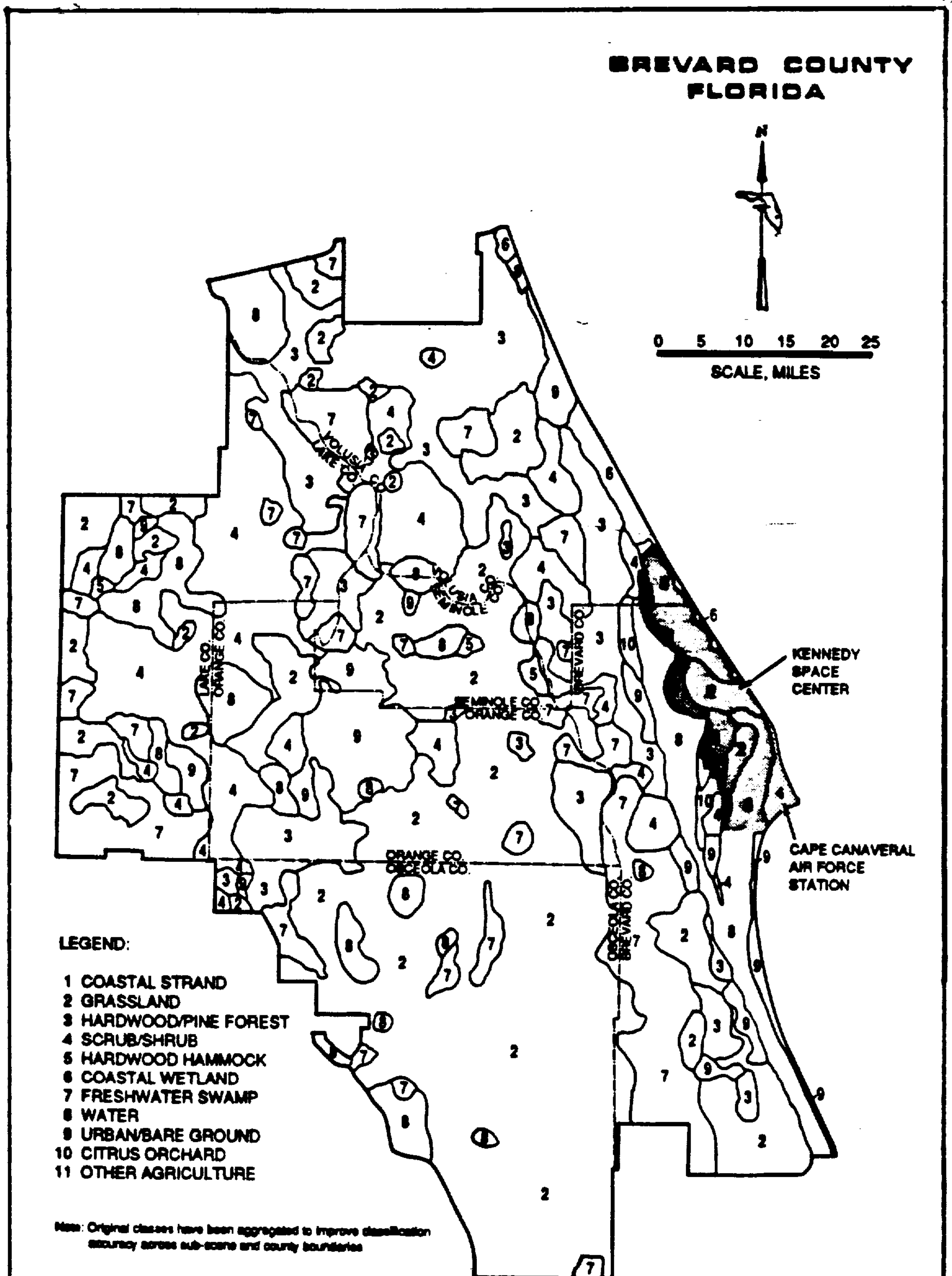
3.2.5.1 Terrestrial Biota

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. 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.



SOURCE: ECFRPC 1988

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

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. Brevard County leads the State in the production of hard clams (quahogs) and scallops. The commercial scallop fishery predominates off shore; it is estimated that 30 to 40 million pounds of calico scallops were harvested off Cape Canaveral in 1984. 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.

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.

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).

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 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

- 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.

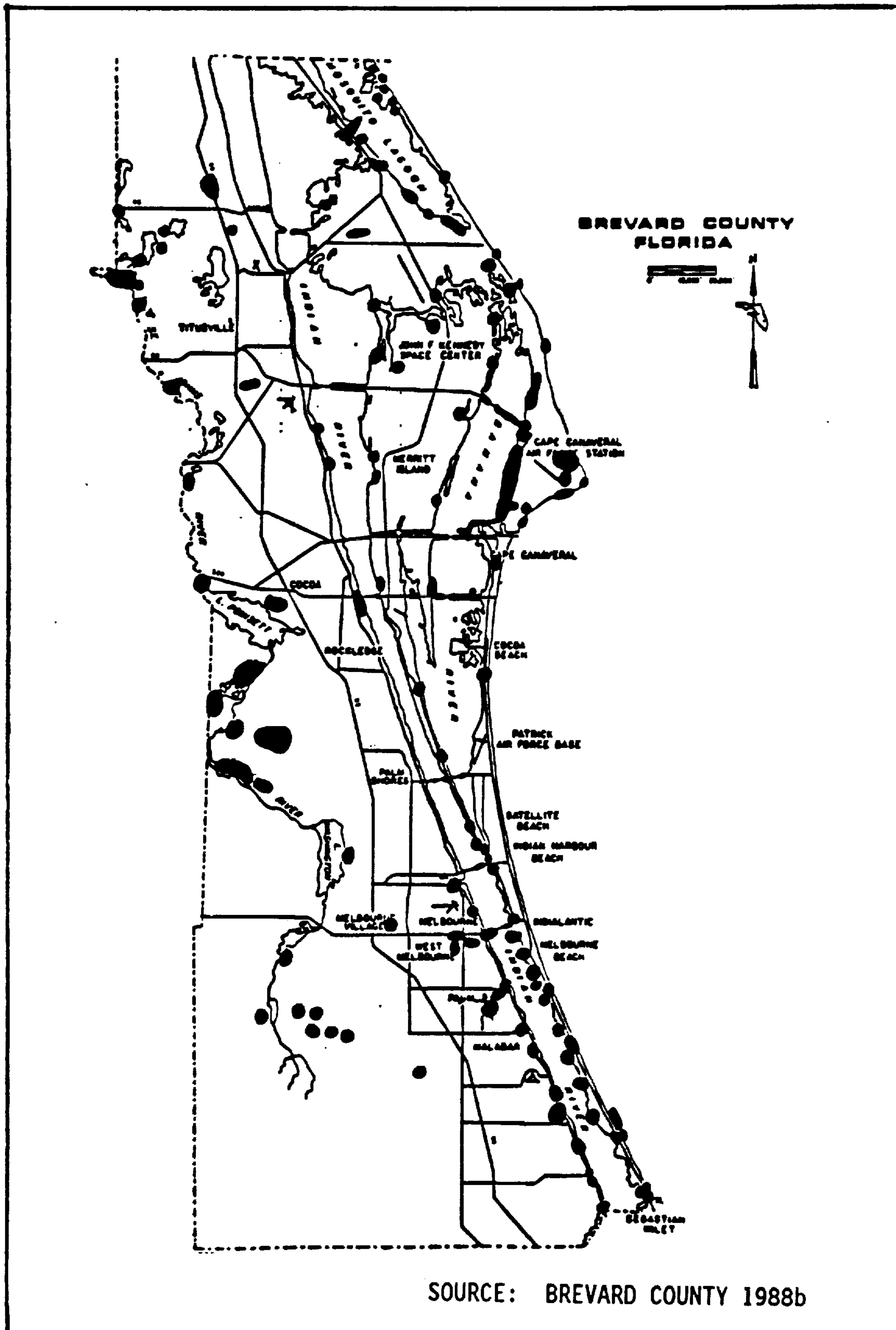


FIGURE 3-18. GENERAL LOCATIONS OF HISTORICAL/ARCHAEOLOGICAL RESOURCES IN THE VICINITY OF KSC/CCAFS

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 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.

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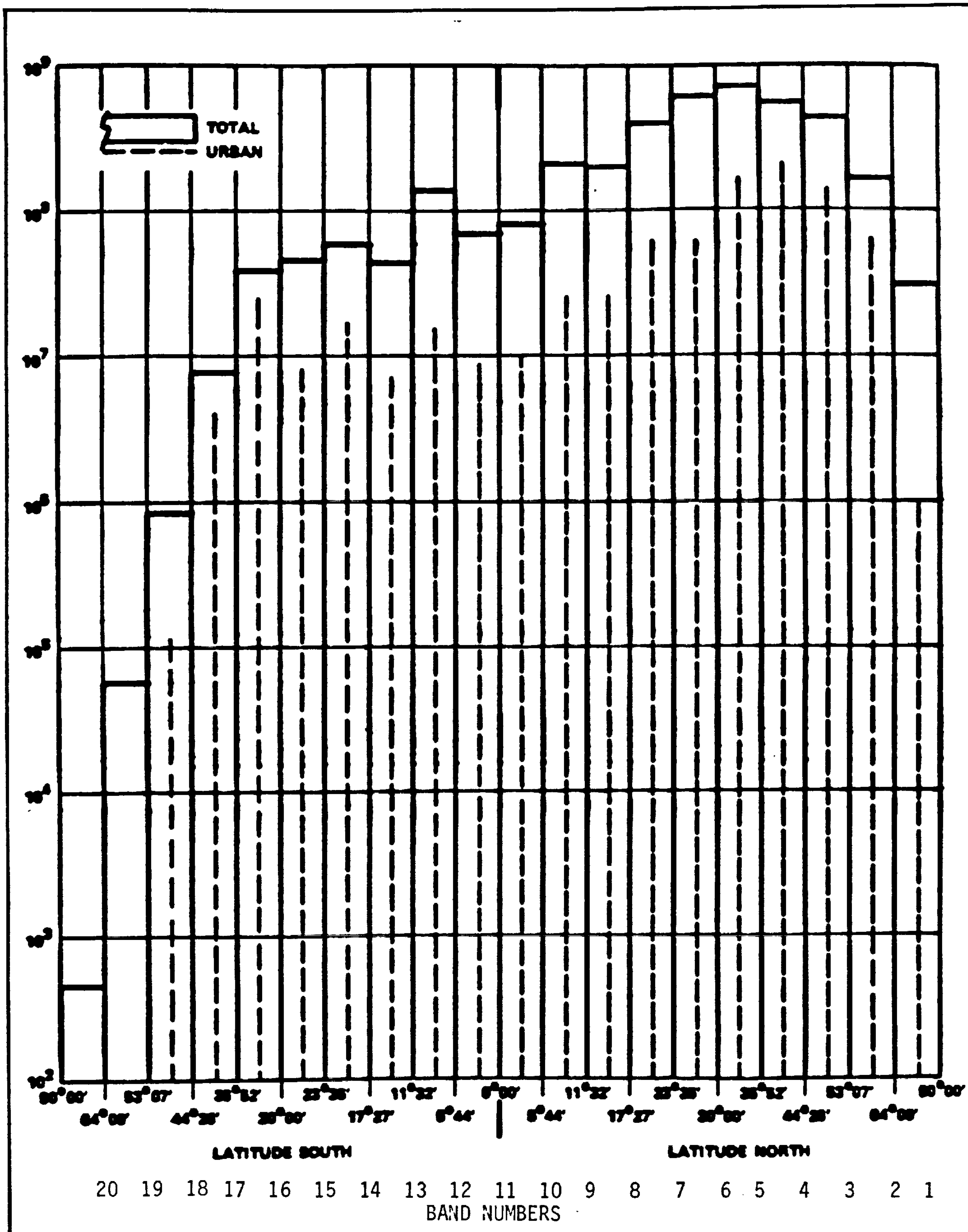

Source: USAEC 1975

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

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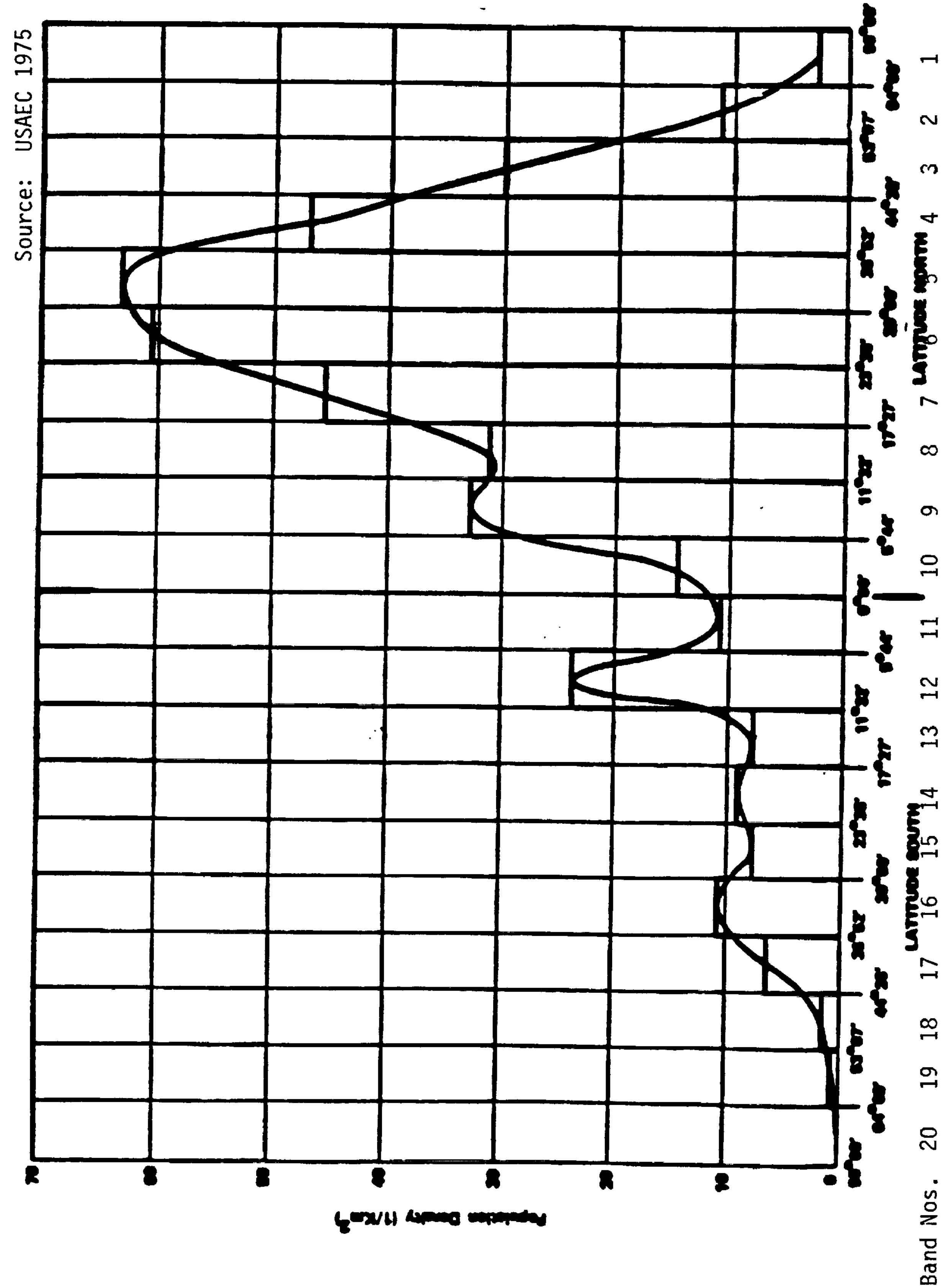


FIGURE 3-20. WORLD POPULATION (BAND LAND AREA) DENSITY BY LATITUDE BANDS

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

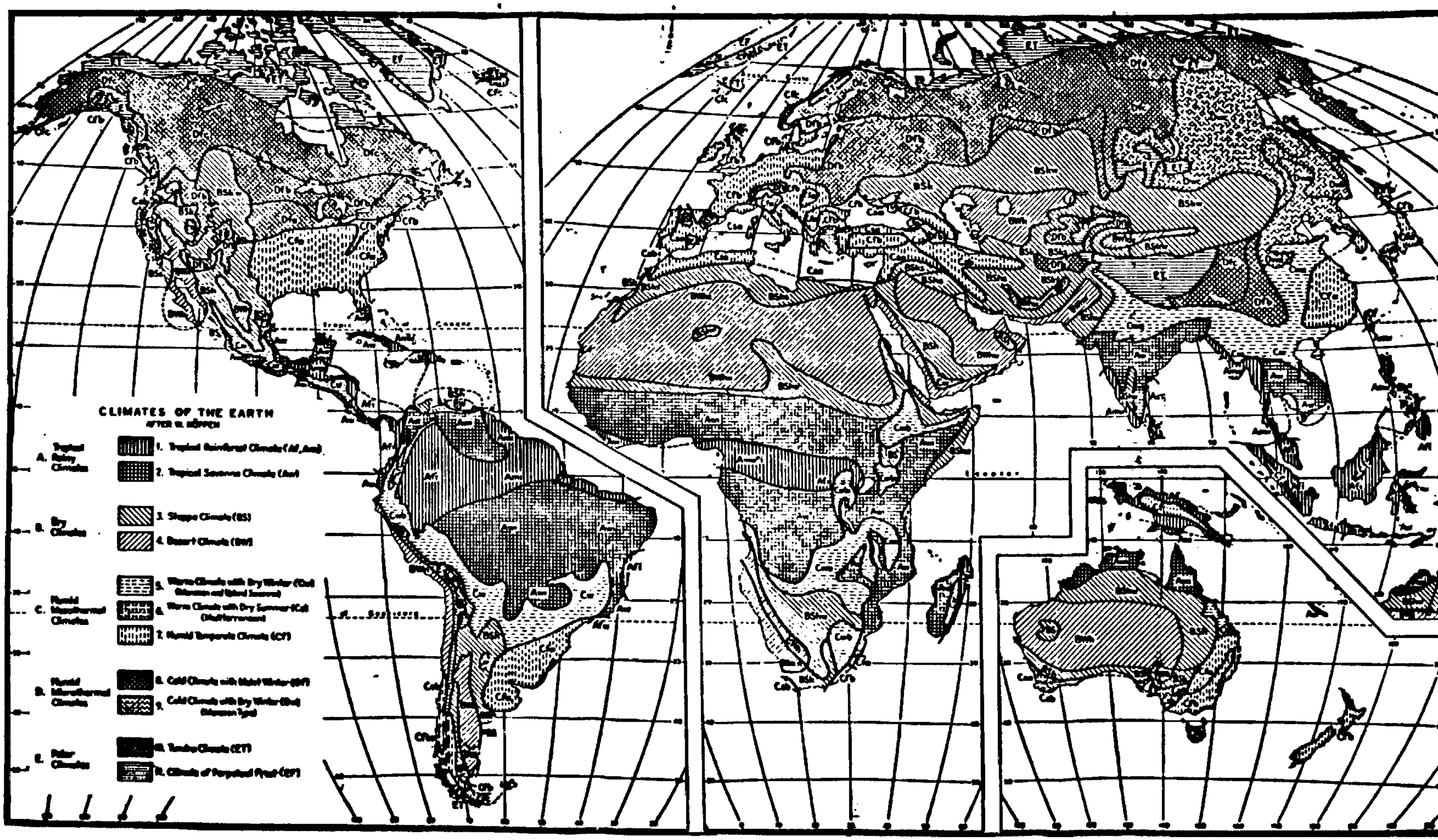
The distribution of surface types, worldwide, is an important characteristic in considering the potential consequences of accident scenarios analyzed for the Ulysses mission. Table 3-6 provides a breakdown, by each of the 20 equal area latitude bands noted previously, of the total land fraction and the 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.

Over the period 1945 through 1974, above-ground nuclear weapons tests produced about 440,000 curies of plutonium (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.

Of the approximately 430,000 curies of Pu-239 produced, about 105,000 curies were deposited at and near the test sites (EPA 1977). The remaining 325,000 curies were injected into the stratosphere (about 6 to 15 miles above the Earth's surface). The stratospheric inventory returned to Earth as "fallout." About 25,000 curies were deposited in the northern hemisphere, primarily in the mid-latitudes, with about 70,000 curies deposited over the southern latitudes (EPA 1977). About 5,000 curies remained aloft as of 1974.



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

Approximately 16,000 curies of fallout settled on the continental United States (USAEC 1974). Figure 3-22 illustrates the accumulation of Pu-239 fallout in millicuries per square kilometer measured at various locations in the United States. In general, drier areas of the United States had lower accumulations than wet areas, indicating scavenging of Pu-239 from the atmosphere by rainfall. Some dry western areas are apparent exceptions to this indicating the possibility that there are regions where stratospheric debris may preferentially enter the troposphere to be deposited on the Earth's surface.

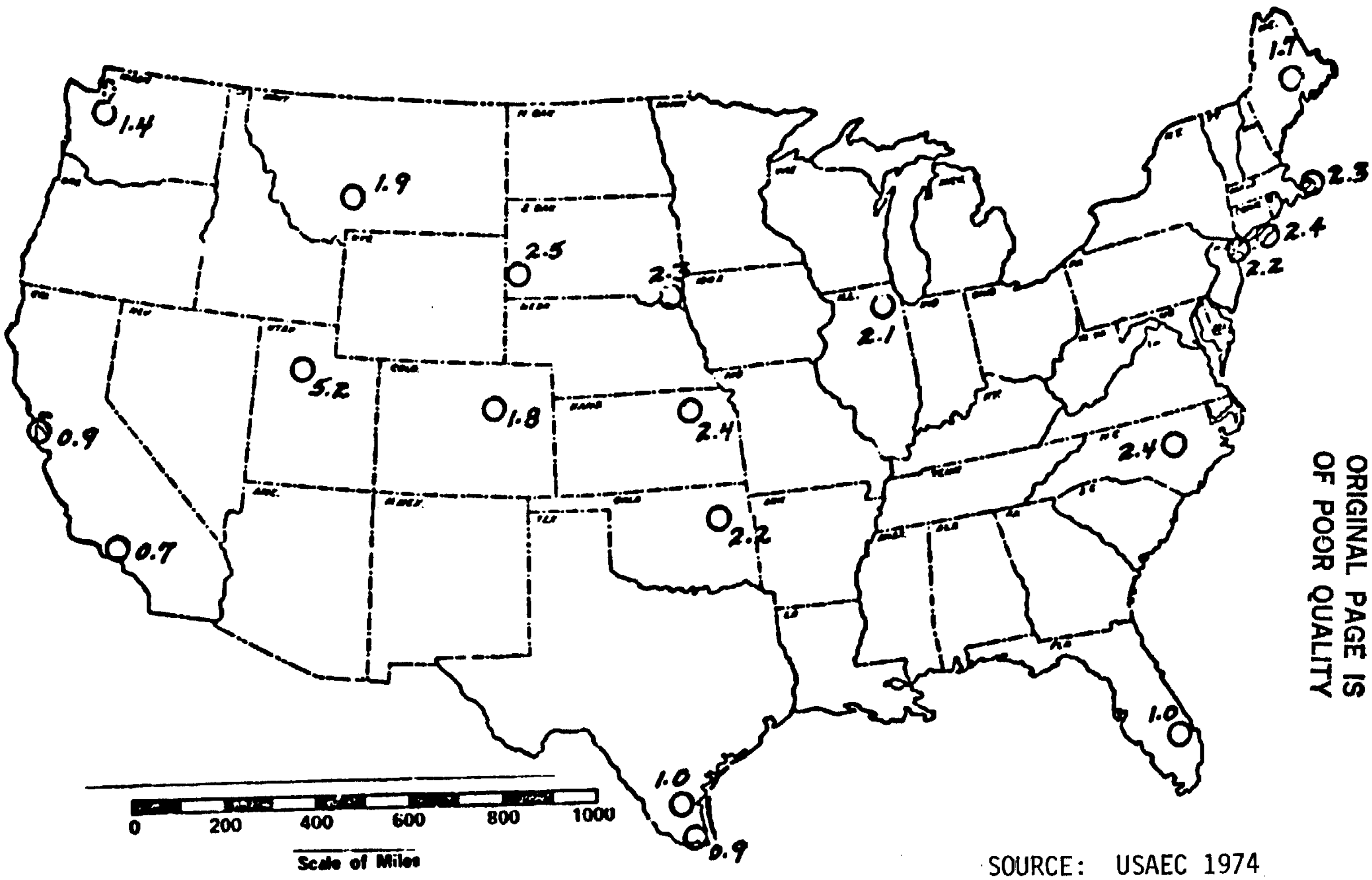
Table 3-7 indicates that the Pu-238 inventory from weapons tests (about 9,000 curies) was increased by a space nuclear source, specifically from the 1964 reentry and burn-up of a SNAP-9A Radioisotopic Thermoelectric Generator. This release of plutonium into the atmosphere was consistent with the RTG design philosophy of the time. Subsequent RTGs, including those 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.

The addition of 17,000 curies of Pu-238 from the SNAP-9A brought the total global inventory of plutonium to about 457,000 curies. Since 1964, essentially all of 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. MAJOR SOURCES AND APPROXIMATE AMOUNTS OF PLUTONIUM DISTRIBUTED WORLDWIDE

Sources	Amount (Curies)	% Activity by Isotope		
		Pu-238	Pu-239	Pu-240
Atmospheric Testing 1945-74				
• Deposited near testing sites	110,000	3	58	38
• Deposited world wide	330,000	3	58	39
Space Nuclear (Snap-9A, 1964)	17,000	100	-	-
Total	457,000			
Total global excluding amounts near to test sites	347,000			

Source: USAEC 1975



SOURCE: USAEC 1974

FIGURE 3-22. CUMULATIVE DEPOSIT OF PU 239 IN mCi PER km^2

C-2

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. These consequences were also discussed in detail in previously published National Aeronautics and Space Administration (NASA) documents, including Environmental Impact Statements (EISs) on the Space Shuttle Program (NASA 1978) and the Kennedy Space Center (KSC) EIS (NASA 1979), the KSC Environmental Resource Document (NASA 1986), the Tier 1 EIS for the Galileo and Ulysses missions (NASA 1988a).

4.1.3 Nonradiological 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.

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

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 mosquito control impoundments expected with each Shuttle launch. No significant adverse effects outside the near-field.
Endangered and Threatened Species	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

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. 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. 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. Small quantities of hydrocarbon on-board STS would float to the surface with no significant impact.

are summarized in Figure 4-1. For the Ulysses mission, work on the FSAR has been underway since mid 1989, but is not yet complete. Therefore, DOE has prepared a Safety Status Report (DOE 1990a, DOE 1990b, DOE 1990c) to provide the basic safety data used in this Draft (Tier 2) EIS. The analytical steps and the information flow used in preparing the interim report were precisely the same as those for the FSAR; however, certain data from the final input are not available for use by this DEIS. 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 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 process 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 then estimated by NASA (1988c) and provided to DOE for use in the development of the FSAR presently underway. Additional details regarding this process and the accident environments can be found in Appendix B. Of particular importance, however, is the elimination of certain accident scenarios and environments as contributors to fuel releases on the basis of further test and analysis. These were principally:

- The RTG case and General Purpose Heat Source (GPHS) failure criteria for a solid rocket booster (SRB) fragment impact were revised to reflect results from the Large Fragment Test series (Cull 1989).

- 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/Interagency Nuclear Safety Review Panel (INSRP) Explosion Working Group's evaluation of the Challenger and Titan 34-D accidents (NASA et al. 1989). This had the effect of eliminating vapor cloud explosions as a threat to the RTG.

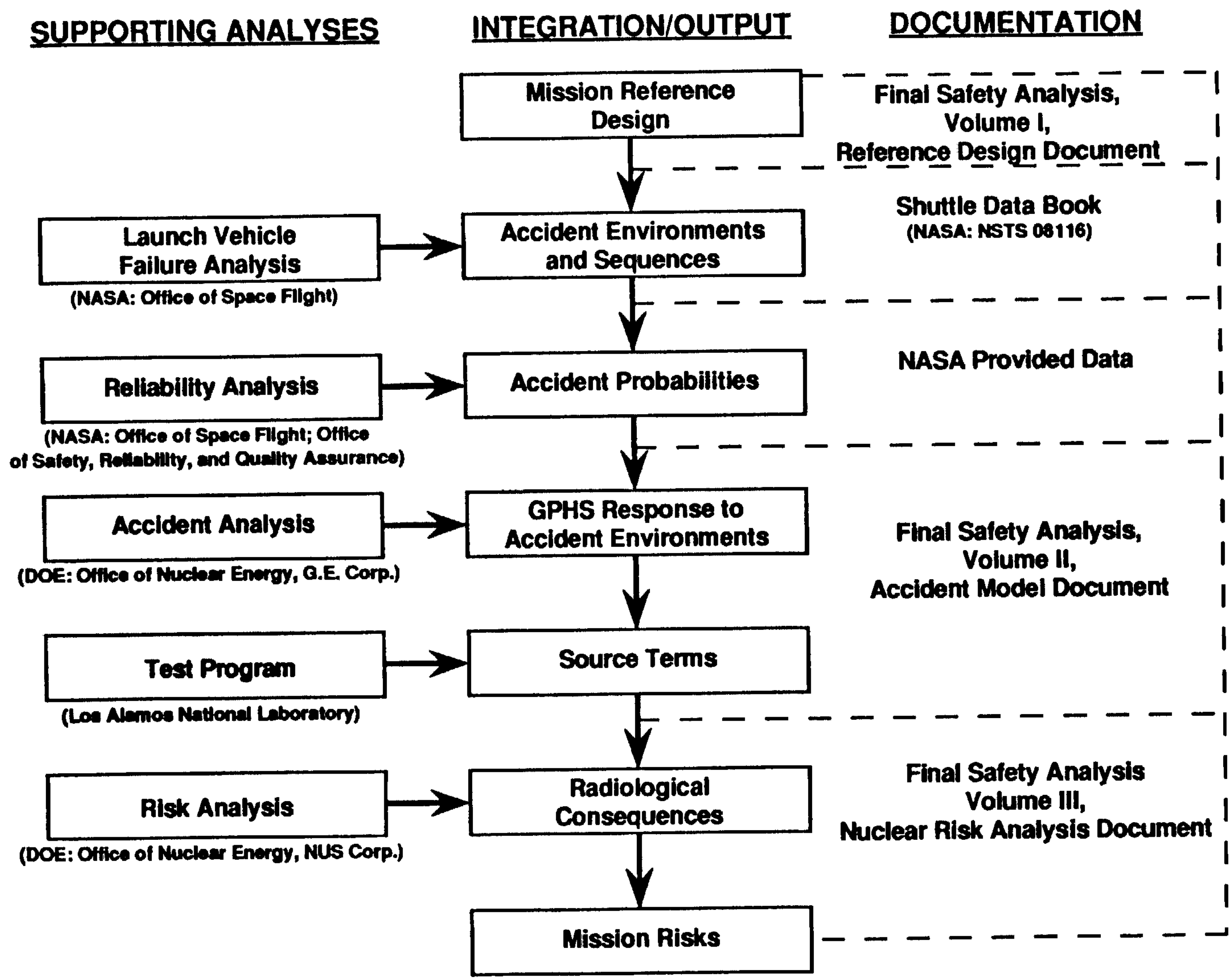


FIGURE 4-1. FINAL SAFETY ANALYSIS REPORT DEVELOPMENT PROCESS

- 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.

4.1.4.2 Accident Source Terms and Consequences

Not all SRB accidents will lead to a release. For instance, in an SRB case failure 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 then run for all 40 meteorological data sets of interest and a median (50th percentile) consequence was identified. For Phases 2, 3, and 4, a modified dispersion calculation was performed to estimate consequences for these phases (see Appendix C).

4.1.4.3 Risk Assessment

The aim of the analysis is to characterize the distribution of possible accidents and their consequences. The consequence analyses for early first stage ascent phases use meteorological data sets compiled from the Cape Canaveral local area climatology. Health and environmental effects were based on detailed land use and demographic statistics projected for 1990.

After about 45 seconds mission elapsed time, the vehicle is sufficiently high in the atmosphere that 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. 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).

The results of the analyses are summarized in Table 4-3, which lists the source terms, and Table 4-4, which lists phase value for the consequences. Table 4-3 presents the source terms utilized in the Risk Analyses for the Ulysses mission (DOE 1990c). Table 4-4 provides 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 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.

In Table 4-4, columns 3 and 4 list Maximum Individual Dose and Collective Dose in units of millirem (mrem) and person-rem, respectively. The largest value of Maximum Individual Dose results from an accident in either of the last two mission phases (on-orbit, payload deploy), in which an RTG module impacts hard rock at the Earth's surface. This leads to a localized release and Maximum Individual Dose of 36.2 millirem. These calculations use a 50-year dose commitment, as explained in Appendix C. While this dose is a 50-year dose, by assuming it is delivered in only 1 year, a conservative comparison can be made with the values listed in Table 4-5 for radiation exposures routinely encountered. Column 5 lists the amount of the Collective Dose that is above de minimis. As the released material is dispersed, it generally becomes more dilute but a larger population is exposed. The Collective Dose counts each person exposed and the dose level of their exposure; the units are person-rem. A linear multiplier of 3.5×10^{-4} cancer fatalities per person-rem is used to estimate the number of health effects (column 6). Health effects are defined as the number of additional cancer mortalities that would be expected in the exposed population, over and above the number that would normally occur.

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 Safety Status Report 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 such a 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

TABLE 4-3. ACCIDENT SOURCE TERM CALCULATIONS FOR VARIOUS SCENARIOS OF THE ULYSSES MISSION

Phase	Release Probability	Average Source Term (Ci)			Altitude of Release (ft)
		Fireball	Ground-Level	At-Altitude	
First Stage Ascent[1]	1.77×10^{-7} (1 in 6 million)	132	2.05	254	48,478
Second Stage Ascent	2.31×10^{-6} (1 in 433 thousand)	0	0.834	0	0
On Orbit	6.16×10^{-6} (1 in 162 thousand)	0	0.477	0	0
Payload Deploy	2.40×10^{-4} (1 in 4,200)	0	0.477	0	0

NOTES

1 For the ascent phase, listed values are probability weighted means, summed over the five time intervals. (See Appendix C.)

EXAMPLE

Phase Value for Fireball Release =

$$\frac{(8.16 \times 10^{-8} \times 288) + (1.92 \times 10^{-8} \times 0) + (0.482 \times 10^{-8} \times 0) + (0.793 \times 10^{-8} \times 0) + (6.38 \times 10^{-8} \times 0)}{(8.16 \times 10^{-8}) + (1.92 \times 10^{-8}) + (0.482 \times 10^{-8}) + (0.793 \times 10^{-8}) + (6.38 \times 10^{-8})}$$

$$= 132 \text{ Ci}$$

TABLE 4-4. BASE CASE RADIOLOGICAL CONSEQUENCES

(1) Phase	(2) Total Probability of Release	(3) Maximum Individual Dose (mrem)[c]	(4) Collective Dose (person-rem)[c]	(5) Collective Dose Above De Minimis[c] (person-rem)	(6) Health Effects[a]	(7) Dry Land Area Within Which Dose Level is Exceeded (km^2): 100 mrem/yr	(8) 25 mrem/yr	(9) 10 mrem/yr	(10) Area Exceeding 0.2 $\mu Ci/m^2$ (km^2) (Land)	(11) (Ocean)
First Stage Ascent*	1.77×10^{-7} (1 in 6 million)	2	242	0	.0847	0	0	0	12.3	20.7
Second Stage Ascent	2.31×10^{-6} (1 in 433 thousand)	20	.157	.0271	.000055	0	0	0	b	0
On Orbit	6.16×10^{-6} (1 in 162 thousand)	36.2	.529	0.164	.0002	0	0	0	b	0
Payload Deploy	2.40×10^{-4} (1 in 4,200)	36.2	.529	0.164	.0002	0	0	0	b	0

* Probability weighted average of all time intervals in the phase.

Source: DOE 1990c

a - Without de minimis, i.e., based upon total collective dose times health effects factor of 3.5×10^{-4} excess cancer fatalities per person-rem of exposure.

b - Very localized contamination only.

c - 50-year committed dose.

Example

Phase Value for Collective Dose =

$$\frac{(8.16 \times 10^{-8} \times 59.3) + (1.92 \times 10^{-8} \times 17.8) + (4.82 \times 10^{-9} \times 1.06) + (7.93 \times 10^{-9} \times 101) + (6.38 \times 10^{-8} \times 579)}{(8.16 \times 10^{-8}) + (1.92 \times 10^{-8}) + (4.82 \times 10^{-9}) + (7.93 \times 10^{-9}) + (6.38 \times 10^{-8})}$$

= 242 Person-rem

This was the method for calculating value shown on line 6 (0-120 seconds met) of Table C-2.

TABLE 4-5. AVERAGE ANNUAL EFFECTIVE DOSE EQUIVALENT OF IONIZING RADIATIONS TO A MEMBER OF THE U.S. POPULATION

Source	Dose Equivalent[a]	Effective Dose Equivalent	
	mrem	mrem	% 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.

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 Safety Status Report (DOE 1990c). The result of this calculation, specific for plutonium dioxide and reflecting all particle sizes and ingestion pathways, can range from 3.2×10^{-4} to 3.5×10^{-4} excess cancer fatalities per person-rem. For the purposes of calculating health effects for the base cases, a value of 3.5×10^{-4} has been used. No health effects are anticipated from any of the accidents analyzed.

Columns 7, 8, and 9 in Table 4-4 list the areas of deposition in which the dose levels at the second year after an accident release would be greater than 100, 25, and 10 mrem, respectively. For the purposes of this analysis, 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 (DOE 1990c). 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 10 mrem/yr; however, some limited areas on site at KSC 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 Table 4-4 lists the land areas estimated to initially receive deposition at or above an EPA suggested screening level of 0.2 $\mu Ci/m^2$ at or above which monitoring is recommended (EPA 1977). This is a deposition level below which monitoring should not be necessary. (See Section 4.2.1 and Appendix C for more detail.)

The ocean area where initial deposition could exceed 0.2 $\mu Ci/m^2$ is provided only as an indication of potential impact.

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 risks associated with this mission to risks encountered elsewhere, one may calculate an average individual risk. That is, the risk of a particular consequence divided by the affected population. For the purposes of this discussion, risk is defined as the product of the total probability of release and the consequence of that release. For instance, for Phase 4, the total probability of release is 2.4×10^{-4}. That release could lead to 0.0002 conditional incremental cancer mortalities. The risk of fatality from a Phase 4 release is 4.8×10^{-8} health effects. In the absence of the de minimis assumption, the collective dose affects a population of 5,000 people. So the average individual risk of fatality in the affected population is 4.8×10^{-8} divided by 5,000, or approximately 1 in 100 billion. This risk value is well below the risks encountered in everyday life as tabulated in Table 4-6.

TABLE 4-6. 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 in 10 thousand
Falls	11,733	5 in 100 thousand
Drowning	4,360	2 in 100 thousand
Fires and Flames	4,710	2 in 100 thousand
Poison	5,315	2 in 100 thousand
Water Transport	949	4 in 1 million
Air Travel	1,263	5 in 1 million
Manufacturing[d]	1,200	5 in 1 million
Railway	624	5 in 2 million
Electrocution	760	6 in 2 million
Lightning	99	4 in 10 million
Tornadoes[b]	114[b]	5 in 10 million
Hurricanes[b]	46[b]	2 in 10 million
Suicide	30,796	12 in 100 thousand
Homicide and Legal Intervention (Executions)	21,103	9 in 100 thousand
Guns, Firearms, and Explosives	1,656	7 in 1 million
Suffocation	3,688	3 in 200 thousand
All Accidents	95,020	4 in 10 thousand
Diseases	1,993,381	8 in 1 thousand
ALL CAUSES	2,123,323	9 in 1 thousand

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

Appendix C summarizes the DOE Safety Status Report for the Ulysses mission and describes the work of the DOE to characterize the distribution of consequences in a mathematically rigorous way. That work is treated in a section entitled Integrated Risk Assessment but is not yet complete and so has not been incorporated in this DEIS. That work will be completed in the Final Safety Analysis Report and will be included in the Final Environmental Impact Statement.

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. Included within the Kennedy Space Center assessment methodology is a discussion of the relationship of PuO_2 particle size distribution to the potential areas of radioactive deposition. The methodology for estimating potential economic costs resulting from the accidents is also provided.

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 45 seconds after launch) involves 3 main steps. 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 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 data presented in Table 4-4 identify the calculated areas initially contaminated above 0.2 $\mu Ci/m^2$ for two categories: inland areas and ocean. The screening level applies only to land contamination. The ocean area contaminated is provided only as an indication of potential impact. The inland category includes: all non-wetland inland land cover classes, such as upland forest, urban, and agricultural areas; all wetland types, such as coastal marshes and mangrove, freshwater marshes and swamps; and all estuarine (brackish) and fresh open water. The ocean category is any marine waters.

The second step is to adjust the inland area category to reflect the amount of dry land uses that occur within this category. The third step is to partition the dry land category into the three major types of environmental resources that could be impacted, specifically urban, natural habitat, and agriculture. To estimate environmental resources within the dry land category that could be affected by deposition, the dry land areas were assumed to be similar to the percentage of urban, agriculture, and natural vegetation land cover types in Brevard County. This allows the impact assessment to be refined because, for example, potential impacts to natural habitats within the dry land category are likely to be quite different from potential impacts to urban and agricultural areas also within the dry land category.

The percentages for Brevard County are used as an approximation of the relative amounts of these land cover types in any area contaminated by an early ascent phase release. A data base obtained from the East Central Florida Regional Planning Council (ECFRPC 1988a) was used to determine the percentage of urban area and natural vegetation. Data on the percentage of agricultural lands were obtained from another study (DOE 1983), which included identification and tabulation of land uses within 32 kilometers of Launch Complex 39 at Kennedy Space Center and overlaid on the East Central Florida Regional Planning Council data base to determine the relative percentages of the three cover types. The results of this analysis show that dry land areas are composed of approximately 74 percent natural vegetation, 21 percent urban areas, and 5 percent agricultural land. These percentages, represented as decimal numbers, are then multiplied with the dry land total reflected in Table 4-4, to estimate the area of these cover types affected for each early ascent phase accident case.

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 45 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. The relative percentages of natural vegetation, urban areas, and agricultural land cover types elsewhere in the world are unlikely to match the percentage for the KSC vicinity. Therefore, no distinctions are made within the dry land class presented in Table 4-4 for these later phases.

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). However, since the accident consequence results do not exceed this level, these costs were not generated (see Table 4-4). 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 4-7.

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

TABLE 4-7. 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

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.

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 accident consequences results predict that cleanup would not be indicated (see Table 4-4). 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 effects, 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 than the contamination resulting from an RTG accident, the decontamination and mitigation activities would be very similar. Therefore, the NRC findings are considered applicable in this study. 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, namely the urban and agricultural land cover types described in Section 4.2.1.

As a benchmark for purposes of this EIS only, cleanup to a level of 25 mrem/yr is utilized. In other words, the land area contaminated by accidents at a level of greater than a dose of 25 mrem/yr would be subject to cleanup to the 25 mrem/yr level. The 25 mrem/yr level was selected as a reasonable level on the basis of adoption of this level by Federal agencies for the protection of radiation workers and the public from releases associated with the land disposal of radioactive wastes (10 CFR 61.41); from radionuclide emissions from DOE facilities (40 CFR 61.92); and as associated with the management and disposal of spent nuclear fuel, high-level waste, and transuranic waste (40 CFR 191.15). In addition, the 25 mrem/yr level is one-fourth of the 100 mrem/yr continuous exposure level recommended by the National Council on Radiation Protection and Measurements (NCRP 1987) as an "acceptable risk" for latent cancer mortality risk to individual members of the public over their lifetime. 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. The potential range of cleanup techniques that could be utilized are listed in Table 4-8.

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

Cleanup costs beyond that required for the monitoring program, as described above, are not presented in the EIS, because review of Table 4-4 indicates that for the Base Cases over all mission phases, no dry land areas are contaminated at levels where an individual could receive a dose of 25 mrem. In fact, the dispersion modeling did not result in any land areas contaminated at doses exceeding 10 mrem/yr at the second year following an accident.

TABLE 4-8. 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 - Water rinses of vegetation - Recreational and other use restrictions	- Removal of large particles - Removal and disposal of all vegetation - Removal and disposal of topsoil - Relocation of animals - Habitat restoration
Urban	- Removal of large particles - Rinsing of building exteriors and hard surfaces - Rinsing of ornamental vegetation - Deep irrigation of lawns	- Removal of large particles - Removal and disposal of all vegetation - Land use restrictions - Demolition of some or all structures - Permanent relocation of affected population
Agriculture	- Removal of large particles - Deep irrigation of cropland - Destruction of first year crop, including citrus crops - Rinsing of citrus and other growing stocks - Shallow plowing of pasture and grain crop areas	- Removal of large particles - Destruction of citrus and other perennial growing stocks - Banning of future agricultural land uses
Wetland	- Removal of large particles - Rinsing of emergent vegetation - Recreational and other use restrictions	- Removal of large particles - Removal of disposal of all vegetation - Dredging and disposal of sediments - Habitat restoration
Inland Water	- Removal of large particles - Boating and recreational restrictions	- Removal of large particles - Dredging and disposal of contaminated sediment - Commercial and recreational fishing restrictions
Ocean	- Removal of large particles - Shoreline use restrictions	- Removal of large particles - Dredging and disposal of contaminated sediment - Commercial and recreational fishing restrictions

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.

Results are presented for exposure impacts and mitigation impacts. Exposure impacts are those that result from the deposition of PuO_2 on various environmental media and subsequent movement of PuO_2 in the environment. They include impacts to natural environments, water resources, man-used resources, and agricultural resources. Mitigation impacts are those impacts caused by decontamination and mitigation activities undertaken to reduce radioactive contamination levels in the environment.

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

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.

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 being transported to the shoreline (Bartram & Wilkinson 1983). 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.

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 $nCi/m^2/sec$ in sea water and fresh water, respectively, based upon the dissolution rate per unit surface area of the fuel.

It is also important to note that dissolved plutonium concentrations in water can increase under the following conditions (Bartram & Wilkinson 1983):

- Increasing pH
- Increasing dissolved organic carbon concentrations
- Increasing oxidizing conditions
- Increasing carbonate concentrations
- Increasing nitrate concentrations
- Increasing sulfate concentrations.

Plutonium dioxide also tends to dissolve more readily in fresh water and at cooler temperatures. Once in solution, this plutonium dioxide can coexist in multiple oxidation states that can affect its availability to organisms.

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. The solid/solute distribution coefficient (K_d) for plutonium has been estimated at 10^1 to 10^6 (Looney et al. 1987, Bartram & Wilkinson 1983). The K_d for plutonium also varies based on the oxidation state of the element. Under the oxidizing conditions similar to those encountered in most surface water bodies, Pu^{5+} would tend to be the dominant species of plutonium, and the K_d would be approximately 10^3. Under the reducing conditions encountered in most bottom sediments and ground-water bodies, Pu^{4+} would tend to be dominant, and the K_d would be approximately 10^6 (Bartram & Wilkinson 1983).

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 man. 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 (Bartram & Wilkinson 1983, 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 (Bartram and Wilkinson 1983, 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 et al. 1980). However, most of these studies also indicate that the bioaccumulation of PuO_2 is not critical to the upper trophic levels, including man.

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 1×10^{-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 (DOE 1990c), 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 (DOE 1990a, DOE 1990b, DOE 1990c), 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 land and ocean areas potentially contaminated by the release are noted in Table 4-4.

Accidents occurring within the first 45 seconds of the first stage ascent phase would result primarily in deposition on the controlled land areas of KSC. Beyond 45 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 [1×10^{-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 1×10^{-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 $2X10^{-5}$ $\mu Ci/m^2$ 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 man. 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 migration activities (see Table 4-8) 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 are likely to 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

The areas of land cover used by man (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. Given the results of the accident consequences analyses of the base case (Table 4-4), which show no dry land areas contaminated at 25 mrem/yr (or even 10 mrem/yr), it is likely that monitoring would indicate no cleanup is 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 4-8), should monitoring indicate otherwise, these sites could be affected.

The deposition also has 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 supercedes 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.

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 man.

- 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.

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 Table 4-4.

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 provided in the Safety Status Report (DOE 1990a, DOE 1990b, DOE 1990c).

4.3.3 Emergency Response Planning

For NASA missions involving space nuclear power, comprehensive radiological contingency plans are developed to address all launch/landing phase accidents involving an RTG. These plans are developed through the combined efforts of various government agencies, including NASA, DOE, the Department of Defense, the EPA, and the State of Florida, and are formulated to conform to the Federal Radiological Emergency Response Plan. These plans are being updated for the Ulysses mission. Development and implementation of these plans will ensure the availability of appropriate response personnel, equipment, facilities, and procedures in the event of a launch accident.

The primary objectives during the early phases of an accident are to determine whether a release of radioactive materials has occurred, to assess and characterize the extent of the release, to predict the propagation of the released materials, and to formulate/recommend mitigating actions to safeguard humans and the environment from the consequences of the release. Another objective is to locate and recover the RTG. These objectives will be achieved through the evaluation and analysis of real-time data provided by mobile field monitoring teams and ground air-sampling stations, airborne monitoring and surveillance aircraft, ground and airborne meteorological stations, and computerized dispersion modeling.

Follow-on objectives would be to isolate contaminated areas, recover the fuel materials, and decontaminate and/or recover affected areas, facilities, equipment, and properties.

4.4 INCOMPLETE OR UNAVAILABLE INFORMATION

This Draft EIS (Tier 2) uses as its primary data source, the safety analysis being conducted by DOE for the Ulysses mission. That safety analysis is in preparation, and therefore, DOE has not published its FSAR for the Ulysses mission. The analyses of the last three mission phases are complete.

There is continuing analysis of the fragment environment in Phase 1, first stage ascent phase. Most of the possible impact situations have been analyzed and are reflected in the first stage ascent phase data in Tables 4-3 and 4-4. Based upon available information, it is anticipated that the risks associated with the Ulysses mission are well below any of the common risk values encountered in everyday life (see Table 4-6).

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. Cancellation of the mission would violate the agreement between NASA and the European Space Agency (ESA). 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 the mosquito control ponds 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 Table 3-3) for a short period, but will be below levels of exposure considered hazardous by the National Academy of Sciences. No significant deterioration in ambient air quality has been recorded at the two environmental air quality monitoring stations located 3 and 5 miles from Launch Complex 39, however. The deposition could 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.

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 1.77×10^{-7} (1 in 6 million). 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 MAN'S 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 environments of other planets.

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 EL 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 EL in the preparation of this document. Table 5-1 summarizes, for each contributor, the sections of the EIS for which inputs were prepared.

PREPARER

<u>National Aeronautics and Space Administration</u>

Dudley McConnell, Ph.D.	Deputy Director for Advanced Program Studies, Code EL

LIST OF CONTRIBUTORS

<u>Science Applications International Corporation</u>

Barry Nichols	SAIC Project Manager
Dennis Ford, Ph.D.	Senior Environmental Analyst
Jeffrey Weiler	Senior Environmental Analyst
Douglas Outlaw, Ph.D.	Senior Environmental Scientist
Reginald Gotchy, Ph.D.	Senior Health Physicist
Isaac Kwarteng, Ph.D.	Environmental Engineer
Abe Zeitoun, Ph.D.	Senior Environmental Scientist

<u>Jet Propulsion Laboratory</u>

Reed Wilcox	Supervisor, Launch Approval Planning Group
Donald Meyer	Manager, Ulysses Mission Design, Operations and Engineering
Doug Abraham	Member, Technical Staff
John Klein, Ph.D.	Supervisor of Power Systems Engineering and Control Group

LIST OF REVIEWERS

<u>National Aeronautics and Space Administration</u>

Joyce Jatko	NASA Acting NEPA Coordinator, Code NXF

<u>Jet Propulsion Laboratory</u>

M. Joseph Cork	Manager of Engineering Operations, Flight Projects Office
Lawrence Reinhart, Ph.D.	Member, Technical Staff

U.S. Department of Energy

A. Thomas Clark, Ph.D.	Manager, Operations Group
Alfred Mowery, Ph.D.	Safety Program Manager

NUS Corporation

Bart Bartram	Senior Executive Consultant
Richard Englehart, Ph.D.	Senior Executive Consultant

TABLE 5-1. CONTRIBUTORS AND REVIEWERS OF THE EIS

Responsible Person	Summary	Chapter 1	2	3	4	5	6	7	8	Appendix A	B	C
NASA												
DUDLEY McCONNELL Ph.D. Aerospace Science	X	X	X	X	X						X	X
JOYCE JATKO M.S. Environmental Engineering							X					
SAIC												
BARRY NICHOLS B.S. Natural Science			X		X						X	X
DENNIS FORD Ph.D. Zoology				X	X						X	X
JEFFREY WEILER M.S. Resource Economics/ Environmental Management	X	X	X			X	X		X	X		
REGINALD GOTCHY Ph.D. Radiation Biology			X		X							
ISAAC KWARTENG Ph.D. Chemical Engineering			X		X			X				
DOUGLAS OUTLAW Ph.D. Nuclear Physics					X						X	
ABE ZEITOUN Ph.D. Environmental Sciences					X						X	X
JPL												
M. JOSEPH CORK M.S. Aeronautical Engineering			X								X	
REED WILCOX M.S. City and Regional Planning	X	X	X	X							X	
DONALD MEYER A.B. Physics		X	X									
DOUG ABRAHAM B.A. Physics		X	X									

TABLE 5-1. CONTRIBUTORS AND REVIEWERS OF THE EIS (Continued)

Responsible Person	Summary	Chapter								Appendix		
		1	2	3	4	5	6	7	8	A	B	C
JPL												
JOHN KLEIN Ph.D. Electrical Engineering			X									
LAWRENCE REINHART Ph.D. Mechanical Engineering											X	
DOE												
A. THOMAS CLARK Ph.D. Nuclear Engineering	X		X		X						X	
ALFRED MOWERY Ph.D. Physics					X						X	
NUS												
BART BARTRAM M.S. Mechanical Engineering M.S. Physics	X		X		X						X	
RICHARD ENGLEHART Ph.D. Nuclear Engineering					X						X	

6. AGENCIES AND INDIVIDUALS CONSULTED

This Draft Environmental Impact Statement (DEIS) will be 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 will be considered during the preparation of the Final EIS.

In scoping this EIS, NASA has actively solicited comments from a wide group of interested parties. NASA views this process as an opportunity to get inputs from groups of individuals having differing viewpoints concerning the launch of the Ulysses spacecraft and to incorporate any subjects that may have been inadvertently missed during NASA's internal planning for the EIS. In addition to the publication in the Federal Register (54FR 48168) of a Notice of Intent (NOI), as required under the National Environmental Policy Act (NEPA), NASA mailed copies of the NOI to agencies and organizations which may have interest in environmental impacts and alternatives associated with the Ulysses mission. Comments will be solicited from the following:

Federal Agencies:

- Council on Environmental Quality
- Federal Emergency Management Agency
- National Academy of Sciences
- 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
- Intergovernmental Coordination--Office of the Governor of California
- State of Florida, Office of the Governor
- State of New Mexico
- State of California

Local Agencies:

- Brevard County: Board of Commissioners
  - Economic Development Council
  - Planning and Zoning Department
- Canaveral Port Authority
- Cape Canaveral, City of
- Cocoa, City of
- Titusville, City of

Organizations:

- Air Pollution Control Association
- Brevardians for Peace and Justice
- Center for Law and Social Policy
- Christic Institute
- Citizens for Peace in Space
- Citizens to Stop Plutonium in Space
- Common Cause
- Concern, Inc.
- 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 Audubon Society
- National Mobilization for Survival
- 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, Florida Chapter
- The American Association for the Advancement of Science
- The Committee to Bridge the Gap
- The Planetary Society
- The Union of Concerned Scientists
- Women's International Coalition to Stop Making Radioactive Waste

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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
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
uCi	micro Curies
ug/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 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 (NASA 1988c). 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.

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

* Indicates scenario potentially resulting in release of RTG fuel.

TABLE B-2. MISSION ACCIDENT PROBABILITIES

PHASE 0 PRE-LAUNCH/LAUNCH	PHASE 1 FIRST STAGE ASCENT	PHASE 2 SECOND STAGE ASCENT	PHASE 3 ON-ORBIT	PHASE 4 PAYLOAD DEPLOY
INADVERTENT RSS DESTRUCT 6.32×10^{-9}	SRB FAILURES 3.80×10^{-3}	ORBITER FAILURES 2.37×10^{-4}	ORBITER FAILURE & REENTRY 1.58×10^{-4}	IUS SRM CASE BURST 2.89×10^{-3}
FIRE/EXPLOSION 1.79×10^{-4}	RSS DESTRUCT 1.51×10^{-6}	ET FAILURES 1.9×10^{-5}		OTHER IUS FAILURES & REENTRY 1.48×10^{-2}
	AFT COMPARTMENT EXPLOSION 3.95×10^{-4}	SSME FAILURES 1.23×10^{-3}		
		PAYLOAD FAILURES 2.40×10^{-5}		
	VEHICLE BREAK-UP 8.98×10^{-5}	RSS DESTRUCT 1.58×10^{-6}		
	CRASH LANDING 3.79×10^{-6}	CRASH LANDING 8.85×10^{-6}		
	OCEAN DITCH 7.21×10^{-5}	OCEAN DITCH 1.68×10^{-4}		

Source: DOE 1990b

B.2 ACCIDENT SCENARIOS

This section summarizes information contained in the Accident Analysis document of the DOE Safety Status Report for the Ulysses mission (DOE 1990b).

Accident scenarios and environments by mission phase (from NASA 1988, and as described in DOE 1990b) 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 Safety Status Report (DOE 1990a, DOE 1990b, DOE 1990c).

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. If the RTG impacts rock or a similar hard surface during the African overfly portion of this phase (5.5 seconds of the entire 404 second Phase 2), the impact shell could be damaged and a small amount of fuel released.

Non-catastrophic shutdown of one or more SSMEs during this phase can lead to a variety of intact or contingency abort modes. The TAL abort mode is used if a SSME shutdown places the vehicle beyond the trajectory limits of a RTLS abort yet prior to attaining an AOA or ATO capability. After selection of this abort mode, the vehicle will continue to accelerate downrange to the TAL MECO target. After ET separation, the onboard computers are loaded with the entry flight software, and the Orbiter glides to the designated landing site. Tentative TAL sites for the Ulysses mission are:

- Primary - Ben Guerir, Morocco
- Alternates - Moron, Spain
  - Dakar, Senegal
  - Zaragosa, Spain
  - Banjeel, Gambia.

If a SSME shutdown occurs after the vehicle exceeds the parameters for a TAL, the Shuttle will attempt to reach the nominal MECO target. A combination of orbital maneuvering system (OMS) engine burns and propellant dumps can be performed to increase powered flight performance. After MECO, the OMS fuel, vehicle velocity, and velocity required for orbit are evaluated. If performance margins do not exist for orbit insertion and a subsequent deorbit, an AOA maneuver will be performed with the OMS engines. The following AOA landing sites have been identified for NSTS-34:

- Primary - Edwards Air Force Base, California
- Alternate - White Sands Space Harbor, New Mexico
- Alternate - Kennedy Space Center, Florida.

An ATO generally involves loss of propulsion late in the ascent where the vehicle velocity is adequate to achieve a safe, yet lower than planned orbit. Since the Shuttle must achieve a specified orbit to perform the initial conditions for IUS injection, it is likely that an ATO will result in transition to an AFO.

Contingency abort conditions are defined when two SSMEs fail prior to single engine TAL capability, or when three engines fail prior to achieving an AOA capability. These events would result in a crew bailout and subsequent ocean ditch of the Orbiter. There is a possibility of performing an RTLS abort if two or three main engines fail within 20 seconds after launch, or a TAL, if three engines fail during the last 30 seconds of powered flight. However, during the remainder of the ascent phase, two or three main engine failures result in a contingency abort scenario.

Phase 3 Accident Scenarios [1st Orbital Maneuvering System Burn to IUS/Propulsion 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 (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 RTG impact rock or a similar hard surface, a small amount of fuel could be released.

B.3 ACCIDENT ENVIRONMENTS

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

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).

<u>Pre- and Early-Flight Ground Pool Explosions</u>

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 fuel 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 of at least 4,360°F, almost 400 degrees greater than expected in the peak fireball (experimental data = 4,000°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 up to 177 fps and concrete up to 213 fps, 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 THE DOE SAFETY STATUS REPORT RISK ANALYSES FOR THE ULYSSES MISSION

APPENDIX C

SUMMARY OF THE DOE SAFETY STATUS REPORT RISK ANALYSES FOR THE ULYSSES MISSION

C.1 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 that analysis in a Final Safety Analysis Report (FSAR). The elements of the analysis and the information flow are summarized in Figure C-1. For the Ulysses mission, work on the FSAR is underway but not yet complete. Therefore, the DOE has prepared a Safety Status Report (DOE 1990a, DOE 1990b, DOE 1990c) to provide the basic safety data used in this Draft (Tier 2) Environmental Impact Statement (DEIS). The information flow illustrated in Figure C-1 is the same as that utilized in developing the Safety Status Report. 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 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 the DOE Safety Status Report (DOE 1990b, DOE 1990c), which forms the basis for the evaluation of radiological consequences found in Chapter 4 of the Ulysses DEIS.

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 (see Appendix B, Table B-1).

C.2 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 Safety Status Report (DOE 1990b) 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 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 model directs the calculations to arrive

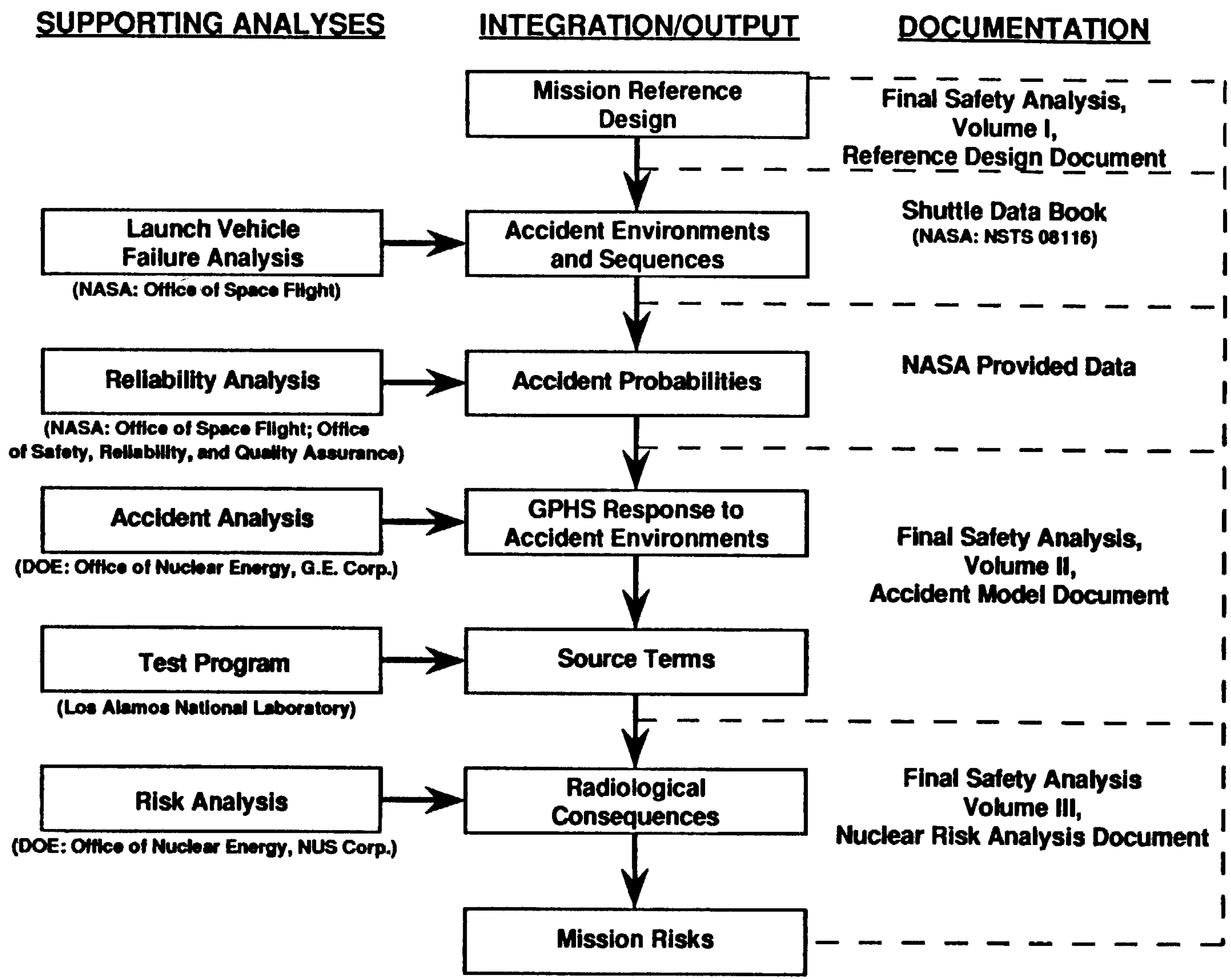

FIGURE C-1. FINAL SAFETY ANALYSIS REPORT DEVELOPMENT PROCESS ultimately at fueled clad distortion and quantification of fuel release if it is found to occur. LASEP-3 was developed specifically for the Ulysses safety analysis, utilizing the LASEP-2 program developed for the Galileo analysis (DOE 1988a, 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.

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 Analysis document of the Safety Status Report (DOE 1990b)].

LASEP-3 Model

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 Safety Status Report (DOE 1990a, DOE 1990b, DOE 1990c).

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 folded into 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 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 and at what altitude. 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 Analysis document of the Safety Status Report (DOE 1990b) 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 mechanism (in-air fragment; GPHS module impacts on steel, concrete, or sand; and fueled clad impacts on steel, concrete, or sand).

Source terms resulting from accidents in Phases 2, 3, and 4 associated with GPHS modules hitting rock were estimated on the basis of test data.

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.2.1 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.2.2 PHASE 1 SOURCE TERMS

The Monte Carlo runs for the Phase 1 SRB case rupture scenario were treated differently than the other accident scenarios. The National Aeronautics and Space Administration (NASA)-supplied failure probabilities (NASA 1988b) indicated that the conditional probability of a random SRB failure varied over six different periods in Phase 1: 0-10 seconds, 11-20 seconds, 21-70 seconds, 71-105 seconds, 106-120 seconds, and 121-128 seconds. (A conditional probability is defined as the probability of a particular event occurring, given a defined set of precursor events happening.)

The 121-128 second interval has a conditional probability of zero for a case rupture because 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.

Thus 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 are thus the principle 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. The particle size distributions which are the basis for these cases are summarized in the risk analysis volume of the Safety Status Report (DOE 1990c).

A more detailed discussion of the particle size considerations is presented in Appendix D to the Risk Analysis document of the Safety Status Report (DOE 1990c). The results of this analysis 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.2.3 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. The RTG or GPHS modules will impact only the ocean during Phase 2, except for a 5.5 second period when the ground-track of the vehicle crosses the African continent (i.e., 5.5 seconds out of the total 404 second duration of Phase 2).

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 18 GPHS modules in the RTG are assumed to each reenter and impact the Earth's surface independently of each other over a large area of the impact band. Based upon the reentry analysis performed for the Ulysses Safety Status Report (see DOE 1990b, 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.

C.3 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.

For the purposes of the Risk Analysis document of the Safety Status Report (DOE 1990c), the original LASEP-3 runs from the accident modeling volume were utilized to develop the average source terms for radiological consequence analyses on the basis of configuration of the release (i.e., in the fireball, at ground-level, in the air). Thus, the source terms within a given LASEP-3 run were not modified or changed, but reaggregated by transport mechanism for use in the dispersion analyses used to develop individual and population exposures (doses) to the given accident release. The embedded probabilities for impact on rock found in Phases 2, 3, and 4 source terms were separated out for the development of the average source terms to be used in the radiological consequence analyses. The reaggregated average source terms to be used in the radiological consequences analyses are listed in Table C-1.

It should be noted that the Phase 1 RSS destruct scenario analyses yielded release probabilities on the order of 10^{-10} (1 in 10 billion) to 10^{-11} (1 in 100 billion) or about 1,000 times less probable than the SRB case rupture 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

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

PHASE	Time Period(Sec)	Probability: Initiating	Probability: Conditional	Probability: Total	Maximum Source Term(Ci): Fireball	Maximum Source Term(Ci): Ground Level	Maximum Source Term(Ci): Altitude	Maximum Source Term(Ci): At Altitude(ft)
1 (SRB Case Rupture)	0- 10	5.10×10^{-4} (1 in 2,000)	1.60×10^{-4} (1 in 6,000)	8.16×10^{-8} (1 in 12 million)	288	0.283	-	-
	11- 20	1.28×10^{-4} (1 in 8,000)	1.50×10^{-4} (1 in 6,750)	1.92×10^{-8} (1 in 52 million)	-	17.7	34.9	2,260
	21- 70	2.41×10^{-4} (1 in 4,000)	2.00×10^{-5} (1 in 50,000)	4.82×10^{-9} (1 in 207 million)	-	-	23.5	12,195
	71-105	9.91×10^{-5} (1 in 10,000)	8.00×10^{-5} (1 in 12,500)	7.93×10^{-9} (1 in 126 million)	-	-	69.8	97,396
	106-120	4.25×10^{-5} (1 in 24,000)	1.50×10^{-3} (1 in 670)	6.38×10^{-8} (1 in 16 million)	-	-	684	121,052
	0-120[a]	-	-	1.77×10^{-7} (1 in 6 million)	132	2.05	254	48,478
2	-	1.51×10^{-3} (1 in 660)	1.53×10^{-3} (1 in 650)	2.31×10^{-6} (1 in 433,000)	-	0.834	-	-
3	-	1.58×10^{-4} (1 in 6,300)	3.90×10^{-2} (1 in 25)	6.16×10^{-6} (1 in 162,000)	-	0.477	-	-
4	-	6.16×10^{-3} (1 in 160)	3.90×10^{-2} (1 in 25)	2.40×10^{-4} (1 in 4,200)	-	0.477	-	-

Source: DOE 1990c

(a) This represents an expectation source term reflecting all of Phase 1, determined by probability weighting the average source terms for each time period; developed from subphase values presented in DOE (1990c).

average population densities from the worldwide demographic data base for the affected area, and time-independent median meteorological conditions utilzing the EMERGE model.

Key features and assumptions of the analysis are summarized below. Details of the methodology are presented in the Risk Analysis document of the Safety Status Report (DOE 1990c).

The reaggregated 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 (assuming involvement of the full load of External Tank propellant) 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 calculated from the average source terms utilizing the 50th percentile data set to define the Base Case consequences associated with each phase and sub-phase of the Ulysses mission.

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).

In presenting population doses, the concept of de minimis has been used, meaning a dose level below regulatory concern and from which negligible health effects are expected. De minimis, as a concept in determining the risk from exposure to ionizing radiation, remains a controversial topic within the regulatory as well as in the scientific community. The Council on Environmental Quality has been following the issue for some time; however, it presently offers no guidance on either the approach to de minimis or the levels of "de minimis risk." While EPA appears to be moving toward proposing a "below regulatory concern" (de minimis) level for individual dose, it has not yet supported the concept for collective doses. The National Council on Radiation Protection and Measurement in 1987 established a "Negligible Individual Risk Level" of 1 in 10 million annual risk, which corresponds to a dose rate of 1 mrem/yr applicable to truncation of collective dose estimates (NCRPM 1987a). For the purpose of this document, the de minimis dose was taken to be 1 mrem/yr and 50 mrem total dose commitment. It should be noted that these values are considerably below the average U.S. individual's exposure to natural background radiation: 360 mrem/yr; 18,000 mrem over a 50-year period (NCRPM 1987b). Total population doses are reported both with and without de minimis.

The assumptions and 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.4 RADIOLOGICAL CONSEQUENCE RESULTS

The results of the radiological consequence analysis for the Base Case are summarized in Table C-2. Reference should be made to Table C-1 in relating accident fuel release scenarios and radiological consequences. Table C-3 provides a list of doses experienced in everyday life from common sources, for purposes of comparison.

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.

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.

   (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 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. The collective dose above de minimis is based upon the dose to individuals that is greater than 1 mrem/yr, i.e., the de minimis level.)

TABLE C-2. BASE CASE RADIOLOGICAL CONSEQUENCES

Phase	Time Period(Sec)	Total Probability	Maximum Individual Dose(rem)	Collective Dose (Person-rem) Total	Collective Dose (Person-rem) Above De Minimis	Dry Land Area Within Which Dose Level Exceeded [km^2(mi^2)] 100 mrem/yr	25 mrem/yr	10 mrem/yr	AREA EXCEEDING 0.2 $\mu Ci/m^2$ [area in km^2(mi^2)] INLAND	OCEAN
1	0- 10	8.16×10^{-8}	3.54×10^{-3}	5.93×10^{1}	-	0	0	0	25.7 (10)	-
(SRB Case Rupture)	11- 20	1.92×10^{-8}	3.22×10^{-3}	1.78×10^{1}	-	0	0	0	3.0 (1.2)	-
	21- 70	4.82×10^{-9}	8.73×10^{-4}	1.06×10^{0}	-	0	0	0	4.3 (1.6)	-
	71-105	7.93×10^{-9}	3.07×10^{-8}	1.01×10^{2}	-	0	0	0	-	15.8(6.1)
	106-120	6.38×10^{-8}	1.76×10^{-7}	5.79×10^{2}	-	0	0	0	-	5.57(2.2)
	0-120[a]	1.77×10^{-7}	2.01×10^{-3}	2.42×10^{2}	-	0	0	0	12.3 (4.7)	20.7(8)
2	-	2.31×10^{-6}	2.00×10^{-2}	1.57×10^{-1}	2.71×10^{-2}	0	0	0	-	-
3	-	6.16×10^{-6}	3.62×10^{-2}	5.29×10^{-1}	1.64×10^{-1}	0	0	0	-	-
4	-	2.4×10^{-4} (1 in 4,200)	3.62×10^{-2}	5.29×10^{-1}	1.64×10^{-1}	0	0	0	-	-

Source: DOE 1990c

a - This represents the expectation of all Phase 1 consequences determined by probability weighting the average source terms from each time period; developed from subphase values presented in DOE (1990c).

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

	Dose Equivalent[a]	Effective Dose Equivalent	
Source	mrem	mrem	% 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.

3. Estimates of the dry land area affected within which the annual dose level would exceed 10, 25, and 100 mrem per year at the second year after the accident, assuming no cleanup or other remedial activities have taken place. At this point, the weathering process slows greatly as does the delivery of dose from contaminated soil. It is over these first years when administrative controls can be very effective in controlling human exposure. The estimation of these areas at the second year is consistent with draft EPA guidance which indicates that cleanup actions would occur over the period of 1 to 50 years following an accident (EPA 1988).

4. Land areas on which initial deposition would exceed the screening level of 0.2 $\mu Ci/m^2$ suggested by the EPA, as a level below which no further consideration need be given, has been used (EPA 1977). The ocean area contaminated at this level has been included only as an indication of the areas that could be affected by deposition.

Table C-2 presents for the Base Case, the total probability of a release by mission phase, and within Phase 1, by sub-phase or time interval. Expectation values of all Phase 1 consequences are also included. (The expectation values are determined by probability weighting the average source terms for each time period.) In Phase 1, for example, an SRB case rupture during the first 10 seconds of the phase is predicted to result in a release of 288 Curies into the fireball and 0.283 Curies at ground level (Table C-1), with a total probability of release of 8.16×10^{-8}. As noted in Table C-2, that source term would result in a maximum individual dose of 3.54×10^{-3} rem (3.54 mrem), with a total collective dose to the exposed population of 5.93×10^{1} person-rem (59.3 person-rem), with 0 person-rem above de minimis. A total land area of about 10 mi^2 (25.7 km^2) would be subject to deposition at levels exceeding the 0.2 $\mu Ci/m^2$ screening level. Within the dry land area affected by deposition, the deposition would not be sufficient for the resulting annual dose to exceed 25 mrem/yr or even 10 mrem/yr at the second year following such an accident.

Looking at Phase 1 overall, the expectation source term (388.05 Ci total) has a total release probability of 1.77×10^{-7} (Table C-1). As noted in Table C-2, the expectation release would result in a maximum individual dose of 2×10^{-5} rem (0.02 mrem). Land area contamination would extend over about 4.7 mi^2 (12.3 km^2), with none of that area exceeding a dose level of 25 mrem/yr (or even 10 mrem/yr) at the second year following the accidental release.

Only in Phases 2, 3, and 4 would any of the Base Case accident scenarios result in any collective dose above de minimis (Table C-2).

The Base Case analyses for Phases 2, 3, and 4 yielded maximum individual doses ranging from 2.00×10^{-2} rem (20 mrem) in Phase 2 to 3.62×10^{-2} rem (36.2 mrem) in Phases 3 and 4. Deposition exceeding the 0.2 $\mu Ci/m^2$ screening level would be very localized to small areas in Phases 2, 3, and 4. None of the scenarios resulted in dry land deposition sufficient to yield doses exceeding 25 mrem/yr or even 10 mrem at the second year following the accident.

Collective dose for the Base Case thus ranges from 579 person-rem in a late Phase 1 SRB case rupture accident to 0.157 person-rem for Phase 2.

For the purposes of comparing the accident consequences and the release probabilities from a Ulysses mission accident as estimated in the Safety Status Report (DOE 1990a, DOE 1990b, DOE 1990c), 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.

Representative radiological consequences of accident scenarios were presented in Section C.4 in terms of the Base Case using average source terms, 50th percentile meteorological conditions, and a set of pathway parameter values and assumptions representing central estimates. Variations about the Base Case results reflecting the source term distribution, the range of meteorological conditions, and possible variations in parameter values and assumptions affecting radiological consequences have been characterized through an integrated risk analysis. The analysis combines the output of the entire source term distribution from LASEP-3 and the EMERGE results for the 40 meteorological data sets using Monte Carlo techniques to arrive at a probability distribution of radiological consequences in terms of 5th, 50th, and 95th percentile and mean values. In addition, variations in possible parameter values, assumptions, and initiating accident probabilities affecting the results are also included in the Monte Carlo sampling.

The overall approach taken in the integrated risk analysis consists of the following elements:

- Identification of important parameters, conditions, or assumptions affecting the final results (collective dose, health effects, and area contaminated).
- For each of the above, establish a range of variability in the values used in the development of the radiological consequences and the probability distribution of those values within the range.
- Establish the functional relationship among all important parameters, conditions, and assumptions leading to the final result (e.g. collective dose, health effects, and area contaminated). These are usually multiplicative or additive relationships.
- Combine the probability distributions of all the areas of variability using a Monte Carlo approach to determine an overall probability distribution on the final results. The final results can then be presented along with 5th and 95th percentile values determined from the overall probability distribution.

The integrated risk analysis was implemented using the Monte Carlo techniques provided in the SPASM computer code to evaluate the variation of important parameters or conditions on the radiological consequences and

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

Accident Type	Number of Fatal Accidents for 1987	Approximate Individual Risk Per Year[c]
Motor Vehicle	48,290	2 in 10 thousand
Falls	11,733	5 in 100 thousand
Drowning	4,360	2 in 100 thousand
Fires and Flames	4,710	2 in 100 thousand
Poison	5,315	2 in 100 thousand
Water Transport	949	4 in 1 million
Air Travel	1,263	5 in 1 million
Manufacturing[d]	1,200	5 in 1 million
Railway	624	5 in 2 million
Electrocution	760	6 in 2 million
Lightning	99	4 in 10 million
Tornadoes[b]	114[b]	5 in 10 million
Hurricanes[b]	46[b]	2 in 10 million
Suicide	30,796	12 in 100 thousand
Homicide and Legal Intervention (Executions)	21,103	9 in 100 thousand
Guns, Firearms, and Explosives	1,656	7 in 1 million
Suffocation	3,688	3 in 200 thousand
All Accidents	95,020	4 in 10 thousand
Diseases	1,993,381	8 in 1 thousand
ALL CAUSES	2,123,323	9 in 1 thousand

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

mission risks. The SPASM code is a general purpose Monte Carlo simulation code that propagates variabilities. A total of 15,000 trials for each run were utilized in developing the uncertainties that can be expected in the radiological consequence results.

Important parameters or conditions affecting the radiological consequences and mission risks include the following:

- 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.

Potential variation in these parameters or conditions and their effect on the radiological consequences and mission risks are evaluated in the integrated risk analysis.

A key aspect of the integrated risk analysis was to identify the areas of variability, establish the range for each parameter value, and the probability distribution within the associated range of results. The principal focus of the analysis was the calculation of variability in radiological consequences associated with the ranges of initiating accident probabilities provided by NASA (1988c), the ranges in the source terms calculated by LASEP-3 for the accident modeling volume of the Safety Status Report (DOE 1990b). The integrated risk analysis does not account for variability in LASEP-3 parameter assumptions in the model.

Two types of probability distributions are commonly used. If all values within the range are considered equally probable, then a flat-top distribution can be used. If a "best-estimate" value has been determined, the range of uncertainty can be represented as ± 2 standard deviations of a normal or log-normal distribution with the "best-estimate" treated as a mean or geometric mean, respectively. Other probability distributions can be generated using either actual data for the parameter value range, or by modeling the distribution through a sensitivity analysis.

Combining these ranges and probability distributions using the Monte Carlo techniques, the overall variations in the radiological consequences are combined with the Base Case results presented in Section 4 of the DEIS to estimate mission risks with 5th and 95th percentile bounds.

The risk of an event is defined as the product of the probability of that event and its consequences. The risk from a mission phase is the sum of the risks of the accident scenarios within the phase. Similarly, the mission risk is the sum of the risks of the phases. The results of the integrated risk analysis were used to estimate 5th, 50th, and 95th percentile and mean values of the calculated risk.

Table C-5 shows the results of the analysis described above. When less than one health effect (cancer death) is calculated for an event, then it is reasonable to interpret that result as zero. Nevertheless, there would be radiological impact involved in any accident releasing fuel, and the product of probability and consequence (collective dose or fractional health effect) gives a measure of non-lethal relative risks of the individual phases. It should be noted that for all phases and subphases, with the exception of the 106-120 second time period of Phase 1, even at the 95 percent of the time, an SRB case rupture accident at this point in the mission will yield less than 2.5 excess health effects in the exposed population (ignoring de minimis). Referring back to Table 4-6 of the DEIS, it is noted that the analysis resulted in no collective doses above de minimis for any mission phase. Thus, when de minimis is considered, no health effects would be expected.

TABLE C-5. SUMMARY MISSION NUCLEAR RISK ESTIMATE

Phase	Time Period (sec.)	Total Probability	Health Effects[b] Mean	Health Effects[b] 95th Percentile
1 (SRB Case Rupture)	0-10	8.16×10^{-8}	0.0955	0.2800
	11-20	1.92×10^{-8}	0.0203	0.0104
	21-70	4.82×10^{-9}	0.0016	0.0065
	71-105	7.93×10^{-9}	0.2096	0.7290
	105-120	6.38×10^{-8}	1.1670	3.0000
	0-120[a]	1.77×10^{-7}	0.4754	1.2400
2	-	2.31×10^{-6}	0.0002	0.000588
3	-	6.16×10^{-6}	0.0005	0.00136
4	-	2.40×10^{-4}	0.0005	0.00136

[a] This represents the expectation of all Phase 1 health effects, determined by probability weighting the values for each sub-period.

[b] Health effects calculated without de minimis.