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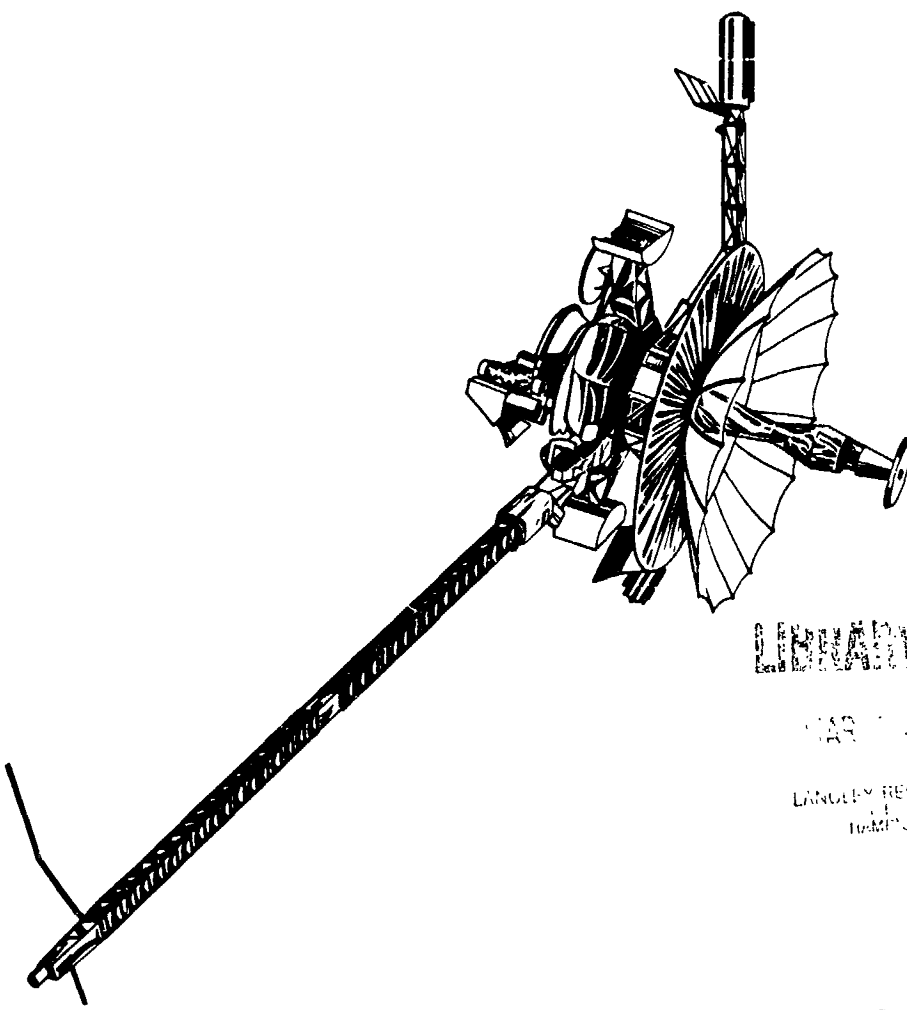
Draft Environmental Impact Statement for the Galileo Mission (Tier 2)



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

Office of Space Science and Applications
Solar System Exploration Division
Washington, D.C. 20546

December 1988

ABSTRACT

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This document is a draft Environmental Impact Statement (EIS) addressing the proposed action of completing the preparation and operation of the Galileo spacecraft, including its planned launch in October 1989, and the alternatives of: (1) delaying preparations in favor of a launch in 1991, and (2) cancelling further work on the mission. The delay alternative may enable consideration of an alternative launch configuration, the Titan IV/Inertial Upper Stage (IUS) expendable launch vehicle.

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), the Kennedy Space Center (NASA 1979), the Titan IV (USAF 1988a), and in the KSC Environmental Resources Document (NASA 1986) and the Galileo Tier 1 EIS (NASA 1988a). The environmental impacts of a normal launch were deemed acceptable. There also may be environmental impacts resulting from launch or mission accidents that could release plutonium fuel used in the Galileo power system. Intensive analysis of the possible accidents associated with the proposed action reveal small health or environmental risks. The results are largely the same under the delay option. There are no environmental impacts in the no-action alternative.

The remote possibility of possible environmental impacts of the proposed action must be weighed against the large adverse fiscal and programmatic impacts inherent in the delay and no-action alternatives.

The U.S. Air Force has notified NASA that a Titan IV launch vehicle will not be available for the May 1991 launch opportunity. Consequently, the Titan IV/IUS launch configuration is no longer a reasonable alternative to the STS/IUS configuration for the delay alternative discussed. The analysis of the Titan IV/IUS is, however, presented in an appendix to this EIS.

EXECUTIVE SUMMARY

The proposed action addressed by this draft Environmental Impact Statement (EIS) is the completion of preparation and operation of the Galileo spacecraft mission, including its planned launch on the Space Transportation System (STS) Shuttle in October 1989.

PURPOSE AND NEED FOR THE ACTION

The Galileo mission is part of the National Aeronautics and Space Administration's (NASA's) Solar System Exploration Program. The Galileo mission will study Jupiter, probe the Jovian planetary atmosphere, and study the four major moons and the planet's extended electromagnetic environment.

ALTERNATIVES CONSIDERED

The proposed action is the completion of preparation and operation of the Galileo mission, including its launch on the Space Shuttle in October 1989. The launch configuration, STS/IUS, will require a Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory, in which a Venus and two Earth flybys are required to provide sufficient velocity for the spacecraft to reach Jupiter.

Alternatives to the proposed action are:

- Delay completion of preparations in favor of a launch in May 1991 which enables consideration of the two launch configurations, the STS/IUS and the Titan IV/IUS. (As noted in the Abstract, the Titan IV/IUS is no longer considered a reasonable alternative to the STS/IUS.)

- No action; that is, terminate further commitment of resources to the mission.

ENVIRONMENTAL CONSEQUENCES

The principal 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), the Kennedy Space Center (NASA 1979), and the Final EIS for the Galileo and Ulysses Missions (NASA 1988a), and the KSC Environmental Resource Document (NASA 1986). The expected environmental consequences of Shuttle launches have not been found to be significant.

In the event of (1) an accident or mission abort during launch, or (2) reentry of the spacecraft from Earth orbit or during an Earth flyby, there are potential adverse health and environmental effects associated with the possible release of plutonium-238 from the spacecraft's Radioisotope Thermoelectric Generators (RTGs) and the Radioisotope Heater Units (RHUs). The potential effects considered in preparing this EIS include: risks of air and water quality impacts; local land area contamination by plutonium-238; 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 socio-economic impacts.

An intensive analysis of the proposed action indicates that the possible health and environmental consequences of launch or mission anomalies pose small risks. The accident estimated to be most probable would pose very small health risks and very small probability of detectable environmental contamination. The maximum credible accident (having a probability of one in 10 million) would be an accidental reentry into the Earth's atmosphere during a planned VEEGA flyby, releasing Pu238 upon impact with the ground. The very low probability "maximum case" would lead to an increase of an estimated 9.8 cancer fatalities over a 70-year period among a population of 83,000 persons, which normally would have an estimated 16,000 cancer fatalities over the same period.

Under the delay alternatives, the analysis of the Shuttle accidents still applies. While the Titan IV/IUS is no longer considered a reasonable alternative to the STS/IUS, the analysis of Titan IV/IUS mission accidents provided in Appendix C indicates that there are risks to human health and the environment similar to the Shuttle. The VEEGA analysis applies to both launch configurations.

There are no environmental consequences associated with the no-action alternative.

There are severe adverse fiscal and programmatic impacts attendant to the delay and no-action alternatives. As of October 1988, some $800 million has been expended on the Galileo mission. No further action would render that expenditure a sunk cost and entail a larger scientific loss in terms of personal effort and the scientific knowledge that would result from the mission. The delay alternative would imply additional costs of at least $4 million per month until the 1991 launch. These impacts must be weighed against the very small risks.

This mission specific EIS follows on a program-level EIS (NASA 1988a) and provides updated and more detailed information to support decision-making regarding the completion and operation of the Galileo mission. Launch approval follows a process set forth in NASA regulations that takes into account all mission specific and programmatic environmental, safety, and health factors.

The U.S. Air Force has notified NASA that a Titan IV/IUS launch vehicle will not be available for the May 1991 launch opportunity. Consequently, the Titan IV/IUS launch vehicle configuration is no longer a reasonable alternative to the STS/IUS configuration for the delay alternative discussed. Nevertheless, the data and analysis on the Titan IV/IUS are presented in an appendix to this document, and thus will be available for decision-makers.

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1. PURPOSE AND NEED FOR ACTION

1.1 BACKGROUND

The Galileo mission, as part of the National Aeronautics and Space Administration's (NASA's) Solar System Exploration Program, is designed to study Jupiter, its four major moons, and its extended electromagnetic environment.

This draft (Tier 2) Environmental Impact Statement (EIS) has been prepared to provide updated information necessary to support decision-making associated with completing preparations for and implementing the Galileo mission. The proposed action addressed in this EIS is to implement the Galileo mission in the 4th quarter of 1989 as presently planned, using the National Space Transportation System (STS) Shuttle with an Inertial Upper Stage (IUS) and a Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory. This document succeeds a program level final EIS (Tier 1) for the Galileo and Ulysses Missions (NASA 1988a).

The Galileo mission supports NASA's Solar System Exploration Program and its continuing responsibility to engage in the scientific exploration of the solar system using Earth-based observations, spacecraft, laboratory studies, and theoretical research. The goals of this Program are as follows:

1) To further the understanding of the origin and evolution of the Solar System

2) To further the understanding of the origin and evolution of life

3) To further the understanding of Earth by comparative studies of the other planets.

The Galileo mission has been designed to further these goals.

Solar system exploration consists generally of three phases: reconnaissance, exploration, and intensive study. These phases are characterized by missions as follows: reconnaissance using remote observations from fly-by missions such as Pioneers 10 and 11 (1973, 1974) and Voyagers 1 and 2 (1977); exploration generally involves orbiters such as Mariner IX and Galileo; and intensive study using landers such as the Apollo missions to the Moon and the Viking mission to Mars.

Development of the Galileo mission was started in October 1977 as the first step in the exploration phase studying the outer planets, Jupiter and beyond, which had been reconnoitered by the Pioneers and Voyagers. Implementation of the Galileo mission has been delayed because of the series of delays and changes in launch configuration (e.g., the Challenger accident and subsequent cancellation of the Shuttle-Centaur upper stage).

1.2 PURPOSE OF THE PROPOSED ACTION

The scientific objectives of the Galileo mission are to conduct comprehensive investigations of the Jovian planetary system by making measurements of the planet, its environment and its satellites. Jupiter is the largest and most massive planet in the solar system, and is unique in that it emits more energy than it receives. Together with its moons, the planet almost comprises a mini solar system. Close-up studies of the planet and its principal satellites will greatly extend the knowledge of the Jovian system and provide insights into the complex and analogous relationships existing between the Sun and its planetary system.

The Galileo objectives will be accomplished through two separate mission elements:

- An orbiter will tour and study the Planet and the Jovian satellites over a 20-month period

- A detachable atmospheric entry probe will descend through the atmosphere of Jupiter and during a period of roughly 1 hour will relay scientific measurements of the atmospheric profile to Earth via the orbiter.

The Galileo mission will be a study of the entire Jovian system, with scientific objectives that fall into three broad categories: (1) the structure and composition of Jupiter's atmosphere; (2) the composition and physical state of the four largest satellites of Jupiter; and (3) the structure, composition, and dynamics of the Jovian magnetosphere.

Previous missions to Jupiter have made only remote measurements of the Jovian atmosphere. Scientists believe that Jupiter is composed of the original material from which stars, and most specifically our Sun, are formed. The atmospheric entry probe should provide data, during a one-hour atmospheric descent period, on the Jovian atmospheric composition to a depth of 10 to 20 times the sea-level pressure on Earth. It is anticipated that this will include all the major cloud layers of the Jovian atmosphere. This will greatly enhance the present understanding of the Jovian atmosphere, and of planetary atmospheres in general. It may be possible to acquire knowledge of the conditions in the solar system at the time of planetary formation. The abundance of helium and rare gases in the Jovian atmosphere are important indicators of conditions in the early solar system and of how the giant planets kept their atmospheres. It is possible that the outer Jovian atmosphere is representative of the unmodified material that subsequently formed the Sun, the planets, and other solar system objects. Other information that will be obtained from the atmospheric entry probe includes the location and characterization of the Jovian clouds, an analysis of how solar energy is absorbed and the quantity of energy that is flowing out of Jupiter's still-cooling interior, a determination of lightning frequency, and a determination of whether or not small quantities of organic molecules are being created from methane and ammonia.

The 20-month period during which the orbiter will be obtaining information while in orbit around Jupiter will provide new information on the deep interior of Jupiter through measurements of the Jovian gravitational field.

The Jovian satellites will be investigated at ranges from 20 to 100 times closer than earlier missions, typically at ranges of 1,000 kilometers or less. This proximity will permit images of 20 meters resolution that are comparable to the Viking imagery of Mars. This increased resolution will result in new and detailed knowledge of the surfaces of the satellites, including interesting features such as the active volcanoes of Io, the innermost of the four Jovian satellites. It should be possible to determine the composition, temperature, and activity of Io's volcanic plumes and volcanic flows over the duration of the orbital investigations. In a manner similar to the investigation of the interior of Jupiter, gravitation data may determine whether Io has a completely molten core, as some theories suggest.

The Jovian magnetosphere is the region of space under the dominant influence of Jupiter's magnetic field. It is an immense structure that, if visible from Earth, would appear several times larger than the full moon. The results of brief flyby measurements of four previous spacecraft have determined that the Jovian magnetosphere is much more complex and dynamic than had been anticipated from Earth-based measurements and theoretical extrapolations from the Earth's magnetosphere. The outer regions of the Jovian magnetosphere expand and contract by millions of kilometers in response to solar wind and internal forces. (The solar wind comprises the magnetic fields, protons (hydrogen nuclei), electrons, and ions of other elements from the Sun.) The inner regions of the Jovian magnetosphere are influenced by Jupiter's rapid spin (one revolution each 10 hours) and by the large quantities of sulfur and oxygen atoms emanating from Io. Jupiter also is a "laboratory" for studying phenomena applicable to other astrophysical objects and to processes of ionized gases in general. The Galileo mission will explore these phenomena with new and more sophisticated instrumentation. Furthermore, the investigations of this dynamic environment will extend over nearly two years. New regions of the outer magnetosphere will be explored, as well as repeated penetrations into the inner regions. The mission will include at least one long orbit into the "magnetotail," a distended, cone-shaped region formed as the solar wind sweeps the magnetic field back away from the planet. This mission will provide the results of measurements which, in detail and specificity, can not conceivably be made from Earth or from Earth orbit.

During its journey to Jupiter, Galileo will perform additional observations of the planet Venus, the Earth/Moon system, and a flyby with one or possibly two asteroids. The specific launch date within the Galileo launch window will determine if flybys with both asteroids Gaspra and Ida are possible. These additional planetary data collection opportunities fully exploit the science return possibilities of the Galileo mission.

1.3 NEED FOR THE ACTION

It is vital, at this stage of planetary science, to get in-situ measurements of the planet Jupiter and its satellites. For instance, the atmospheric probe will return data on the composition, temperature and pressure of the atmosphere that can be attained by no other means. So, even though scientists will continue to study Jupiter from Earth orbit and ground based telescopes, the in-situ data from the Galileo mission will provide otherwise unattainable data to anchor those complementary investigations.

The Galileo mission can be launched only during specific periods in any given decade depending on the position of the planets and the capability of available launch vehicles. Presently, the first available launch opportunity for Galileo occurs during October/November 1989; the next feasible opportunity does not occur until May 1991. The proposed action is needed to implement the mission at the earliest available opportunity.

2. ALTERNATIVES INCLUDING THE PROPOSED ACTION

This draft (Tier 2) Environmental Impact Statement (EIS) addresses the potential environmental impacts associated with the completion of preparations and implementation of the Galileo mission, including its planned launch in October 1989, and alternatives to the proposed action.

2.1 ALTERNATIVES CONSIDERED

This EIS considers the following alternatives:

- Proposed Action: completion of preparation and operation of the mission, including its planned launch on the National Space Transportation System/Inertial Upper Stage (STS/IUS) vehicle in October 1989.

- Delay Alternative: delay preparations in favor of a launch in 1991, which possibly will enable consideration of two launch options - the STS/IUS and the Titan IV/IUS expendible launch configuration (see discussion on availability of Titan IV in Section 2.3.5).

- No-Action Alternative: cancel any further committing of resources to the mission.

2.2 DESCRIPTION OF THE PROPOSED ACTION TO PROCEED AS PLANNED WITH COMPLETION OF PREPARATIONS AND OPERATION OF THE GALILEO MISSION, INCLUDING ITS PLANNED LAUNCH IN OCTOBER 1989

2.2.1 Mission Design

No combination of launch vehicles presently available to NASA has the capability to place the Galileo spacecraft on a direct trajectory from Earth to Jupiter (NASA 1988a). Therefore, Galileo will first fly to Venus and then return to Earth for the first of two Earth flybys. These flybys allow the spacecraft to use the gravitational fields of Earth and Venus to gain sufficient velocity to proceed to Jupiter. Figure 2-1 illustrates the Galileo spacecraft's Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory.

After arriving at Jupiter, the orbiter will fly by the moon Io prior to orbiting Jupiter. The orbiter will conduct a study of Jupiter's atmosphere and the characteristics of the space environment surrounding Jupiter. The atmospheric entry probe, which is to be released prior to the arrival of the orbiter at Jupiter, will descend into Jupiter's atmosphere. During the descent, scientific measurements will be made to determine the structure and composition of Jupiter's atmosphere. The data will be relayed to Earth by the orbiter.

2.2.1.1 Launch Opportunity Considerations

The Galileo mission can be launched only during specific periods depending on the positions of the planets and the capabilities of available launch vehicles. Due to programmatic constraints associated with resumption of Shuttle operations, the first period for the launch of Galileo occurs

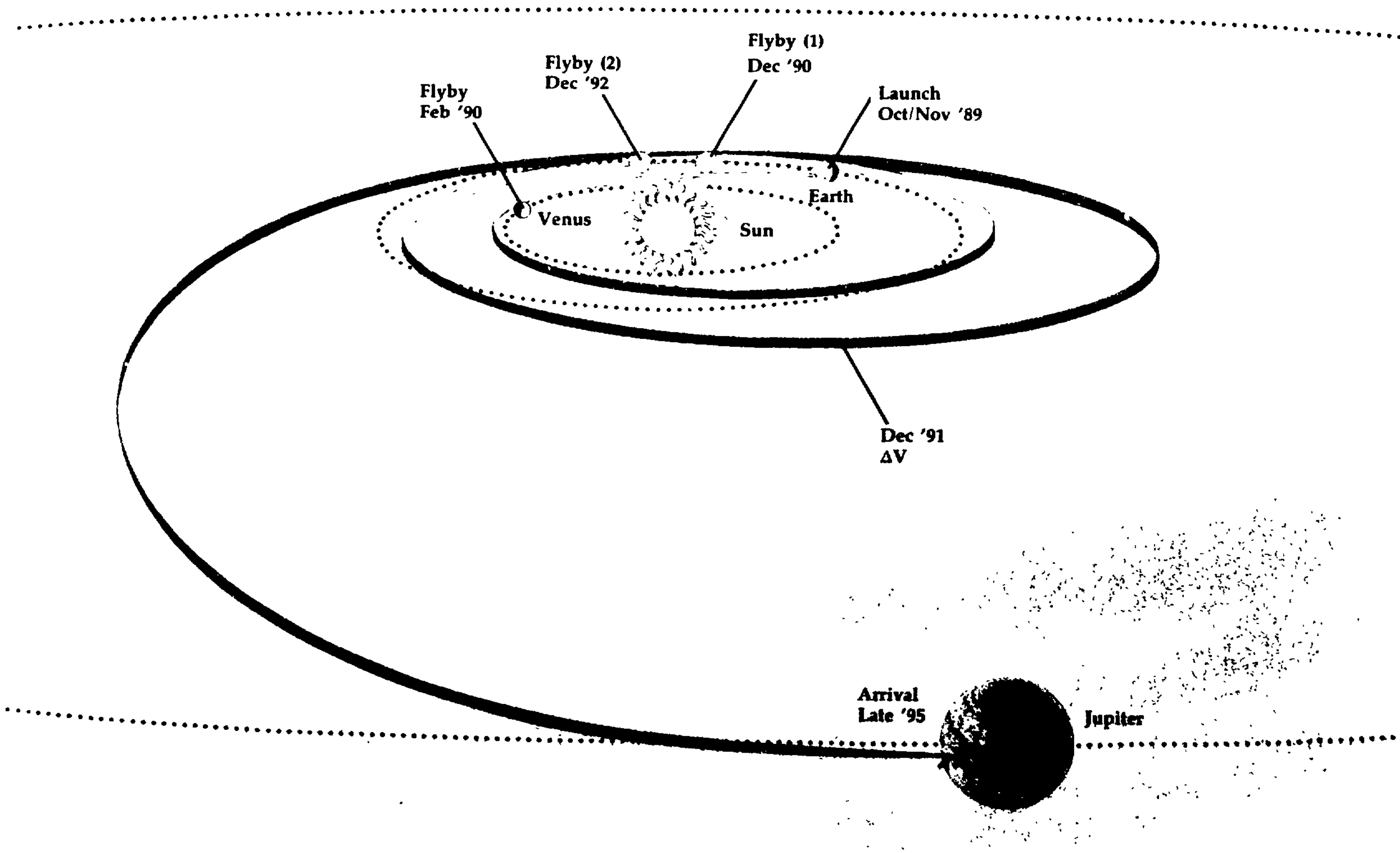

FIGURE 2-1. GALILEO SPACECRAFT TRAJECTORY, 1989 LAUNCH

during October/November 1989. After 1989, the next feasible launch period for Galileo occurs in May/June 1991. For each day of either the 1989 or 1991 period, the rotational position of the Earth limits the launch from a few minutes to an hour of each day.

2.2.1.2 Trajectory (VEEGA)

To gain the velocity required to reach Jupiter, the Galileo spacecraft will first execute a Venus gravity-assist flyby and then two Earth gravity-assist flybys. This trajectory is known as the Venus-Earth-Earth-Gravity-Assist, or VEEGA, trajectory. The VEEGA trajectory and an Earth avoidance analysis are addressed in the Tier I FEIS (NASA 1988a).

The trajectory design and navigation operations are being developed consistent with an Earth avoidance plan to bias the spacecraft's trajectory away from Earth between the time of launch and any Earth flyby. During the majority of Galileo's inner solar system journey, the spacecraft will follow a trajectory that, without any further maneuvers, would miss the Earth by at least several thousand kilometers. The spacecraft is placed on a trajectory passing through the required Earth flyby point only 25 days prior to each passage.

On the final approach to each Earth flyby, additional operational requirements are being imposed to further insure against inadvertent re-entry. Continuous tracking by the Deep Space Network is planned beginning 35 days prior to each flyby. Around-the-clock tracking and monitoring of the spacecraft provides near-real-time evidence of any spacecraft anomalies. During the period from the last spacecraft maneuver 10 days out through each Earth flyby, no commands will be sent to the spacecraft other than those deemed essential for maintaining vehicle operations such as solar pointing for thermal control -- the premise behind this requirement being that minimal spacecraft activity yields a minimum probability of occurrence of unplanned events. The Galileo Earth avoidance strategies result in a total probability of inadvertent re-entry during both Earth flybys of less than 5×10^{-7}. For a detailed VEEGA discussion, see Section 4.

2.2.2 Spacecraft Description

The Galileo spacecraft consists of an orbiter and an atmospheric entry probe and weighs approximately 6,000 pounds (see Figures 2-2 and 2-3). The spacecraft is spin-stabilized, but incorporates a separate section that does not spin. The "spun" part of the spacecraft spins at about three revolutions per minute to allow its instruments to "sweep" the sky continuously to make their measurements. The spinning part of the spacecraft contains communication antennas, the spacecraft propulsion and power subsystems, most of the electronics and communications equipment, and various science instruments. The non-spinning part of the spacecraft provides a stable platform for remote-sensing instruments which must be precisely pointed. The non-spinning part also accommodates the atmospheric entry probe and supporting electronics.

The spacecraft elements that are relevant to the assessment of potential environmental impacts are the two Radioisotope Thermoelectric

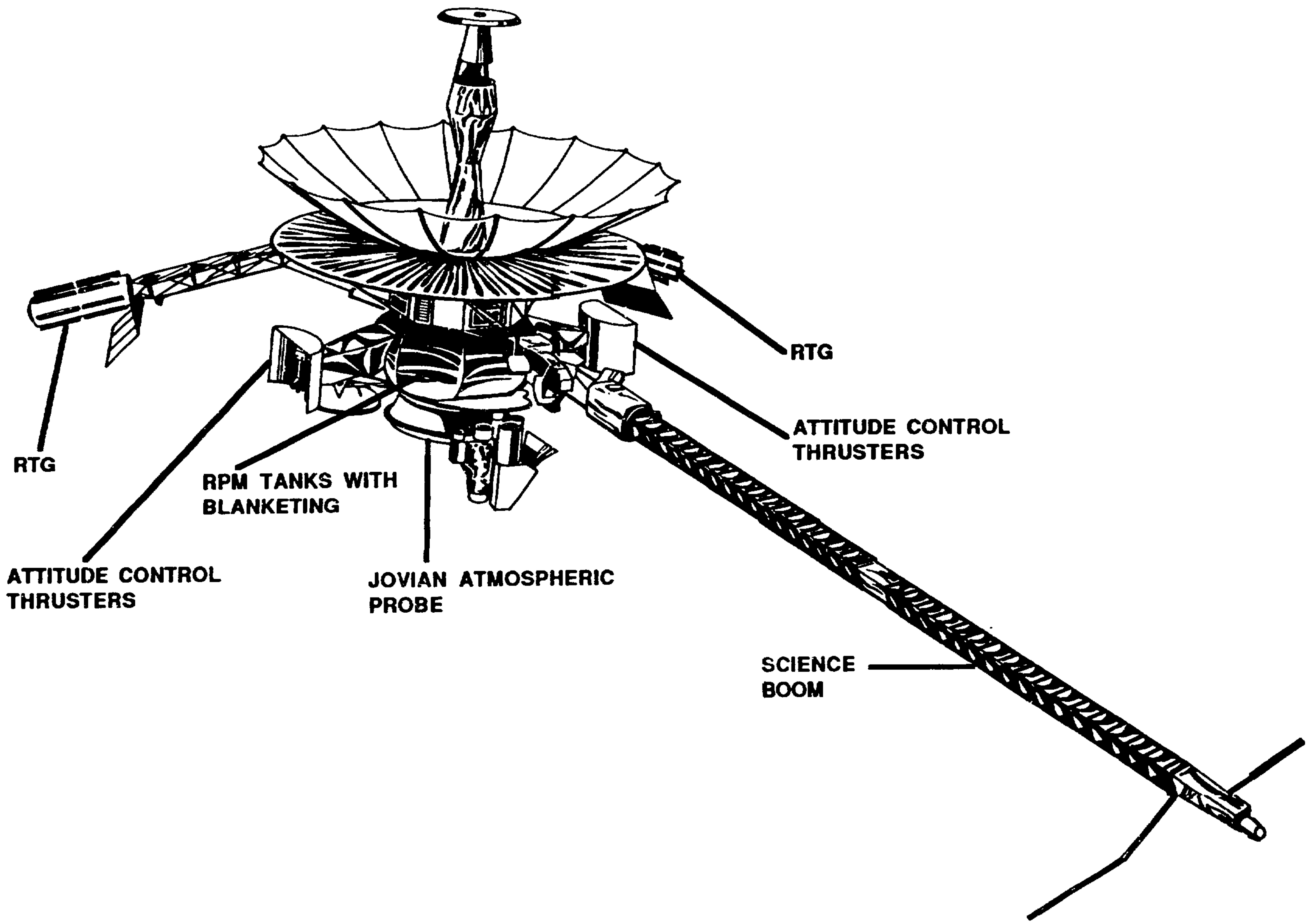

FIGURE 2-2. DIAGRAM OF GALILEO ORBITER

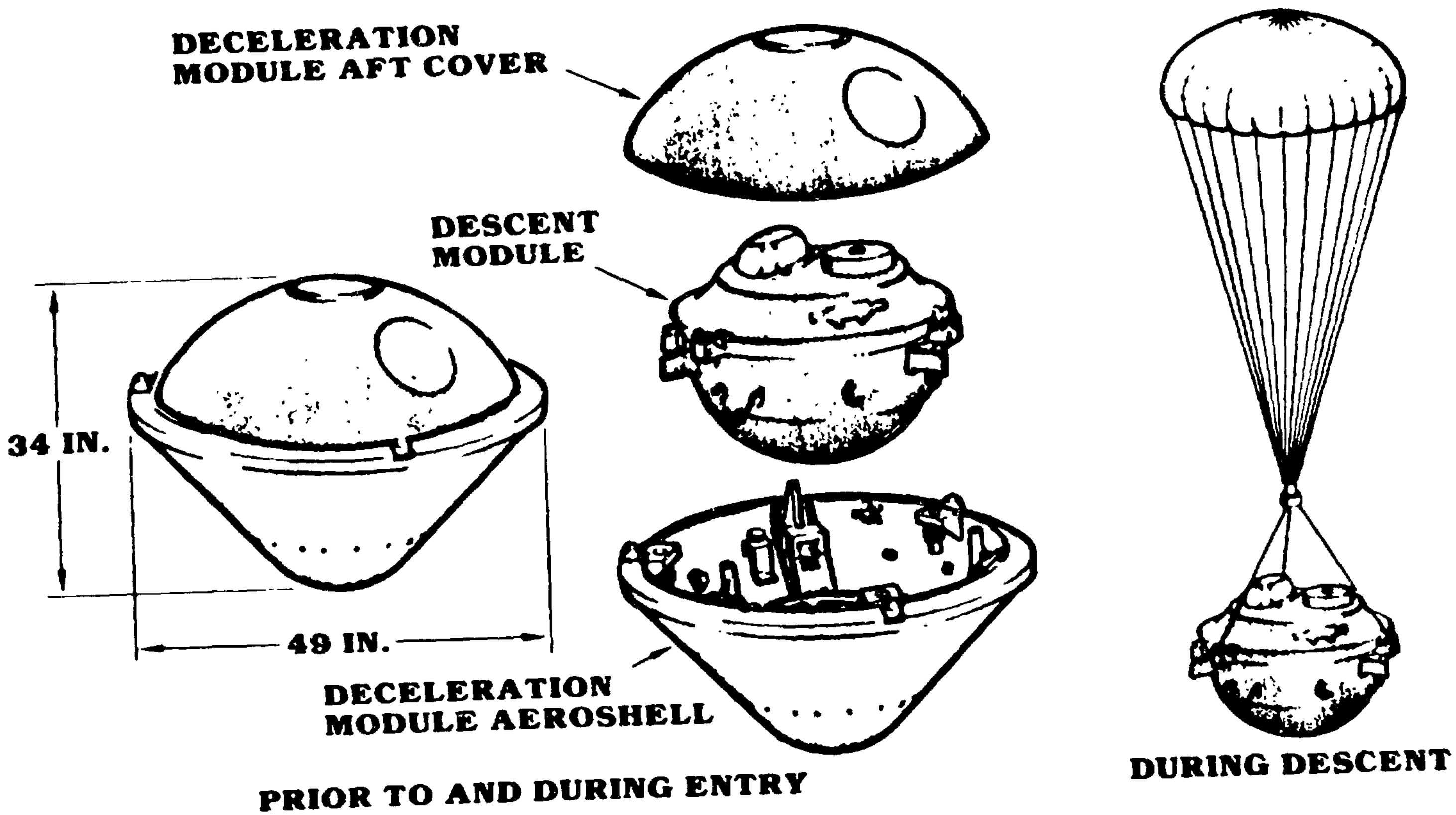

FIGURE 2-3. DIAGRAM OF GALILEO PROBE

Generators (RTGs) in the power subsystem, the Radioisotope Heater Units (RHUs) in the temperature control subsystem, and the propellants in the propulsion subsystem and the attitude control subsystem.

2.2.2.1 Power/Heat Sources

Radioisotope Thermoelectric Generators (RTGs)

A RTG (see Figure 2-4) is a device that converts the heat from the natural radioactive decay of plutonium-238 (a non-weapons grade of plutonium) to electricity for spacecraft instruments. RTGs have been used on 22 previous space missions, including some of NASA's most successful (e.g., Voyager, Pioneer, Viking, and all but the first of the manned Apollo landings on the Moon). The Galileo spacecraft will have two RTGs, each generating approximately 284 watts of electrical power.

The U.S. Department of Energy (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 (Bennett 1981). As indicated above, the dominant form of plutonium used in RTGs, plutonium-238 (see Table 2-1), is not the type used in nuclear weapons (i.e., plutonium-239).

An RTG consists of two major elements: (1) a heat source that contains the plutonium fuel and (2) a thermoelectric converter that converts heat to electricity. The heat source, referred to as the General Purpose Heat Source (GPHS) contains the plutonium-238 fuel in a stacked column of 18 individual modules. Each module consists of a graphite block that encases two graphite cylinders (see Figure 2-5). Each cylinder contains two pellets of plutonium-238 dioxide encased in iridium. In the event that the modules are released in a launch accident and fall back to Earth, the graphite block construction protects the module from burning-up in the atmosphere and releasing any plutonium. The graphite cylinders protect the plutonium pellets from impacts with the ground or debris. The iridium metal contains the fuel and provides an additional layer of protection.

Light-weight Radioisotope Heater Units (RHUs)

The Galileo spacecraft will use 131 light-weight RHUs to maintain portions of the orbiter/atmospheric entry probe temperature within acceptable limits, to minimize the use of electrical power for thermal control, and to reduce electromagnetic interference. Each RHU provides about one Watt of thermal power derived from the radioactive decay of 2.7 grams of plutonium-238. The plutonium (in the form of a plutonium dioxide pellet) of each RHU is contained within a platinum-rhodium alloy capsule. Similar to the RTGs, each RHU is encased in a graphite insulator surrounded by a graphite block to provide protection from atmospheric heating and ground or debris impact in the event of an accident (see Figure 2-6). The RHUs are designed to be lightweight units capable of containing the plutonium dioxide fuel in both normal operations and accidents. The locations of RHUs on the Galileo spacecraft are shown in Figure 2-7.

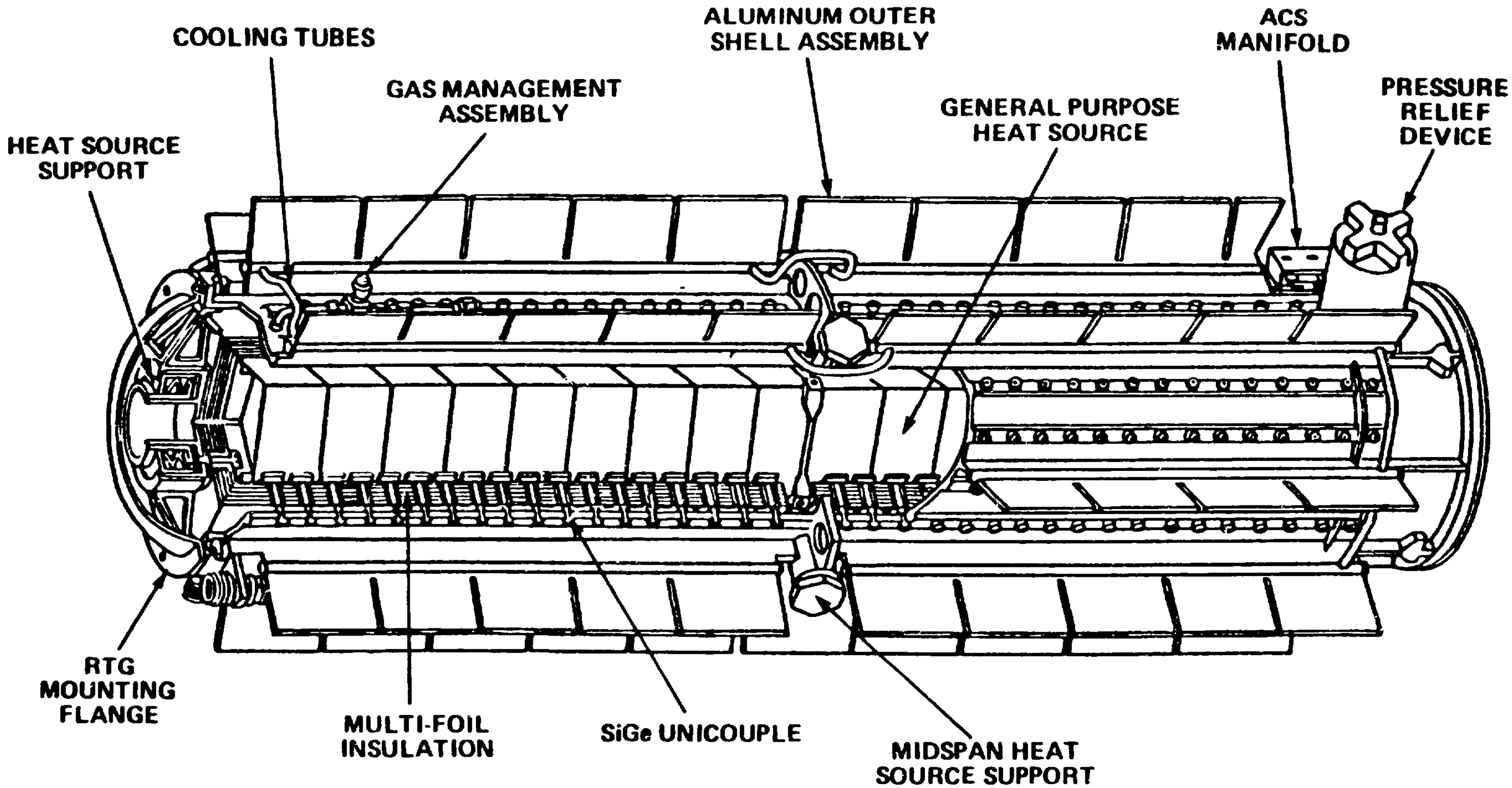

FIGURE 2-4. DIAGRAM OF RTG ASSEMBLY

TABLE 2-1. ISOTOPIC COMPOSITION OF RTG FUEL

Plutonium Isotope	Weight Percent at Manufacture	Half-Life (Years)	Radioactivity (Curies/gram of plutonium*)	Total Curies (11/89)
236	<10-6	2.85	532	<1
238	*83.880	87.7	17.1	**130,050
239	13.490	24,100	0.0621	80.2
240	1.900	6,560	0.227	41.3
241	0.379	14.4	103.2	2,650
242	0.124	376,000	0.00393	<1
Other TRU isotopes	0.228	---	---	3.3
TOTALS	100.00	---	---	132,825

*The radioisotope fuel is a mixture of plutonium dioxide (PuO_2) containing 83.5 % (plus or minus 1%) of Pu 238 (DOE 1988).

**Based on values from Table A-1 in DOE 1988.

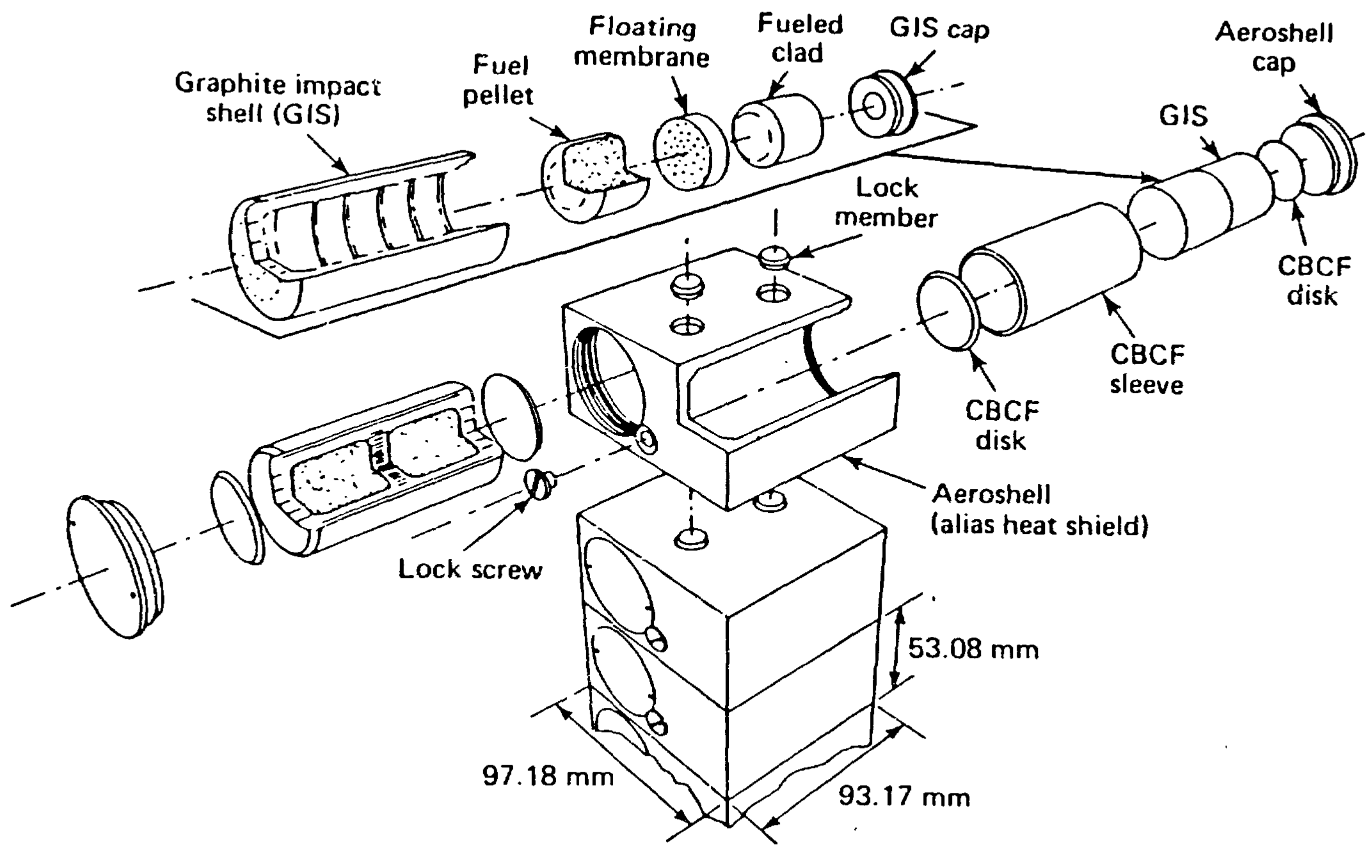

FIGURE 2-5. DIAGRAM OF GENERAL PURPOSE HEAT SOURCE RTG MODULE

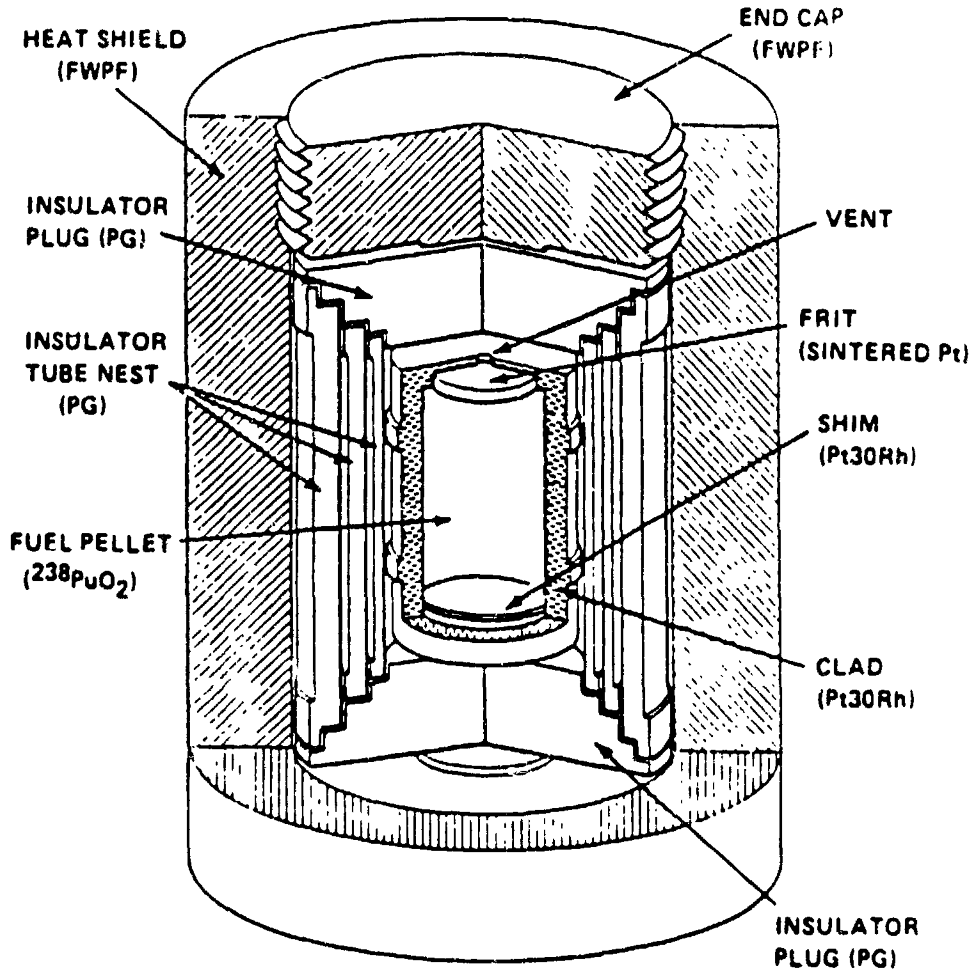

FIGURE 2-6. DIAGRAM OF RHU MODULE

The only alternative to the Galileo spacecraft RHUs would be the addition of another RTG, which would result in an unacceptable weight increase for the spacecraft.

2.2.2.2 RTG and GPHS Design and Performance History

The GPHS, which is the source of energy for the RTGs on the Galileo spacecraft, is the culmination of almost 25 years of design evolution of heat source technology. Safety is a principal engineering design goal of the heat source. The safety-related design goals are to: 1) contain or immobilize the fuel to the maximum extent possible under normal and accident environments, and 2) ensure compatibility with the power generation system. The following is a brief summary (Bennett 1987) of relevant safety environments and GPHS response:

- Liquid Propellant Fires. The GPHS modules survive the most severe fires that can result from on-pad events.

- Solid Propellant Fires. The GPHS survives fires in contact with the burning solid propellant.

- Explosions. Modules were shown to survive up to approximately 1,070 psi overpressures and clads were shown to survive impulses in excess of 2,000 psi.

- High-velocity Fragments. Test data for bare fuel clads impacted by flyer plates representative of structures involved in External Tank (ET) explosions (i.e. aluminum of thickness of approximately 3.5 mm) were only minimally breached at velocities up to 1,170 m/s (3,838 f/s). Further tests representative of Solid Rocket Booster (SRB) fragments (1/2 inch thick stainless steel) show the RTG to survive fragment velocities, with a face-on impact up to 700 fps, with no release of fuel.

- 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; 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. Clads alone showed small release when impacting at terminal velocity on a hard surface. When protected by the aeroshell and graphite impact shell, the normal configuration, no release would be expected to occur.

- Ocean Impact. GPHS modules survive water impact and will resist significant fuel release for virtually unlimited periods.

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

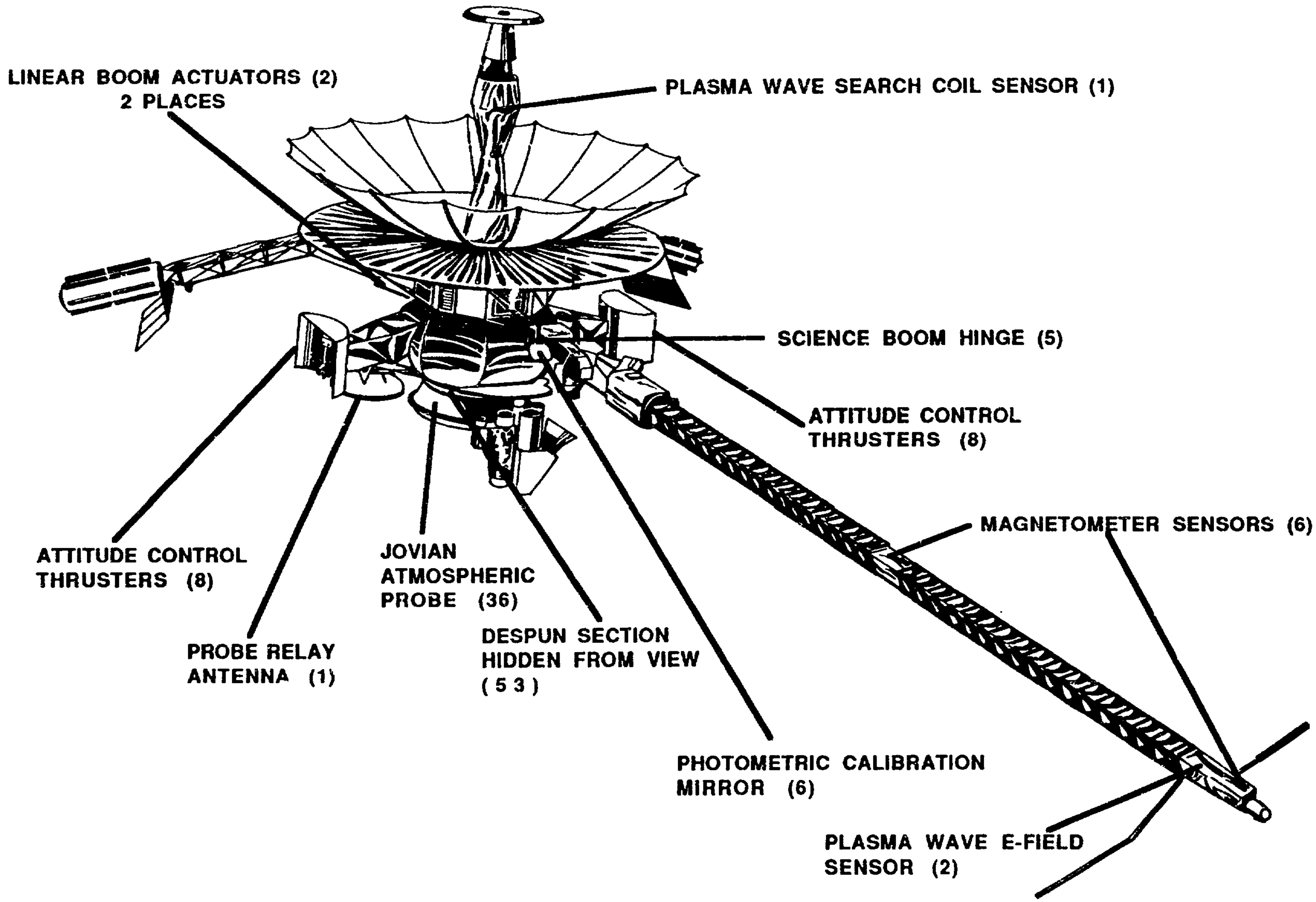

FIGURE 2-7. DIAGRAM OF LOCATIONS OF RHUS ON GALILEO SPACECRAFT

this form, plutonium-238 is virtually insoluble in ground or sea water should such exposure occur.

The primary protective material used to encapsulate 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 frit vent designed to release the helium generated by the fuel alpha particle decay and to prevent the release of plutonium.

The graphitic materials in the GPHS perform several functions. The primary function is to provide reentry protection for the fueled clads. This is the job 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 U.S. Department of Energy (DOE) has spent 9 years in engineering, safety, and environmental testing of the GPHS, building on the experience gained from previous heat source development programs. The test program results have proven the present design to be the most successful of any heat source developed for past programs.

There have been three U.S. spacecraft which failed to achieve their intended mission and included RTGs onboard the spacecraft. Early RTG models carried relatively much smaller amounts of radioactive material and were built to burn up at high altitude during accidental reentry. This design requirement was met in 1964 during the malfunction of the Navy's Transit-5BN-3 navigational satellite which carried the SNAP 9A RTG.

Since 1964, RTG systems have been designed for full fuel containment in the event of an accident. This design philosophy has performed flawlessly in two mission failures where RTGs were present. A SNAP 19B2 RTG landed intact in the Pacific Ocean in May 1968 after a Nimbus B weather satellite failed to reach orbit. The fuel was recovered and used in a later mission.

In April 1970, the Apollo 13 lunar module reentered the atmosphere and its SNAP 27 RTG, which was jettisoned, fell intact into the 20,000 feet deep Tonga Trench in the Pacific Ocean. Measurements show there was no release of radioactive material into the atmosphere.

2.2.2.3 Spacecraft Propulsion Subsystem

The Galileo spacecraft uses monomethyl hydrazine fuel and nitrogen tetroxide oxidizer for its propulsion subsystem. This propellant combination is hypergolic (i.e., the propellants ignite spontaneously upon contact with each other). The spacecraft's propellant tanks are loaded at the KSC with about 807 pounds of monomethyl hydrazine and 1,290 pounds of nitrogen tetroxide.

2.2.3 STS/IUS Launch Vehicle

The STS/IUS launch configuration consists of the STS Shuttle booster with an IUS that is carried to Earth orbit in the Shuttle bay. Figure 2-8 illustrates the configuration of the spacecraft in the Shuttle bay for launch. The selection of the STS/IUS launch vehicle 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 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 and the Shuttle EIS (NASA 1978).

Once deployed from the Shuttle, the IUS can propel payloads into higher Earth orbits or to Earth-escape velocities needed for planetary missions. The IUS proposed for use on the Galileo mission is a two-stage solid rocket (Boeing 1984). Figure 2-9 illustrates the configuration of the Galileo spacecraft assembled with the IUS.

2.2.4 Range Safety Considerations

The Eastern Space and Missile Center 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.

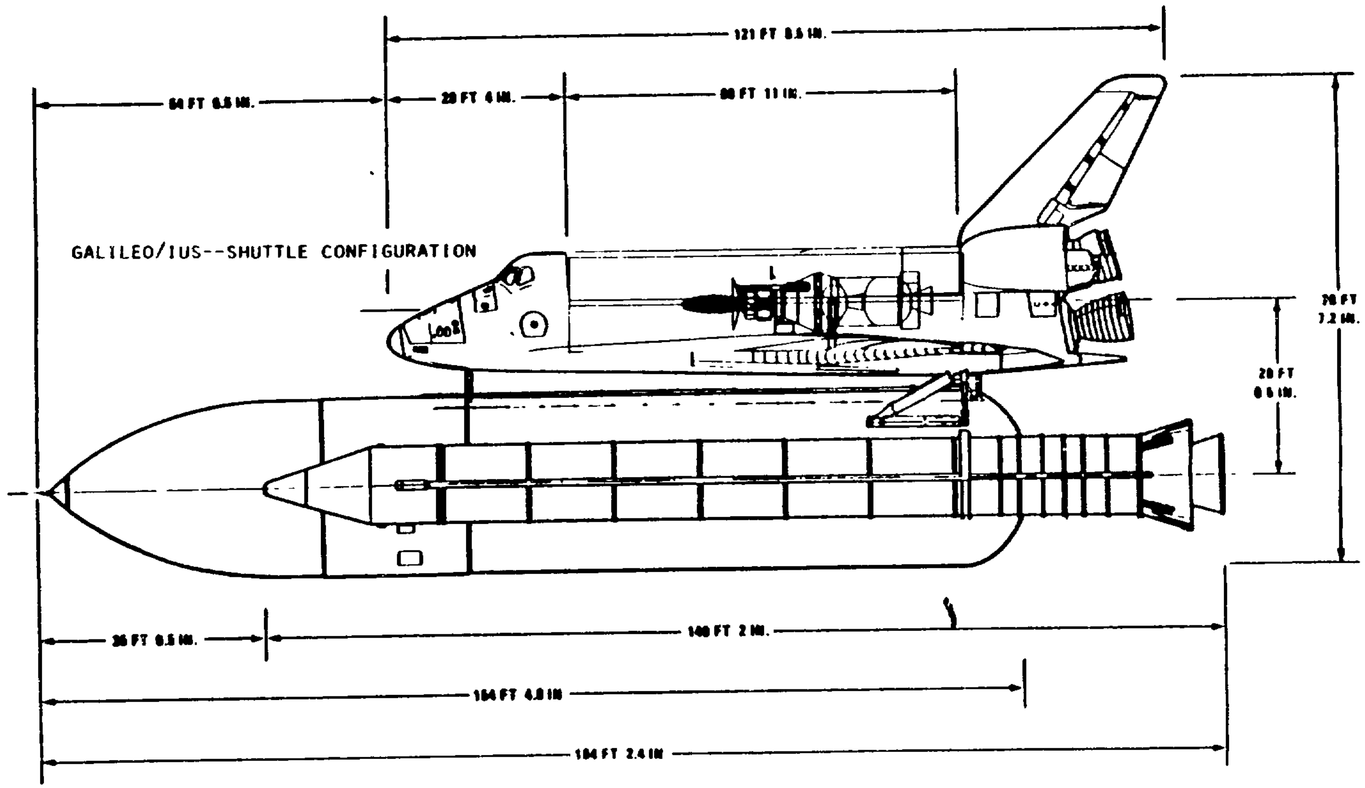

FIGURE 2-8. DIAGRAM SHOWING CONFIGURATION OF GALILEO SPACECRAFT IN SHUTTLE BAY FOR LAUNCH.

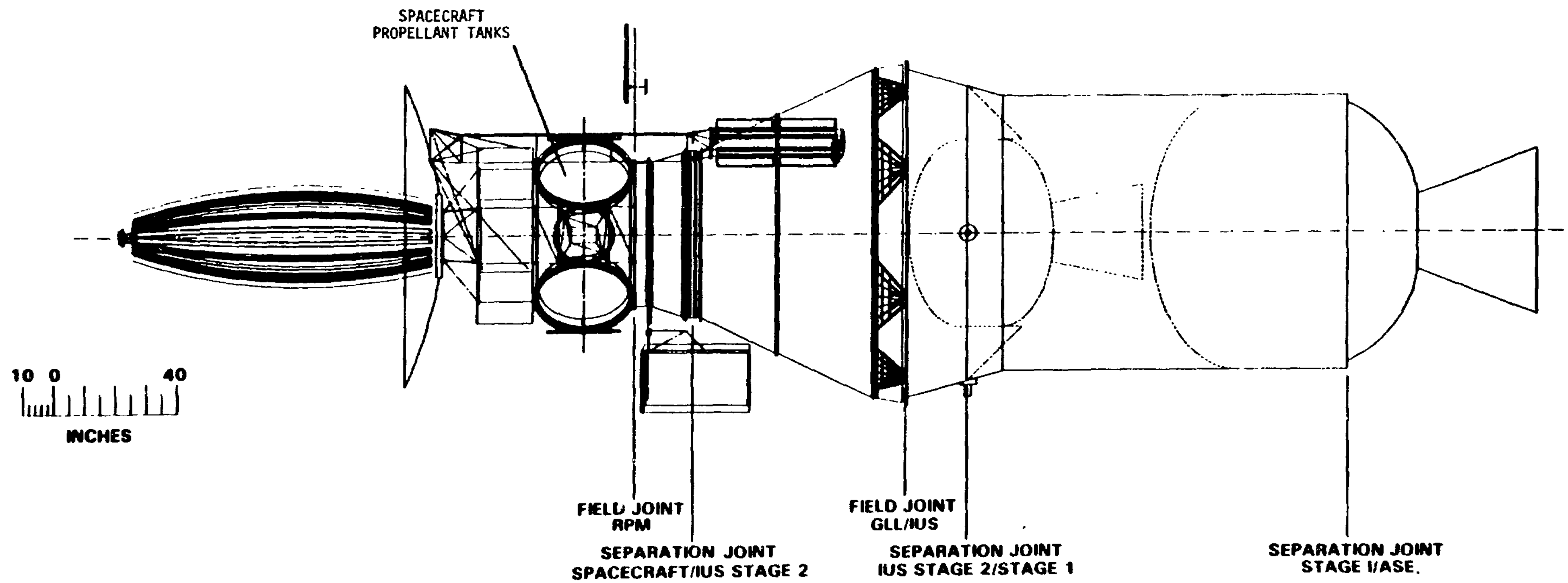

FIGURE 2-9. CONFIGURATION OF GALILEO SPACECRAFT ASSEMBLED WITH IUS.

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 too far from the planned course.

2.2.5 Mission Contingencies

2.2.5.1 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. Therefore, manned systems offer a capability that does not exist on expendable launch vehicles. The planned intact abort landing sites for the Galileo mission are as follows:

Type of Abort	Site
Return to Launch Site	Kennedy Space Center
Transoceanic Abort Landing	Ben Guerir, Morroco Alternate - Moron, Spain
Abort-Once-Around	Edwards Air Force Base, California Alternates - White Sands Space Harbour, NM Kennedy Space Center
Abort-From-Orbit	Edwards Air Force Base, California Alternates - White Sands Space Harbour, NM Kennedy Space Center

2.2.5.2 Contingency Aborts

Contingency abort conditions are defined when two Space Shuttle Main Engines fail prior to single engine Transoceanic Abort Landing capability or when 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. However, during the remainder of the ascent phase, two or three main engine failures result in a contingency abort scenario.

2.2.5.3 On-orbit Spacecraft Aborts

It is also possible to abort the Galileo mission if problems occur after deployment of the Galileo/IUS from the STS Shuttle and before VEEGA trajectory insertion. For example, should the IUS fail to insert the spacecraft into an Earth escape trajectory, the spacecraft will be separated automatically from the IUS. The estimated lifetime of the spacecraft in low Earth orbit will be several days. However, the spacecraft will be carrying a full propellant load and for most scenarios will be capable of achieving an altitude of approximately 2,000 kilometers resulting in an orbital lifetime of several thousand years.

2.3 DESCRIPTION OF THE ALTERNATIVE TO DELAY IMPLEMENTATION OF THE GALILEO MISSION UNTIL 1991 AND CONSIDER THE STS/IUS AND THE TITAN IV AS LAUNCH VEHICLE ALTERNATIVES

This section addresses a delayed launch in terms of scientific returns, spacecraft description, alternative launch vehicle configurations, mission design/contingencies, and spacecraft trajectory.

2.3.1 Overview of Alternative

The alternative of delaying completion of preparations for launching Galileo in 1989 in favor of a launch in 1991 could allow for two potential Galileo launch vehicle configurations: 1) the STS/IUS and 2) the Titan IV/IUS expendable launch vehicle (see discussion on availability of Titan IV given in Section 2.3.5). The STS/IUS launch vehicle configuration for a launch in 1991 (delayed STS/IUS configuration) would essentially duplicate the launch configuration discussed in Section 2.2.

2.3.2 Scientific Returns

In addition to causing a delay in obtaining scientific results, delaying the Galileo launch until 1991 will adversely impact the planetary science mission in several ways:

- The atmospheric entry probe relays data to Earth via the Galileo orbiter. As a consequence of a 1991 launch, a less favorable data relay geometry will exist between orbiter, probe, and Earth.

- The electrical power output capability of RTGs declines over time. A launch delay until 1991 will force spacecraft systems to operate with reduced power margins and reduce the amount of scientific data collected.

- The 1991 trajectory does not provide the performance margin needed to exploit asteroid flyby opportunities. Current studies indicate the opportunities for collecting asteroid data are much less favorable than those projected for a 1989 launch.

2.3.3 Mission Design

The mission design changes required for a 1991 STS/IUS or a Titan IV/IUS launch would be those changes required to accommodate the science mission impacts described in Section 2.3.2 (i.e., less favorable probe relay geometry, reduced power levels, probable lack of asteroid encounters).

A 1991 Galileo launch by either the STS/IUS or a Titan IV/IUS would still require use of the VEEGA trajectory. No U.S. launch vehicle will be available in 1991 with the capability of placing Galileo on a direct trajectory to Jupiter. Therefore, there is no change in the mission design found in Section 2.2.1.2 for the VEEGA trajectory.

2.3.4 Changes Caused by a Launch Delay Until 1991

No hardware design changes are planned to accomodate a 1991 Galileo launch. The spacecraft would essentially be the same as described in Section 2.2. Any changes now expected would be in the areas of mission design, spacecraft trajectory, and the possible option of employing the Titan IV/IUS launch vehicle. At this time, a switch from the STS/IUS to a Titan IV/IUS launch vehicle would require a considerable integration effort to meet the 1991 launch opportunity (see discussion on availability of Titan IV in Section 2.3.5). This topic is further discussed in Section 2.5.

2.3.5 Alternative Launch Vehicle Configurations

The U.S. Air Force (USAF) has informed NASA that a Titan IV will not be available for the May 1991 launch opportunity. Therefore, the Titan IV/IUS launch vehicle configuration is no longer a reasonable alternative to the STS/IUS in the delay alternative. Nevertheless, since the analyses were completed prior to the USAF notification, the data are included in this EIS in Appendix C and thus will be available to decision-makers.

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 Galileo mission, the goals of the NASA Solar System Exploration Program (i.e., the potential scientific returns of this mission) would not be attained.

2.5 COMPARISON OF ALTERNATIVES

The factors pertinent to a comparison of the "Proposed Action", the "Delay Alternative", or the "No Action Alternative" have been separated into those related to normal missions and to accidents. The comparison is presented in Table 2-2.

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. Both the proposed action and the delay alternative 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 NEPA documents (NASA 1985a, NASA 1986, NASA 1988a, USAF 1986, USAF 1988) and are associated with the routine launch operations of the STS and Titan IV launch vehicles. The impacts were determined by NASA to be acceptable. The following subsections briefly summarize the impacts described in Section 4.

TABLE 2-2. SUMMARY COMPARISON OF ALTERNATIVES

PROGRAMMATIC CONSIDERATIONS CONSIDERATIONS	PROPOSED ACTION	DELAY ALTERNATIVE		NO ACTION
	STS/IUS IN 1989	STS/IUS IN 1991	TITAN IV/IUS IN 1991*	
SAFETY & ENVIRONMENTAL IMPACT Expected (Normal Launch)				
o Land Use	No significant adverse impacts on non-launch related land uses.	Same as Proposed Action	Same as Proposed Action	No Effect
o Air Quality	No significant adverse impacts outside the near field environment (within 900 feet of launch pad).	Same as Proposed Action	No significant adverse effects outside the near field (about 700 feet from launch pad).	No Effect
o Sonic Boom	No significant adverse impacts.	Same as Proposed Action	Same as Proposed Action	No Effect
o Hydrology and Water Quality	No significant adverse long-term impacts. Short-term increase in the acidity of nearby water impoundments.	Same as Proposed Action	No significant adverse long-term impacts. Effects on pH rapidly buffered in nearby major water bodies.	No Effect
o Biological Systems	No significant adverse effects outside the near-field (within about 900 feet of launch pad).	Same as Proposed Action	No significant adverse effects outside the near field (within about 700 feet of launch pad).	No Effect
o Endangered and Threatened Species	No significant adverse effects.	Same as Proposed Action	Same as Proposed Action	No Effect
o Socioeconomic Factors	No significant adverse effects. Short-term economic effects from tourism.	Same as Proposed Action	No significant adverse effects. Short-term economic benefits from tourism.	No Effect

* See discussion on availability of Titan IV in Section 2.3.5.

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

PROGRAMMATIC CONSIDERATIONS CONSIDERATIONS	PROPOSED ACTION	DELAY ALTERNATIVE		NO ACTION
	STS/IUS IN 1989	STS/IUS IN 1991	TITAN IV/IUS IN 1991*	
Expected (Balance of Mission)	No significant adverse effects.	Same as Proposed Action	Same as Proposed Action	No Effect
Potential Accidents:				
Overall Probability of Pu-238 Release to Biosphere for Mission	$7x10^{-4}$	Same as Proposed Action	$4x10^{-4}$	0
Quantity of Pu-238 Released to Biosphere in the Event of an Accident during Mission				
Launch Vicinity Accident Causing Release				
- Average/Expectation	920 Curies at $3x10^{-4}$	Same as Proposed Action	468 Curies at $1x10^{-6}$	None
- Maximum Credible	1,864 Curies at $1x10^{-4}$	Same as Proposed Action	936 Curies at $1.37x10^{-6}$	
VEEGA Accident Causing Release				
- Average/Expectation	12,400 Curies at $5x10^{-7}$	Same as Proposed Action	12,400 Curies at $5x10^{-7}$	None
- Maximum Credible	11,568 Curies at $1x10^{-7}$	Same as Proposed Action	11,568 Curies at $1x10^{-7}$	
Lifetime Incremental Population Dose in the Event of a Mission Accident				
Launch Vicinity Accident Causing Release				
- Average/Expectation	203 person-rem at $4x10^{-4}$	Same as Proposed Action	278 person-rem at $1x10^{-6}$	None
- Maximum Credible	4,910 person-rem at $1x10^{-4}$	Same as Proposed Action	2,470 person rem at $1.37x10^{-6}$	
VEEGA Accident Causing Release				
- Average/Expectation	1,430 person-rem at $5x10^{-7}$	Same as Proposed Action	1,430 person-rem at $5x10^{-7}$	None
- Maximum Credible	54,000 person-rem at $1x10^{-7}$	Same as Proposed Action	54,000 person-rem at $1x10^{-7}$	

* See discussion on availability of Titan IV in Section 2.3.5.

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

PROGRAMMATIC CONSIDERATIONS CONSIDERATIONS	PROPOSED ACTION	DELAY ALTERNATIVE		NO ACTION
	STS/IUS IN 1989	STS/IUS IN 1991	TITAN IV/IUS IN 1991*	
Incremental Cancer Fatalities among Exposed Population in the Event of a Mission Accident				
Launch Vicinity Accident Causing Release				
- Average/Expectation	0.0005 at $4x10^{-4}$	Same as Proposed Action	0.05 at $1x10^{-6}$	None
- Maximum Credible	0.7 at $1x10^{-4}$	Same as Proposed Action	0.5 at $1.37x10^{-6}$	
VEEGA Accident Causing Release				
- Average/Expectation	0.3 at $5x10^{-7}$	Same as Proposed Action	0.3 at $5x10^{-7}$	None
- Maximum Credible	10 at $1x10^{-7}$	Same as Proposed Action	10 at $1x10^{-7}$	
Land Area Requiring Assessment and Possible Cleanup in Event of an Accident				
Launch Vicinity Accident Causing Release				
- Average/Expectation	17-70 km^2	Same as Proposed Action	0.56 km^2	None
- Maximum Credible	19-85 km^2	Same as Proposed Action	3 km^2	
VEEGA Accident Causing Release				
- Average/Expectation	15 km^2	Same as Proposed Action	15 km^2	None
- Maximum Credible	15 km^2	Same as Proposed Action	15 km^2	
SCIENCE RETURN				
Jupiter Arrival Date	December 7, 1995	July 1997	July 1997	None
Mission Margins:				
- Power	Adequate	Marginal	Marginal	N/A
- Propellant	Adequate	Marginal	Marginal	N/A
VEEGA Asteroid Opportunities	Gaspra & Ida	None Identified, Nor Likely Because of Reduced Propellant Margins	None Identified, Nor Likely Because of Reduced Propellant Margins	None

* See discussion on availability of Titan IV in Section 2.3.5.

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

PROGRAMMATIC CONSIDERATIONS CONSIDERATIONS	PROPOSED ACTION	DELAY ALTERNATIVE		NO ACTION
	STS/IUS IN 1989	STS/IUS IN 1991	TITAN IV/IUS IN 1991*	
COST				
TOTAL ESTIMATED COST	$1.04 Billion	$1.14 Billion	$1.15 Billion	Sunk [illegible] of $800 Million
LAUNCH OPPORTUNITY				
Vehicle Availability	Firm Commitment	Tentative	Not available to NASA	N/A
Launch Period				N/A
- First Possible Launch Date	October 8, 198[illegible]	May 10, 1991	May 27, 1991	N/A
- Length	47 Days	43 Days	19 Days	N/A
Daily Launch Window	30-40 Minutes	Approximately 3 hours	Approximately 5-6 Hours	N/A
OTHER CONSIDERATIONS				
Supporting Facility Availability	Firm Commitment	Uncertain	Uncertain*	Not Required
Personnel Availability	Project Team in Place	Engineering Personnel Replacements Needed	Engineering Personnel Replacement Needed	None

* See discussion on availability of Titan IV in Section 2.3.5.

Proposed Action and STS/IUS Delay Alternatives

Short term air quality degradation at the launch site and downwind of the launch will occur from the HCl 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 if the launch occurs during precipitation. This 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 ten 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 is 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 in Section 2.5.2.

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 either the "Proposed Action" or the "Delay Alternative" 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

For both the proposed action and the delay alternative, there is a slight chance of adverse impacts. Analysis indicates that the chance of any plutonium releasing accident occurring is remote (NASA 1988a, and Section 4 of this EIS).

The DOE has conducted an extensive program of safety analysis, testing, and verification to determine the chances and consequences of releasing plutonium-238 from the Galileo spacecraft's RTGs and RHUs 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 these analyses are presented in Section 4 and Appendices B and C of this document and are briefly summarized in Table 2-2.

For the proposed action, it can be concluded from the analyses presented in Section 4 that the risks to human health are small (generally less than one chance in 10,000 for health effects) for the more serious of the accident scenarios. In the event of these more serious accidents, some environmental contamination above the screening level of 0.2 uCi/m^2 could occur. The maximum area contaminated in this type of accident is predicted to range from approximately 19 to 85 km^2 for the launch phase and about

15 km^2 for the VEEGA flyby phase. These risks are small compared with those of other human activities.

Under the delay alternative, the possible accidental health and environmental impacts of the STS/IUS option remain unchanged in 1991 from those in the 1989 launch except for those impacts where significant changes occur in population density between 1989 and 1991. The only potentially significant health or environmental impact in the Titan IV/IUS analysis are in the VEEGA flyby. These impacts are identical with the VEEGA fly-by accidental impacts evaluated for the STS/IUS. Thus, the STS/IUS and the Titan IV/IUS have essentially the same level of acceptability in terms of environmental impact.

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

In comparing the alternatives it is clear that there are no significant health or environmental impacts associated with a normal mission for either the proposed action or the delay alternative. There are, however, major adverse fiscal and programmatic impacts attendant upon with the delay or the no-action alternative.

Both the "Proposed Action" and the "Delay Alternative" would accomplish most of NASA's scientific objectives for the Galileo mission's study of Jupiter. The "Proposed Action" would result in the earliest collection of mission scientific data; additionally, it would afford NASA the opportunity for close observation of two asteroids.

Both options under the "Delay Alternative", relative to the "Proposed Action", would delay by one and one-half years NASA's collection of mission scientific data. Additionally, because of less favorable spacecraft trajectories (which result in higher propellant usage) in 1991 and diminished RTG power levels, the "Delay Alternative", relative to the "Proposed Action", would not allow any asteroid observations and would require NASA to limit some spacecraft instrument operations during the Probe's descent into Jupiter's atmosphere and would raise the risk that the mission would be limited to 9 as opposed to 10 encounters with Jupiter's satellites.

The "No Action" alternative by definition would result in not obtaining any science data and therefore would effectively prevent NASA from achieving its solar system exploration program objectives as they relate to advanced studies of Jupiter and its satellites.

2.5.3 Launch Preparation and Operation Costs (Mission only)

The "Proposed Action", with an estimated cost to completion of approximately $1 billion represents the minimum cost alternative to NASA for meeting the objectives of the Galileo mission. Both options under the "Delay Alternative" would cost approximately $100 million more than the "Proposed Action". The next available launch opportunity after the planned

1989 launch is in May 1991. This implies a delay of 19 months. Because of the need to maintain the spacecraft in storage and to retain key project personnel, the cost of delaying the mission will be about $4 million per month or approximately $76 million. In addition, there would be the further delay in gaining the scientific returns. The 1991 STS/IUS option would pose a $90 million cost of delay and, due to inflation effects, increase the operations costs of the mission by an estimated $105 million. The 1991 launch on a Titan IV/IUS, relative to the "Proposed Action", would pose a higher incremental cost to NASA (in excess of $15 million) than the 1991 STS/IUS option as a result of the need to integrate the Galileo spacecraft with the Titan IV/IUS. No difference in NASA costs for STS versus Titan IV launch services is assumed.

The "No Action" alternative would represent the least cost alternative for NASA but would render useless the $800 million current investment. Implementation of this alternative would also incur additional costs for decommissioning facilities dedicated for the Galileo mission and for disassembling and/or storing the Galileo spacecraft.

2.5.4 Launch Schedules and Launch Vehicle Availability

Consistent with the "Proposed Action", the Galileo mission has been manifested for flight onboard the STS in October/November 1989. There are no plans within the existing launch manifest to launch Galileo on board the STS in 1991; however, if NASA decided not to launch Galileo in 1989 and pursue the "Delay Alternative", an STS/IUS launch could likely be made available. The USAF has informed NASA that a Titan IV will not be available for the May 1991 launch opportunity. Therefore, the Titan IV/IUS launch vehicle is no longer a reasonable alternative to the STS/IUS in the delay alternative. Nevertheless, since the analyses were prepared, the data are included in Appendix C to this EIS and will be available to decision-makers.

2.5.5 Facility and Personnel Availability

To maintain the "Proposed Action", the necessary scientific and engineering personnel are in place to implement the Galileo mission in 1989. NASA's Deep Space Network (DSN) is prepared to meet the project's tracking and data relay requirements. The Federal Republic of Germany has agreed to provide spacecraft tracking support for the 1989 mission's science experiments that are planned during the Venus, Earth, and asteroid flyby phases of the mission.

Under the "Delay Alternative", it would be difficult for NASA to maintain the existing Galileo engineering team if the launch is delayed until 1991. Several key individuals and many newer people would likely transfer to other projects; as a result, the Galileo Project could experience some losses that could jeapordize the 1991 launch opportunity. This could represent a significant risk to the Project.

Selection of the "No Action" alternative would result in releasing a Shuttle launch commitment (and an IUS upper stage booster) in October/November 1989 for either a NASA or DOD mission. Existing engineers would be available to work on other NASA projects. Most significantly, the scientific investigations of scores of scientists who have prepared 10 years to conduct experiments as part of the Galileo mission would be terminated.

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 and Cape Canaveral Air Force Station (KSC/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.

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 Kennedy Space Center (KSC) and Cape Canaveral Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (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 acres water area. The region also contains about 5,400 acres of saltwater beaches and about 48 acres of archaeological and historic sites.

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

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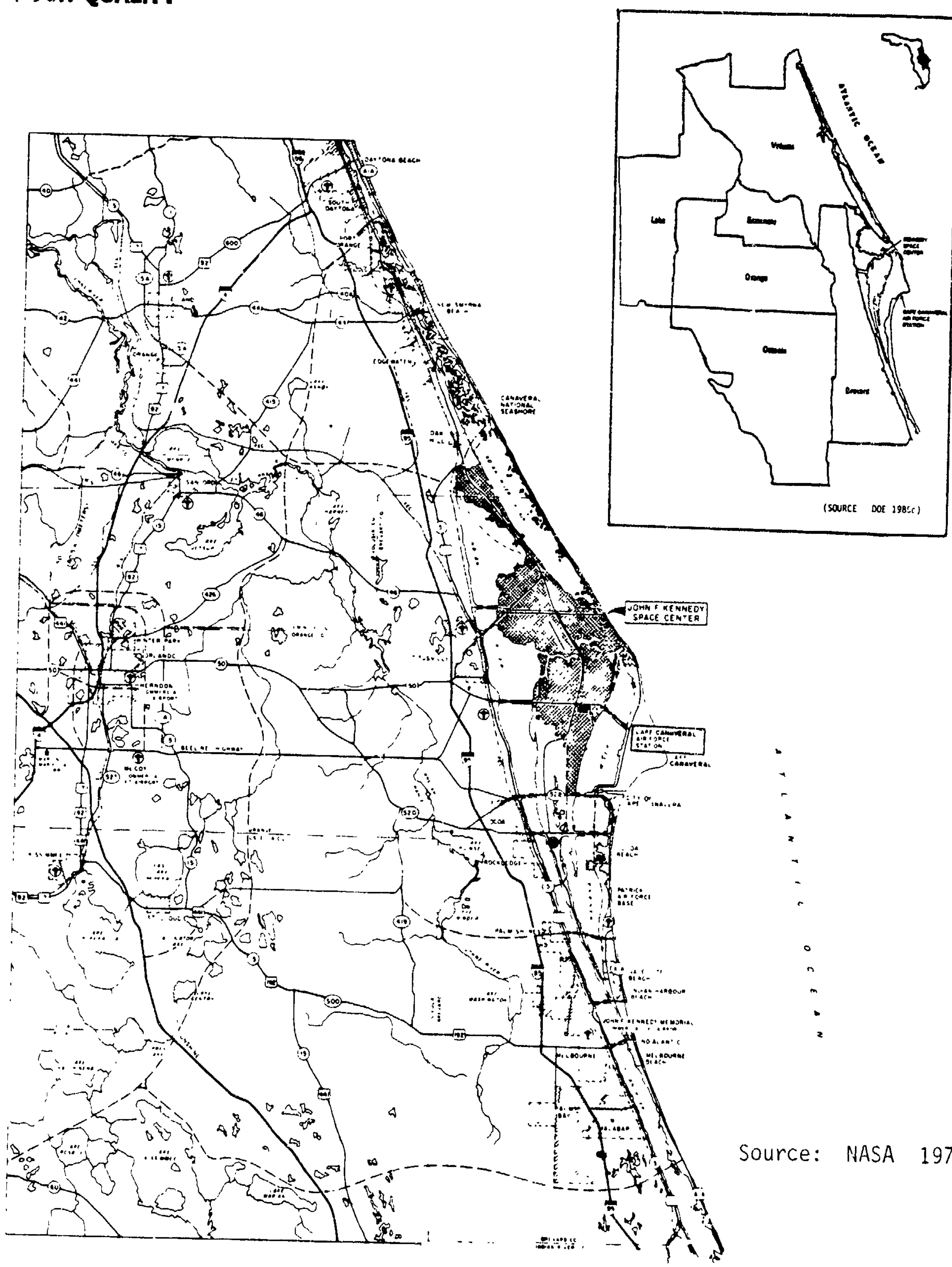

Source: NASA 1979

FIGURE 3-1. LOCATION OF REGIONAL AREA OF INTEREST

Merritt Island National Wildlife Refuge at KSC. The locations of these and other such areas can be found in Appendix D-5.

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 not usually 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 hurricane to strike the region was David in September, 1981, which paralleled the coast, (ECFRPC 1987).

There are 14 air monitoring sites in the region: seven are for total suspended particulates, two each for sulfur dioxide, carbon monoxide and ozone, and one for nitrogen dioxide. Lead (Pb) 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 (Florida 1987). Orange County is expected to be re-designated an ozone "maintenance" area, (ECFRPC 1987).

3.1.3 Hydrology and Water Quality

The region not only borders the Atlantic Ocean but contains approximately 2,300 lakes, two 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 2000 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, 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). (See Appendix D-2 for locations of Brevard County potable water sources.) 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:

(1) the Weikiva River; a federally designated Wild and Scenic River, which forms the border between northwestern Seminole County and eastern Lake County;

(2) the Mosquito Lagoon portion of the Indian River Lagoon which is a State of Florida Aquatic Preserve;

(3) the 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;

(4) the 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 four aquatic preserves, 24 bodies of surface water designated as Outstanding Florida Waters, and one Area of Critical State Concern - the Green Swamp. The locations of these areas can be found in Appendix D-5.

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

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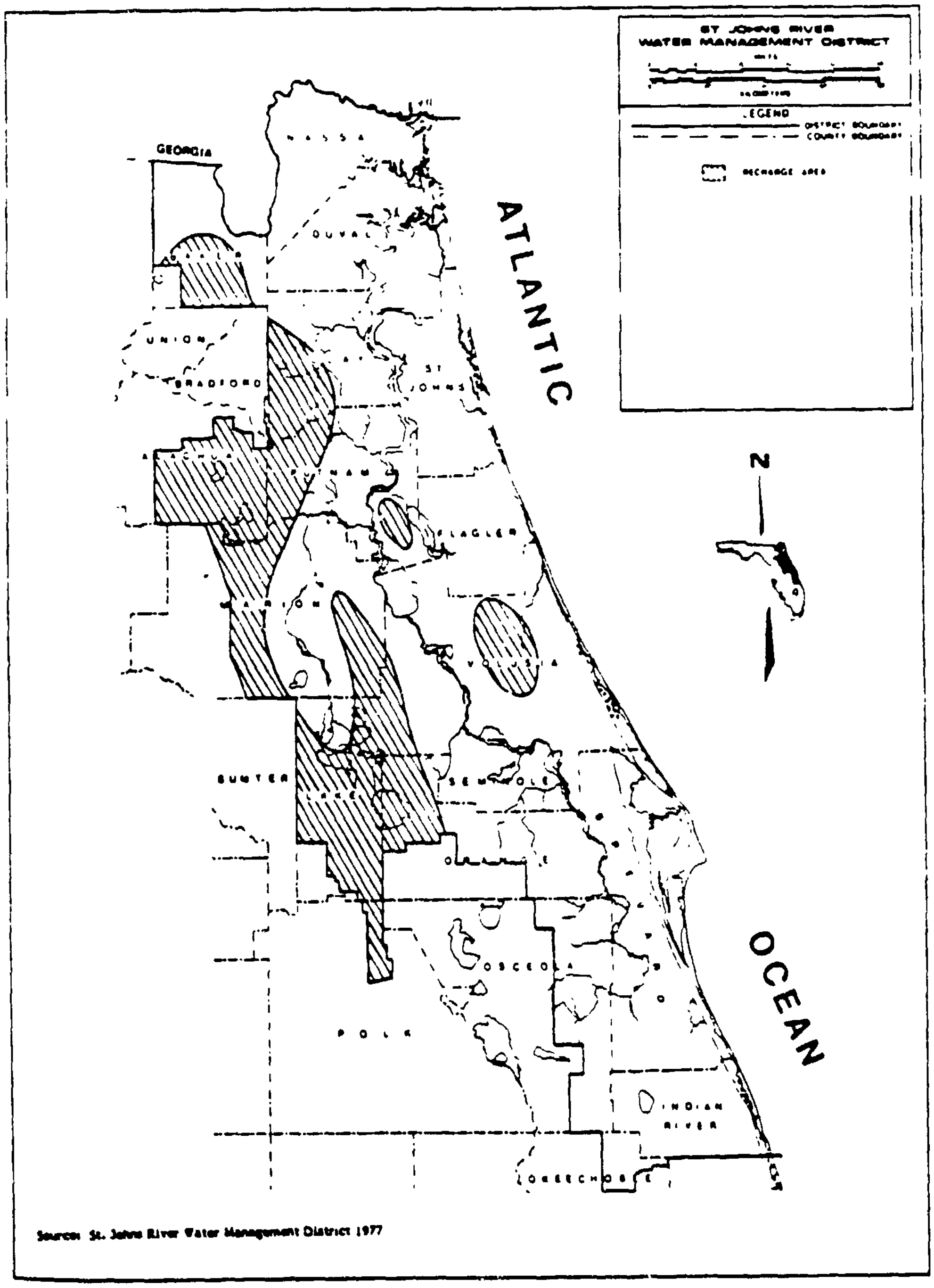

FIGURE 3-2. GENERALIZED MAP OF POTENTIAL GROUND WATER RECHARGE AREAS IN EASTERN CENTRAL FLORIDA (Source: Reference 3-4)

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

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) the dominant cover types in the region.

A total of 141 species of freshwater, esturine and marine fish have been documented within the northern portions of the Indian River Lagoon near KSC (ECFRPC 1988). Of this, 65 species are considered commercial fish and 85 are sport fish and/or 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 1985c). Sport fish include largemouth bass, bluegill, black crappie, bowfin, gar, bullhead, bream and catfish. That the St. Johns River basin is heavily fished is 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 (see Appendix D-5) are hunted for small game, turkey, hogs, or deer.

3.1.5.1 Endangered Species

The Federal government's list, prepared by the USFWS, currently recognizes 19 endangered or threatened species in this region. Another 55

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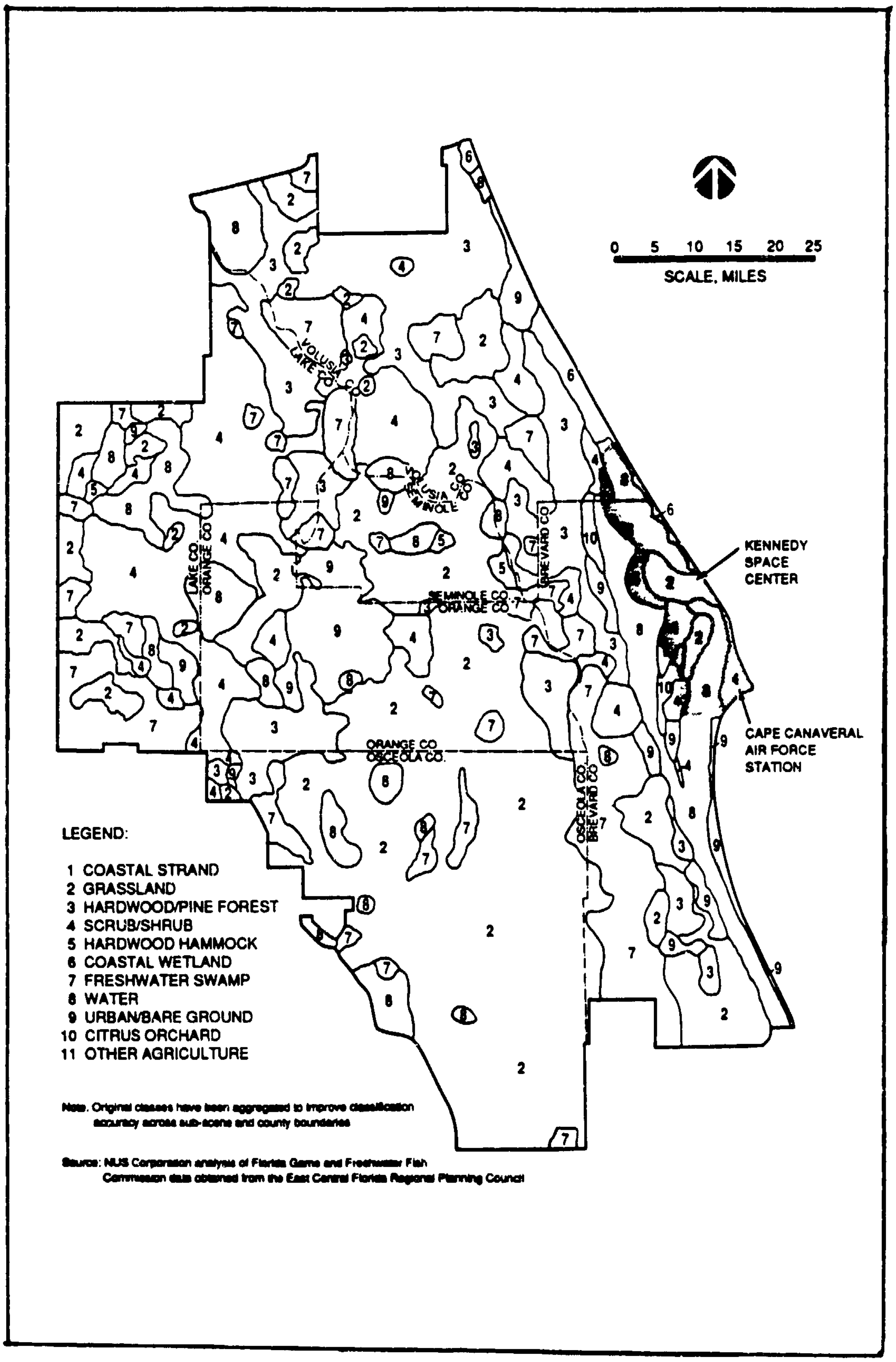

FIGURE 3-3. GENERAL LAND COVER TYPES OF THE REGION

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.

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 (FCREPA), a group consisting largely of research biologists, gives endangered or threatened status to 55 species. The Florida Natural Areas Inventory (FNAI, 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 esturine 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 US 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 Melbo[illegible] Titusville-Palm Bay MSA (Brevard County). The population in Lake C[illegible]y, 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 198[illegible] 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 (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, going 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).

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. The two Walt Disney World theme parks and Sea World, near Orlando, along with Kennedy Space Center are four of the five 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's 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 2 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 (FSU 1984). Brevard and Volusia ranked 5th and 6th 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 5th with about 0.4 million pounds. Brevard also ranked 1st on the east coast with 1.6 million pounds of shrimp; Volusia was 5th 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).

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

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

* BEBR, April 86 estimate (rounded to nearest 100)

(Source: ECFRPC Undated)

percent in Seminole, 49 percent in Osceola, 45 percent in Brevard, and 41 percent in Volusia. The region's labor force and employment has 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 ($7,799) to $12,273 (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 -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 5 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, other heath care professionals and nursing homes are located throughout the region, (ECFRPC 1987). (See Appendix D-3 for locations of Brevard County emergency services.)

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 1988b), 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, and approximately 15 miles north of Patrick Air Force Base (PAFB), about 30 miles south of Daytona Beach and 40 miles due east of Orlando (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.

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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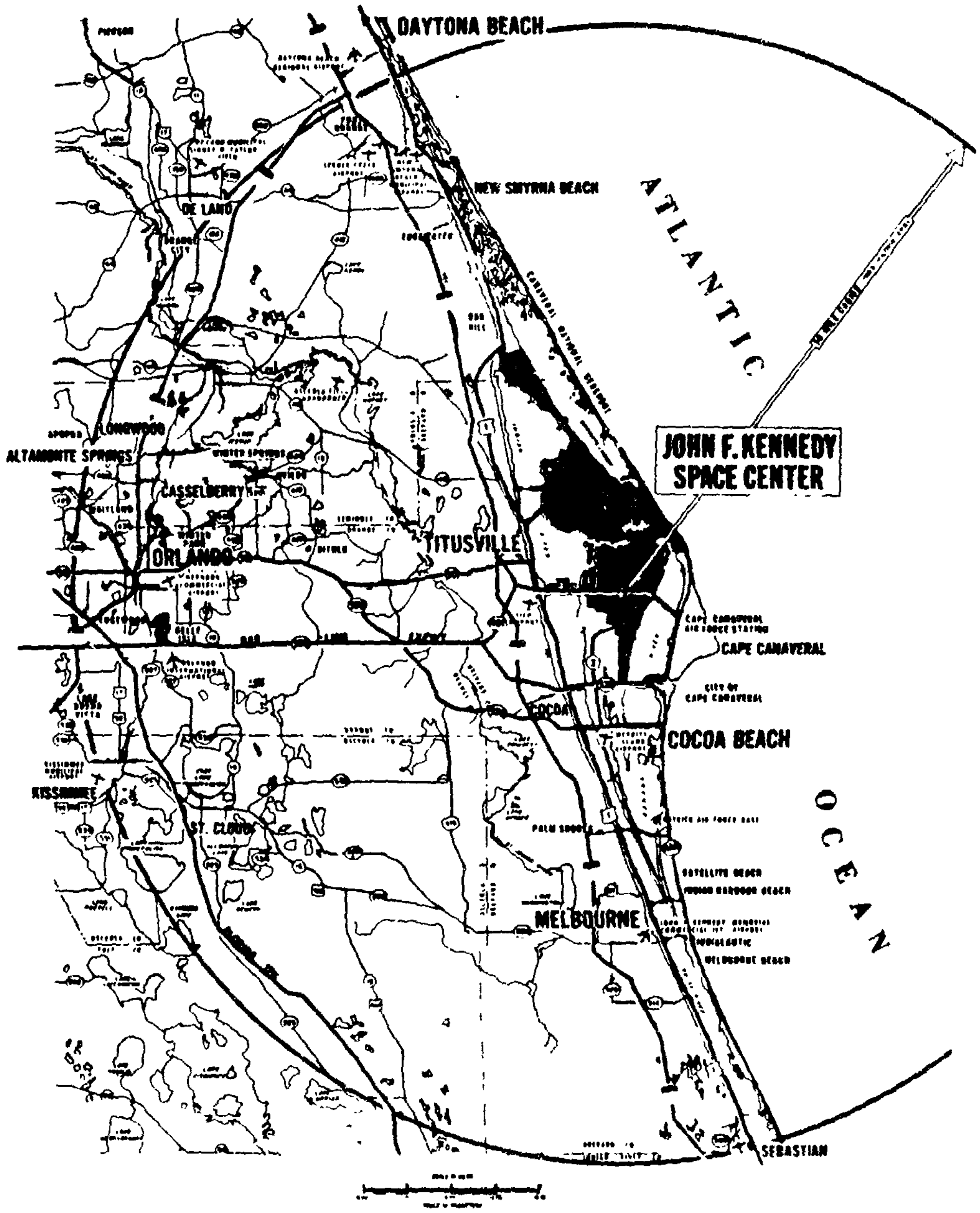

(SOURCE: NASA 1986)

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

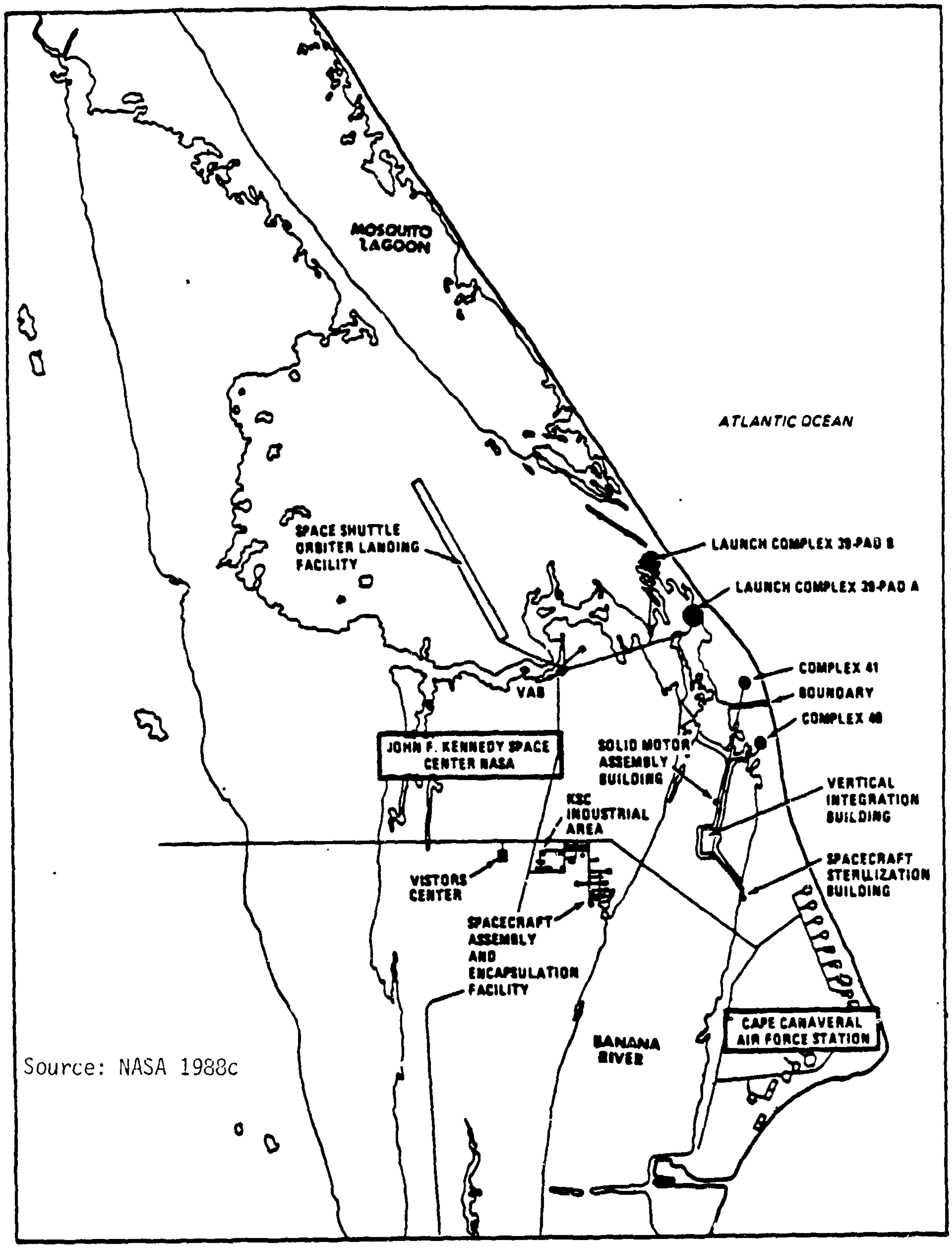

FIGURE 3-5. GENERAL LAND USE AT KENNEDY SPACE CENTER

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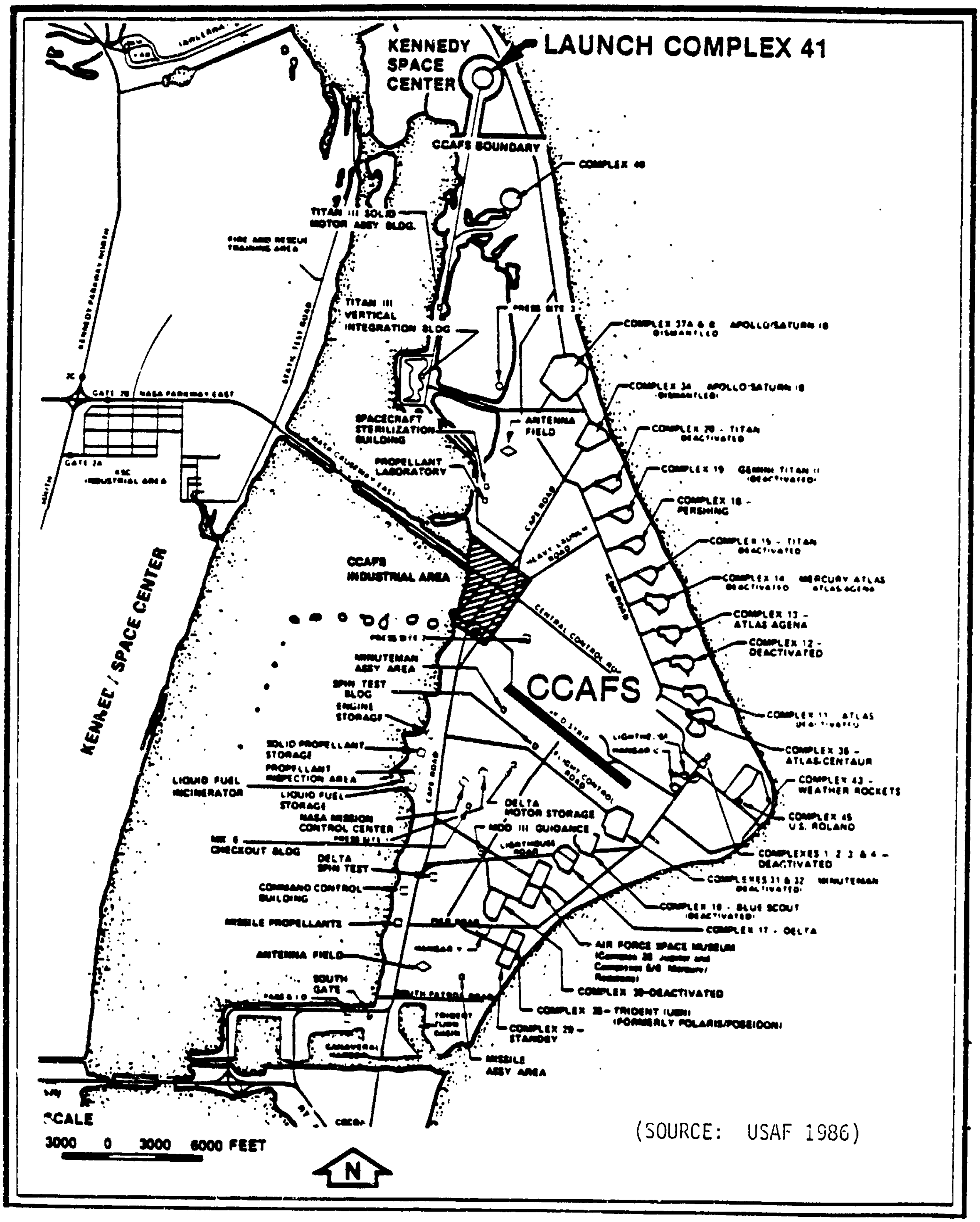


(SOURCE: USAF 1986)

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, 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. Historical climatological data can be found in Appendix D-1.

In general, the winds in September through November occur predominantly from the east to northeast (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 Appendices B and C, use launch window-specific wind roses and meteorological conditions. While those specific wind roses are consistent with the seasonal conditions illustrated here, they do vary slightly for the specific launch window, and can be found in Appendix D-1. 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.

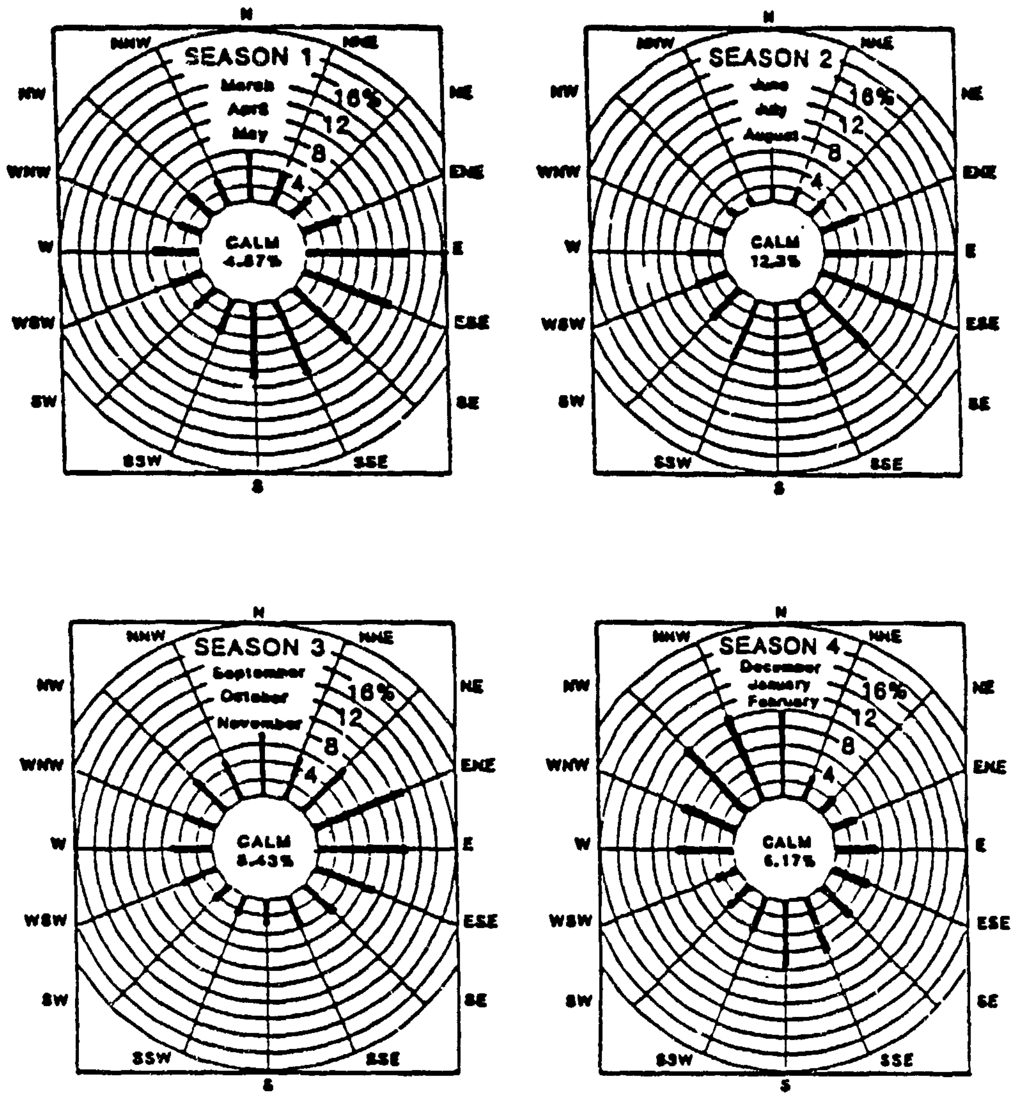
Tropical depressions and hurricanes occur throughout the wet season in Florida. While the possibility for winds to reach hurricane force (74 miles per hour or greater) in any given year in Brevard County is approximately 1 in 20, (USAF 1986), only 24 hurricanes have passed within 115 miles of KSC and CCAFS since 1887 (NASA 1986). Hurricane David (September, 1981) was the last hurricane 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, NOx, 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).

3.2.3 Hydrology and Water Quality

3.2.3.1 Surface Waters

Major inland water bodies in the CCASF 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 Intercostal 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 ft. This area receives drainage from 540,000 acres of surrounding area, (USAF 1986).



(SOURCE: NASA 1986)

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

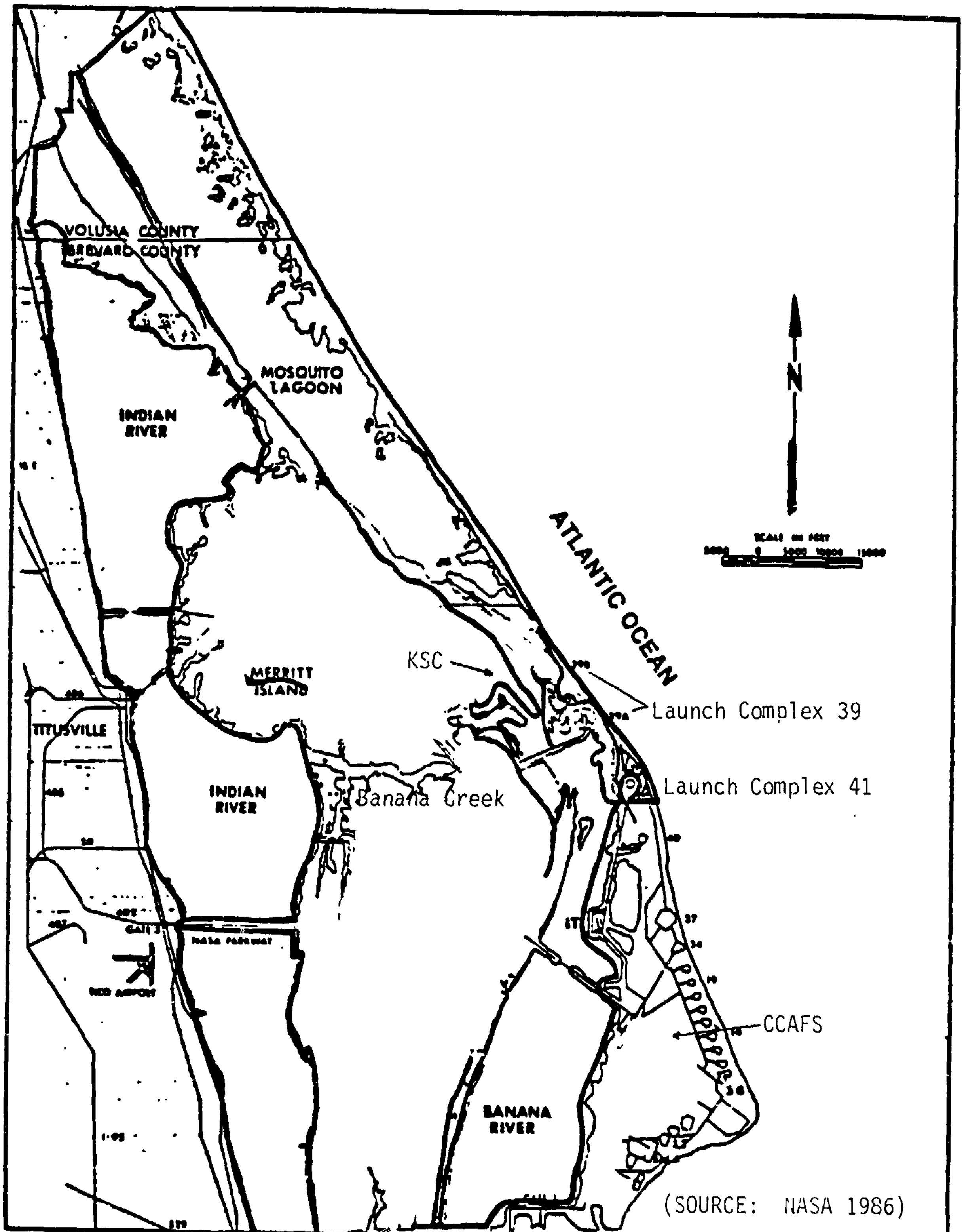


FIGURE 3-8. MAJOR SURFACE WATER BODIES NEAR KSC

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.

3.2.3.2 Surface Water Quality

In compliance with the Clean Water Act (CWA), the state has classified the surrounding surface waters, according to five classifications based upon their potential use and value.

All of the area of Mosquito Lagoon within KSC boundaries and the northern-most segment of the Indian River are designated as Class II waters (Shellfish Propagation and Harvesting) (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 U.S. Fish and Wildlife Service for mosquito control purposes.

Limited water quality data for the Indian River, Banana Creek, the Banana River and Mosquito Lagoon are provided in Table 3-3.

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 (Figure 3-11).

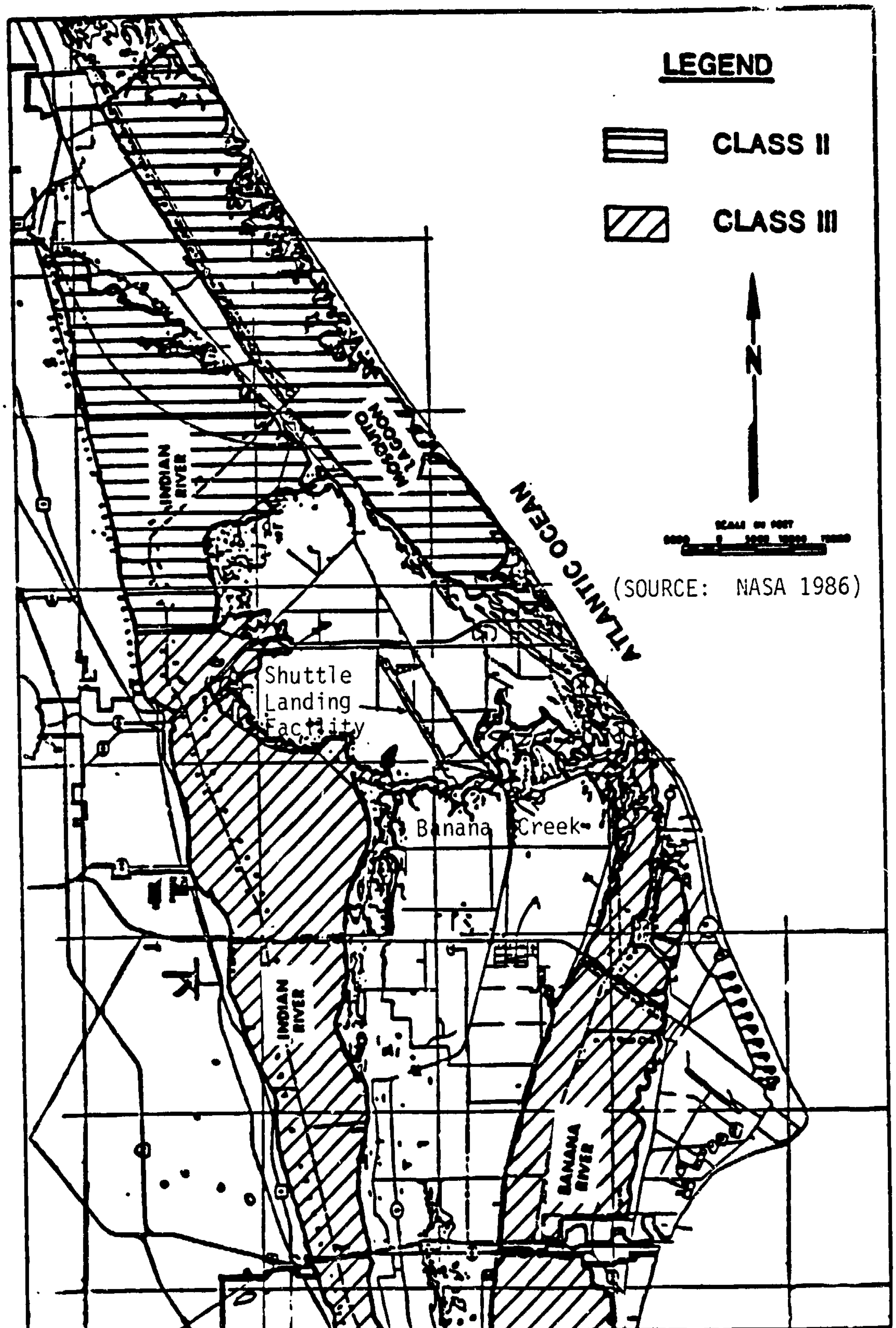


FIGURE 3-9. KSC SURFACE WATER CLASSIFICATIONS

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

Water Body	Salinity (ppt)	pH	Dissolved Oxygen	Nitrogen	Phosphorous	Turbidity (NTU)
Indian River (Titusville - north)	30.2	8.2	6.9	0.03	0.06	3.64
Indian River (Titusville - south to NASA Parkway West)	28.4	8.1	6.9	0.04	0.06	3.75
Indian River (NASA Parkway West south to Bennett Causeway)	27.8	8.1	7.2	0.06	0.05	5.0
Mosquito Lagoon (at KSC)	31.8	8.2	6.9	0.03	0.08	4.9
Banana Creek	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)	25.9	8.2	6.9	0.03	0.05	4.3

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

Source: Reference NASA 1986.

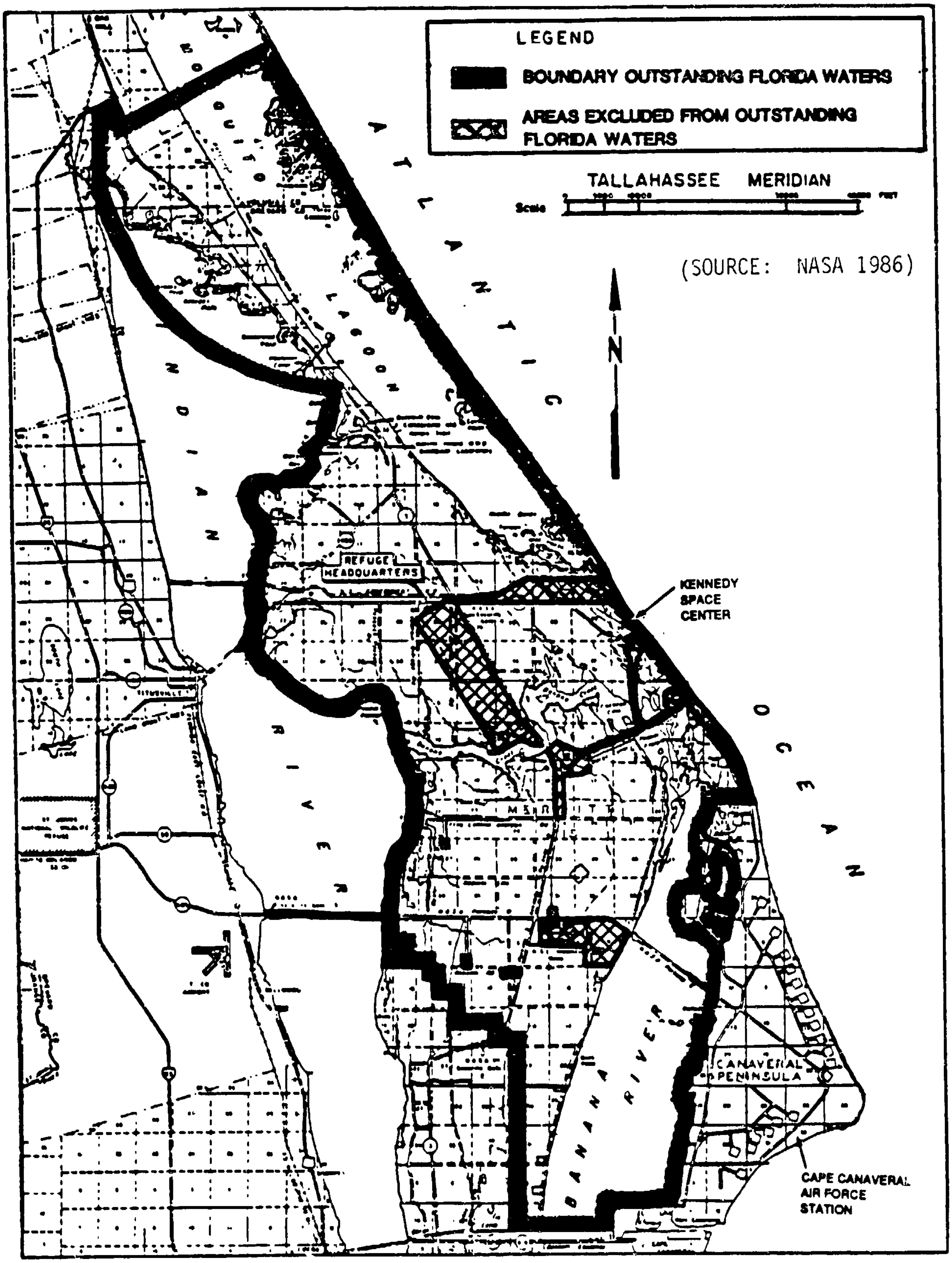


FIGURE 3-10. KSC OUTSTANDING FLORIDA WATERS

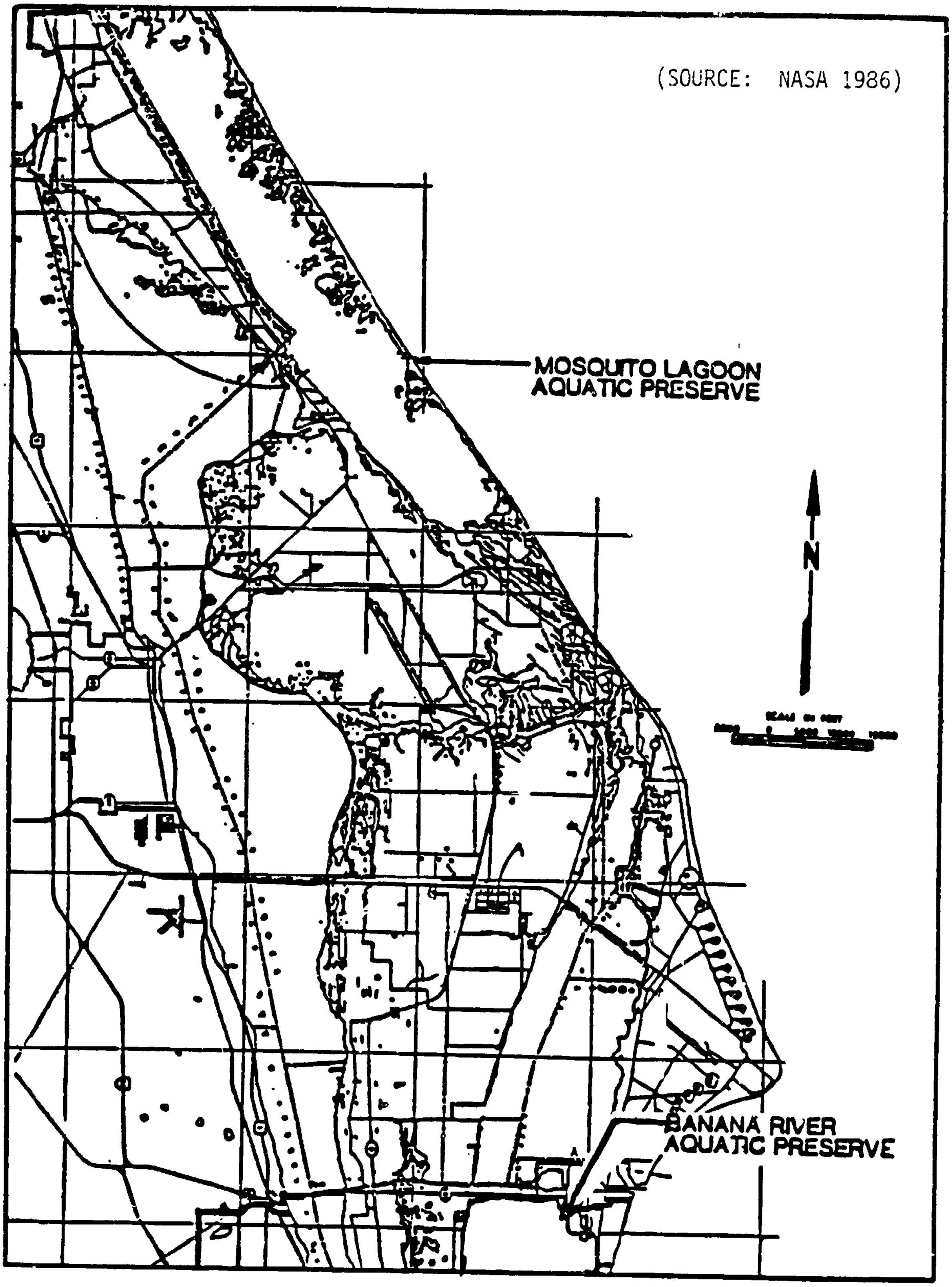


FIGURE 3-11. KSC AREA AQUATIC PRESERVES

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

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

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.

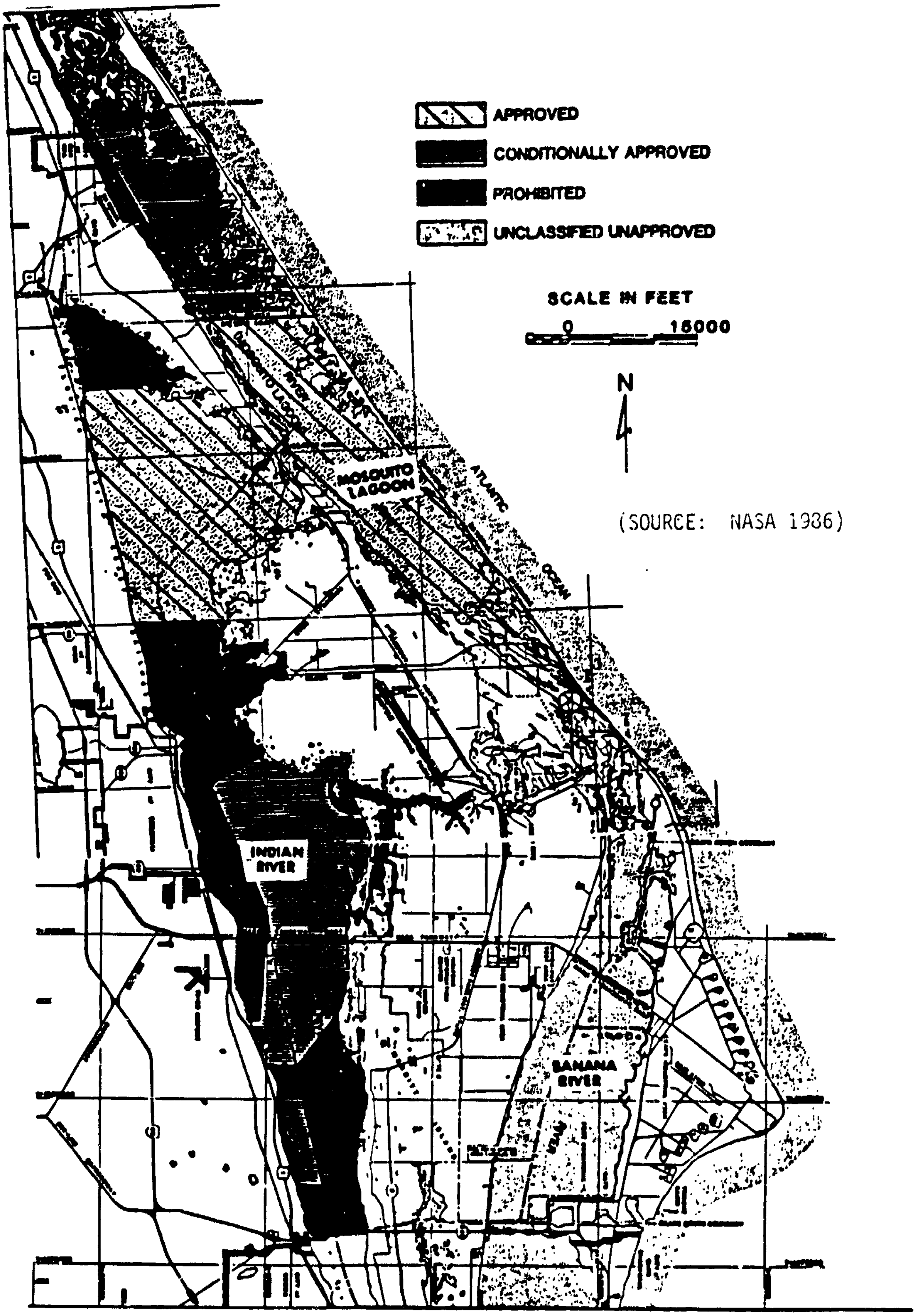
Surficial Aquifer

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. However, because of the thickness and the relatively impermeable nature of the confining units, it is believed 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 County) and discharge areas along the Atlantic coast provides the



(SOURCE: NASA 1986)

FIGURE 3-12. KSC SHELLFISH HARVESTING AREAS

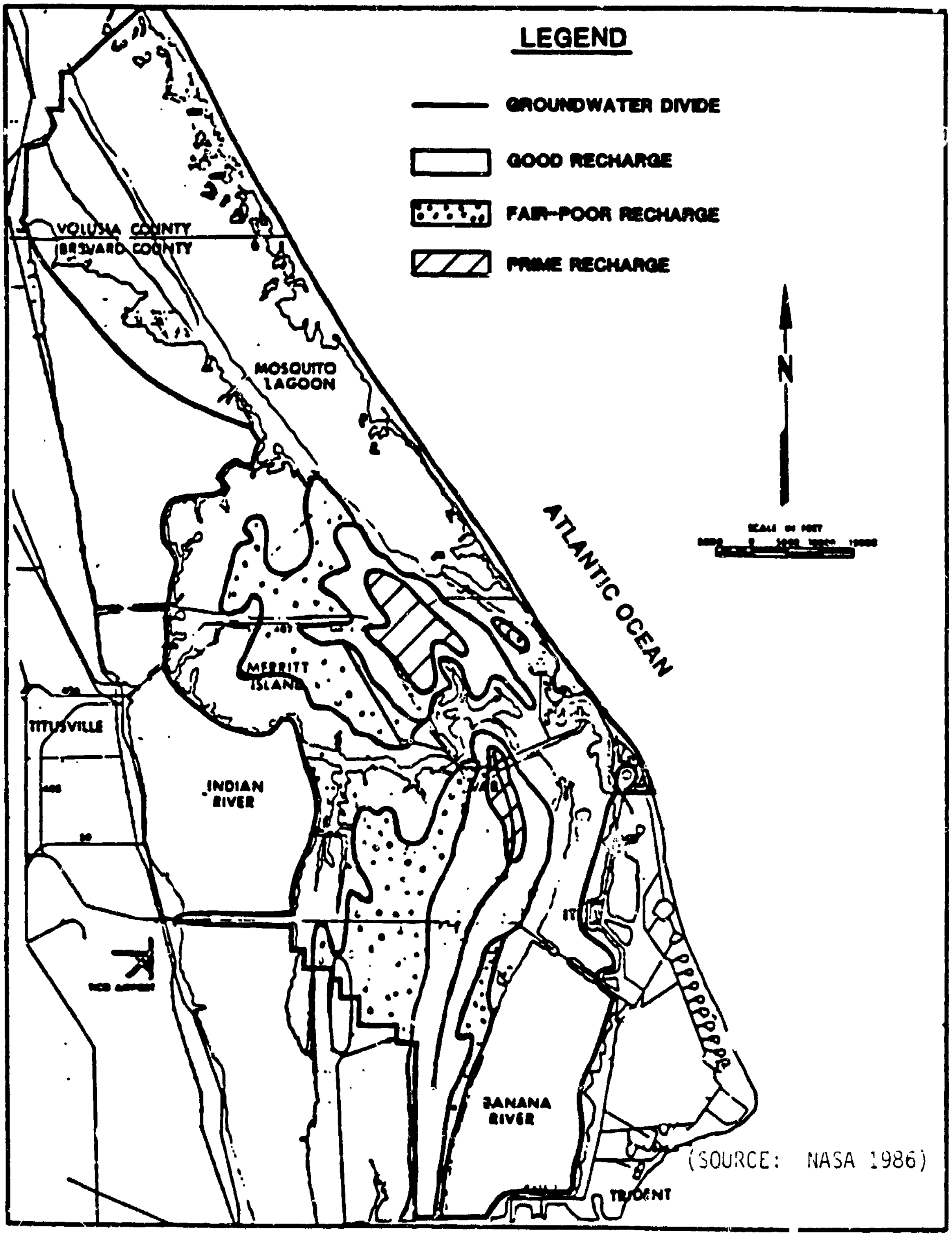


FIGURE 3-13. POTENTIAL RECHARGE FOR SURFICIAL AQUIFER

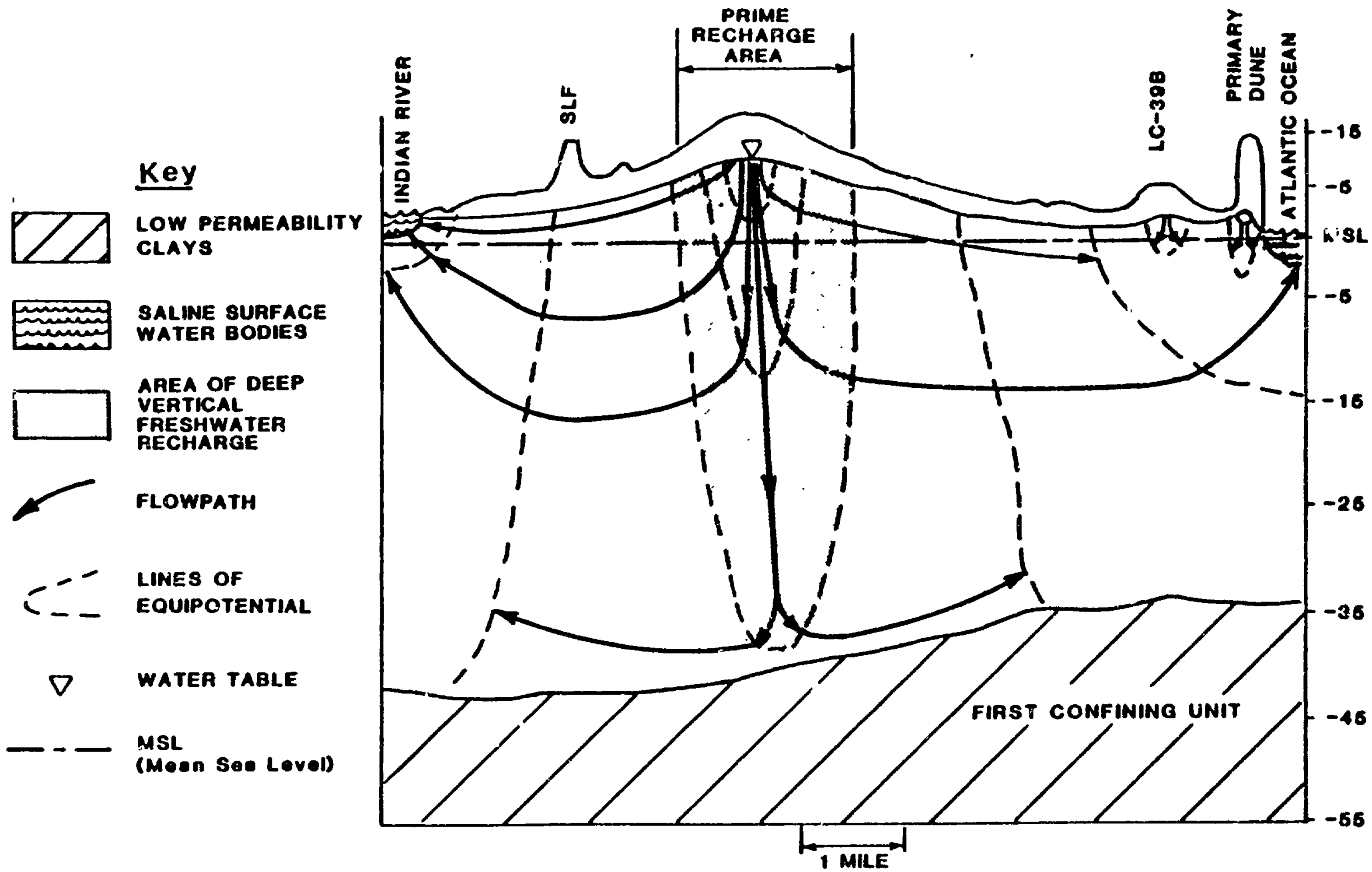


FIGURE 3-14. QUALITATIVE FLOW NET FOR THE SURFICIAL AQUIFER ILLUSTRATING GROUNDWATER CIRCULATION. NOTE AREAS OF DEEP VERTICAL RECHARGE.

(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 of KSC 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.

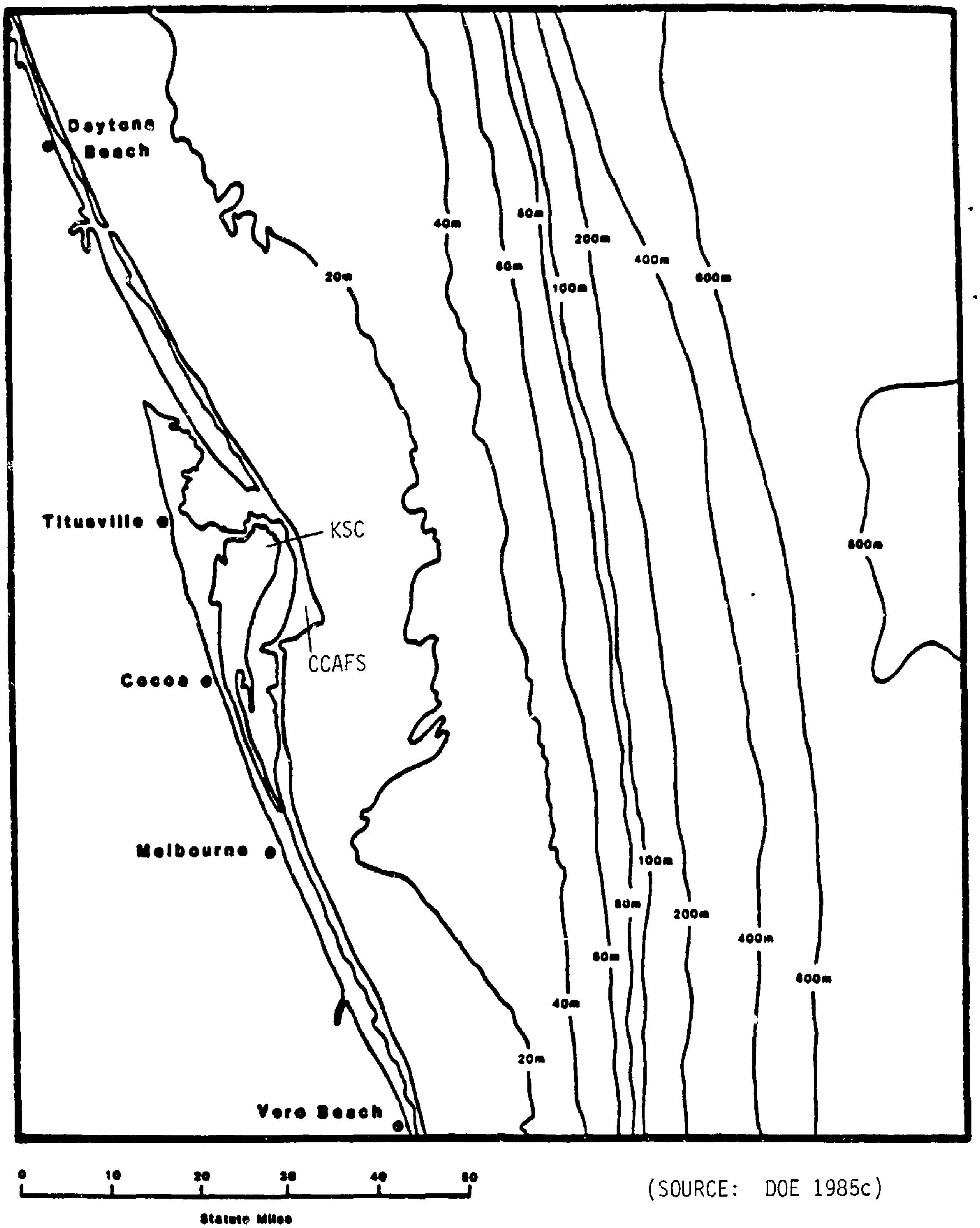
Preliminary data for the Secondary Semi-Confined Aquifer show that some of these aquifers may be marginal water sources; however, it appears that they are not capable of sustaining large scale development.

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.

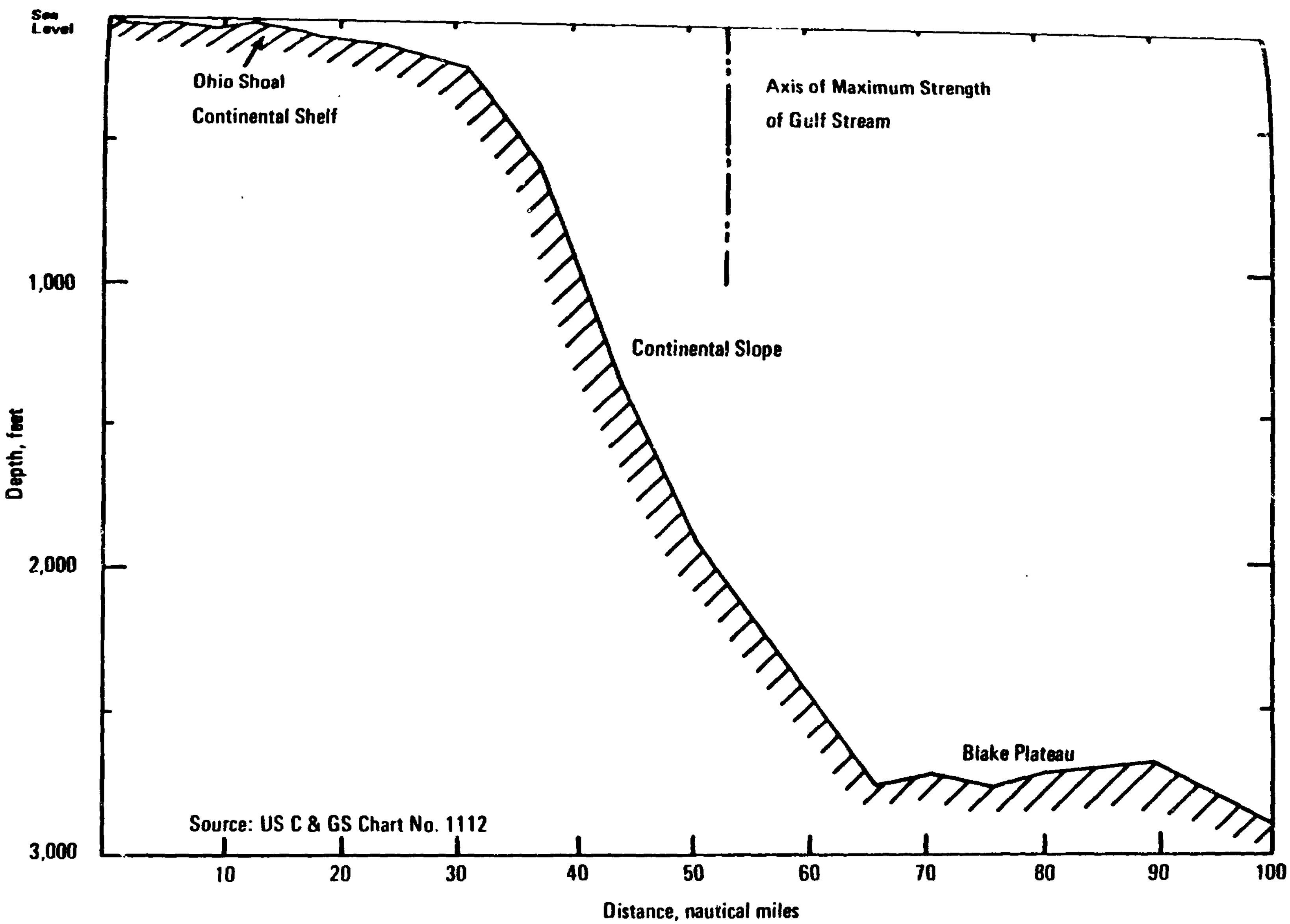
Out to depths of about 60 feet, sandy shoals dominate the underwater topography. The bottom continues seaward at about the same slope out to about 34 miles where the bank slopes down to depths of 2,400 to 3,000 feet to the Blake Plateau. The Blake Plateau extends out to about 230 miles from the shore at KSC/CCAFS. Figure 3-15 shows the bathymetry of the offshore areas. Figure 3-16 illustrates the general ocean bottom for a 100 degree azimuth for 0 to 115 miles from KSC/CCAFS (USAEC 1975).

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 1985c)

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



1 Nautical Mile = 1.15 Statute Miles

(SOURCE: USAEC 1975)

FIGURE 3-16. OCEAN BOTTOM PROFILE OUT TO 100 MILES

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 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.

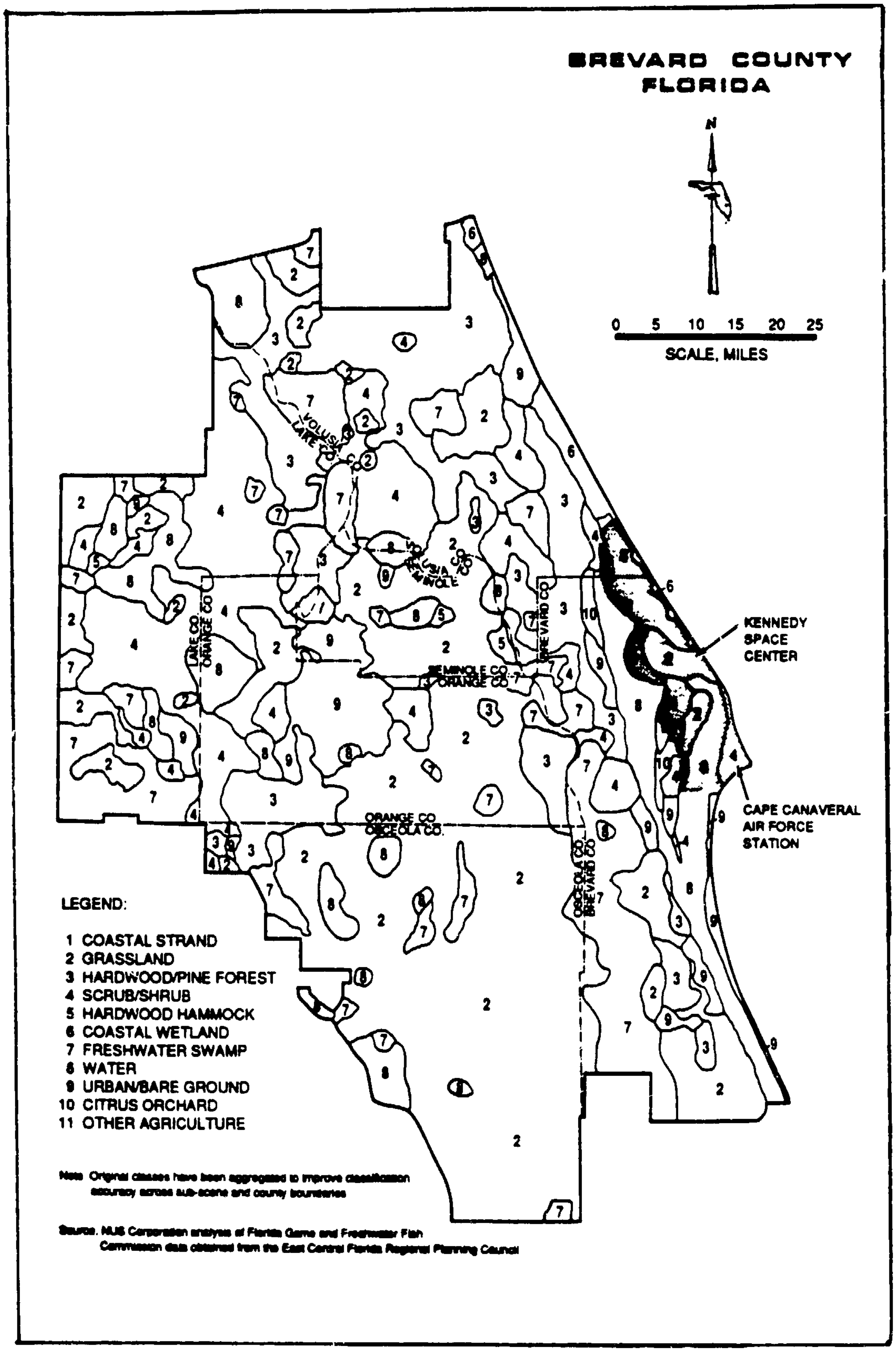


FIGURE 3-17. GENERAL LAND COVER TYPES AT KSC/CCAFS AND VICINITY

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, (see Appendix D-4). 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 forms 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 lagoonal 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 were determined to spawn in the area also.

3.2.5.3 Endangered and Threatened Species

The U.S. Fish and Wildlife Service and Florida Game and Fresh Water Fish Commission 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 3-4. 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 3-4. ENDANGERED AND THREATENED SPECIES RESIDING OR SEASONALLY OCCURRING ON KSC/CCAFS AND ADJOINING WATERS.

Species	Status USFWS*	Status FGFWFCT**	
Mammals			
Caribbean manates (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	

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

(Source: USAF 1986)

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. (See Appendix D-4 for additional details of nesting locations.)

With respect to the West Indian Manatee, the following areas at KSC/CCAFS have been designated as Critical Habitat by the U.S. Fish and Wildlife Service: the entire inland section of water known as the Indian River, from its northernmost point immediately south of the intersection of US 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). Critical habitat and areas of manatee concentration are delineated in Appendix D-4.

Osprey, listed by the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), 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). (See Appendix D-4 for additional detail.)

3.2.6 <u>Socioeconomics</u>

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 (see Appendix D-3 for detail) 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 can not be used)
- 2,000 press members at 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 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 1988). 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, 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 (FECR). 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 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 ft 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 U.S. Fish and Wildlife Service 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 onstation 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.

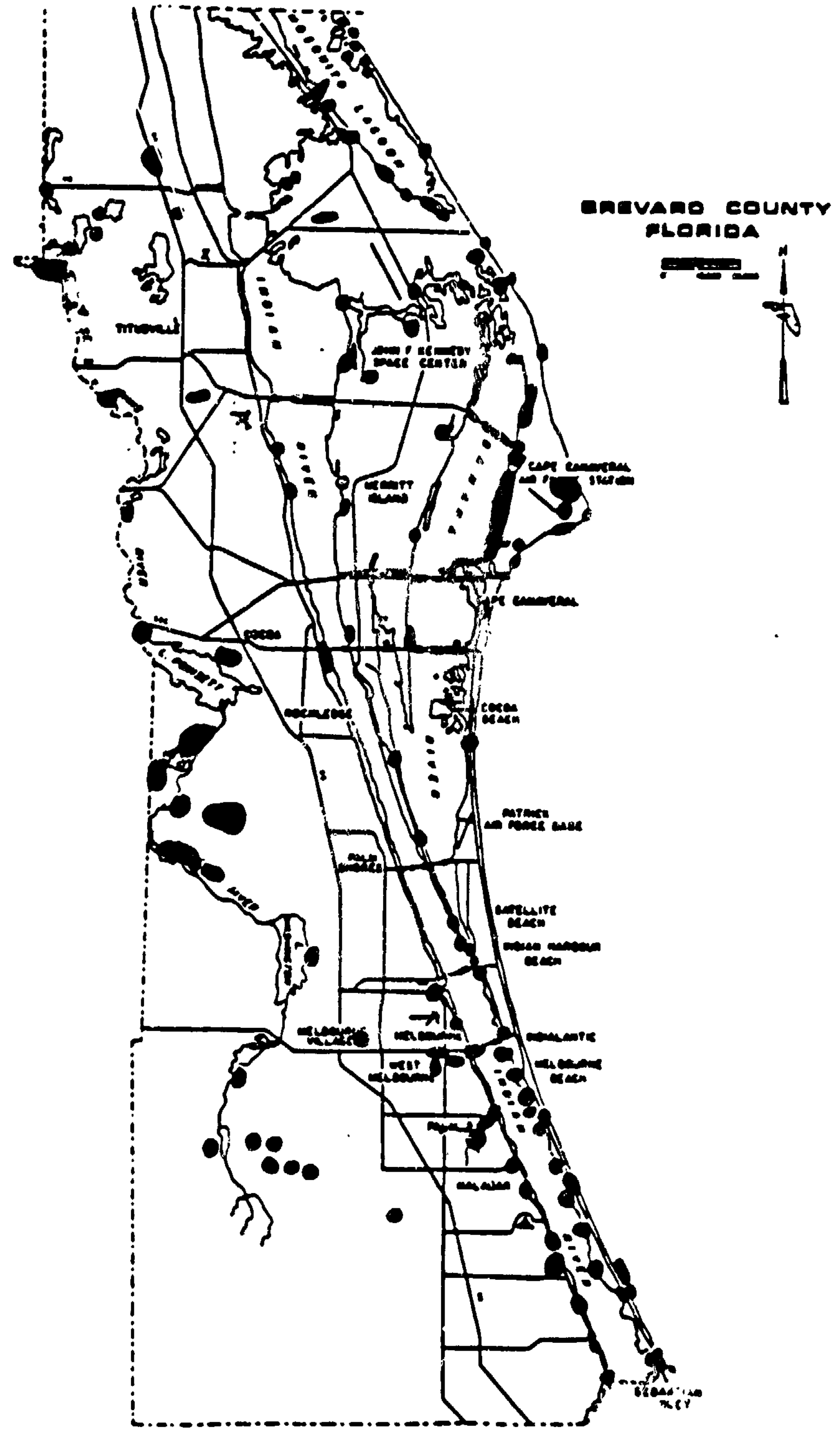
KSC and CCAFS obtain their potable water from the City of Cocoa water system under a contract that provides for some 9 million gallons per day. Approximately half that amount is normally used by the two facilities. The on-site distribution systems are sized to accommodate the constant high volume flow 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).

Additional details of facilities in the local area can be found in Appendix D-2 and D-3.

KSC also enforces procedures, plans and personnel training with respect to the use and handling of radioactive sources. Comprehensive radiological contingency plans are being developed to address all launch/landing phase accidents that could potentially involve the RTGs and RHUs aboard the Galileo spacecraft. These plans conform to the requirements of the Federal Radiological Emergency Response Plan (FRERP) that is under development and involves the efforts of numerous government agencies including NASA, DOE, the Department of Defense, the Environmental Protection Agency and the State of Florida. An overview of radiological controls and emergency planning at KSC can be found in Appendix D-6.

3.2.6.5 Historic/Archaeologic Resources

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



(SOURCE: BREVARD 1988)

FIGURE 3-18. GENERAL LOCATIONS OF HISTORIC/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 some 2,3000 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 that 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.

Most recently, NASA proposed to develop a site along Banana Creek to allow VIPs to view STS launches. It was determined that this site contained state listed archaeologic site BR170. NASA funded an extensive archaeologic dig of this site. The study was completed in August 1988 and the final report is pending.

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 (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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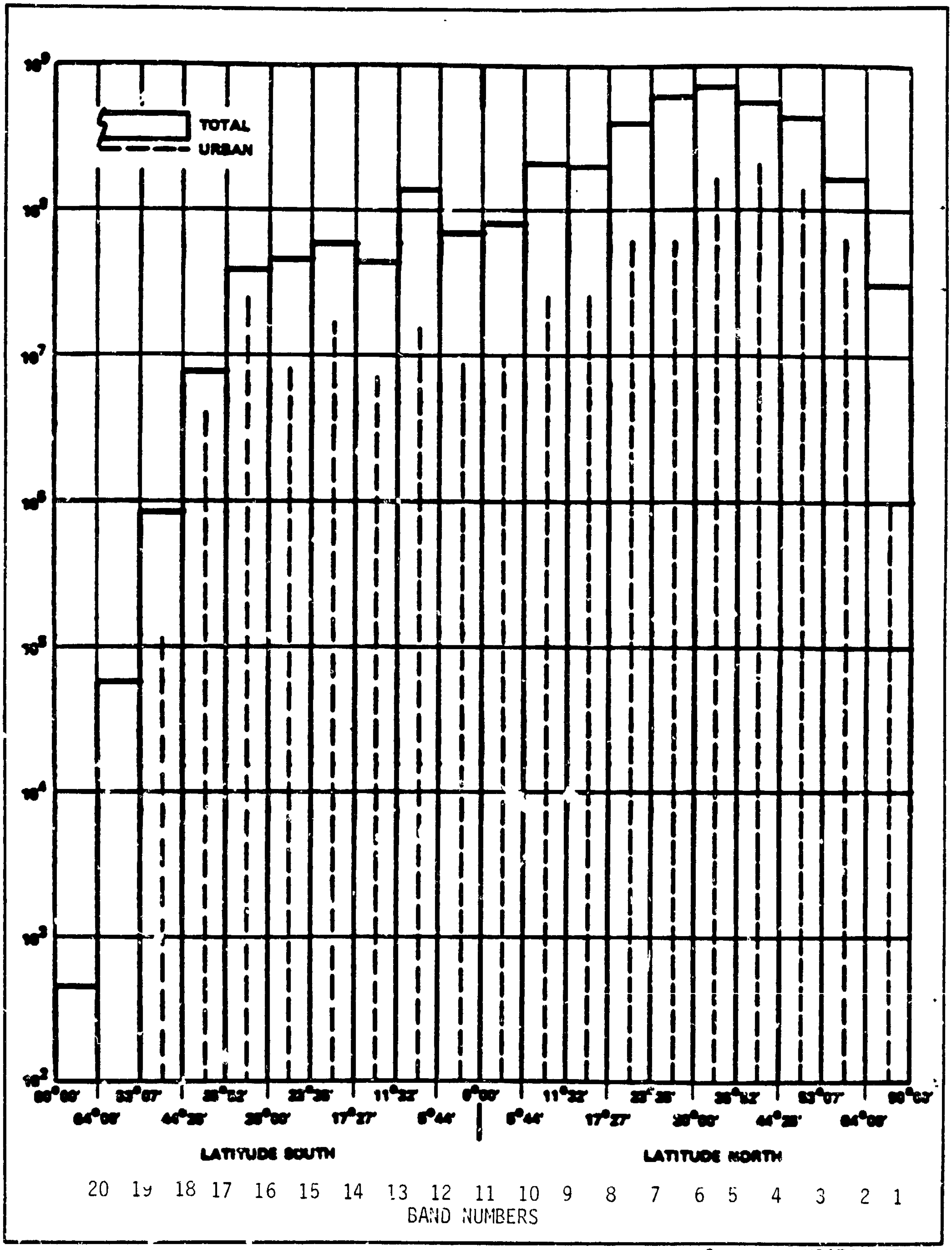


Source: USAEC 1975

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

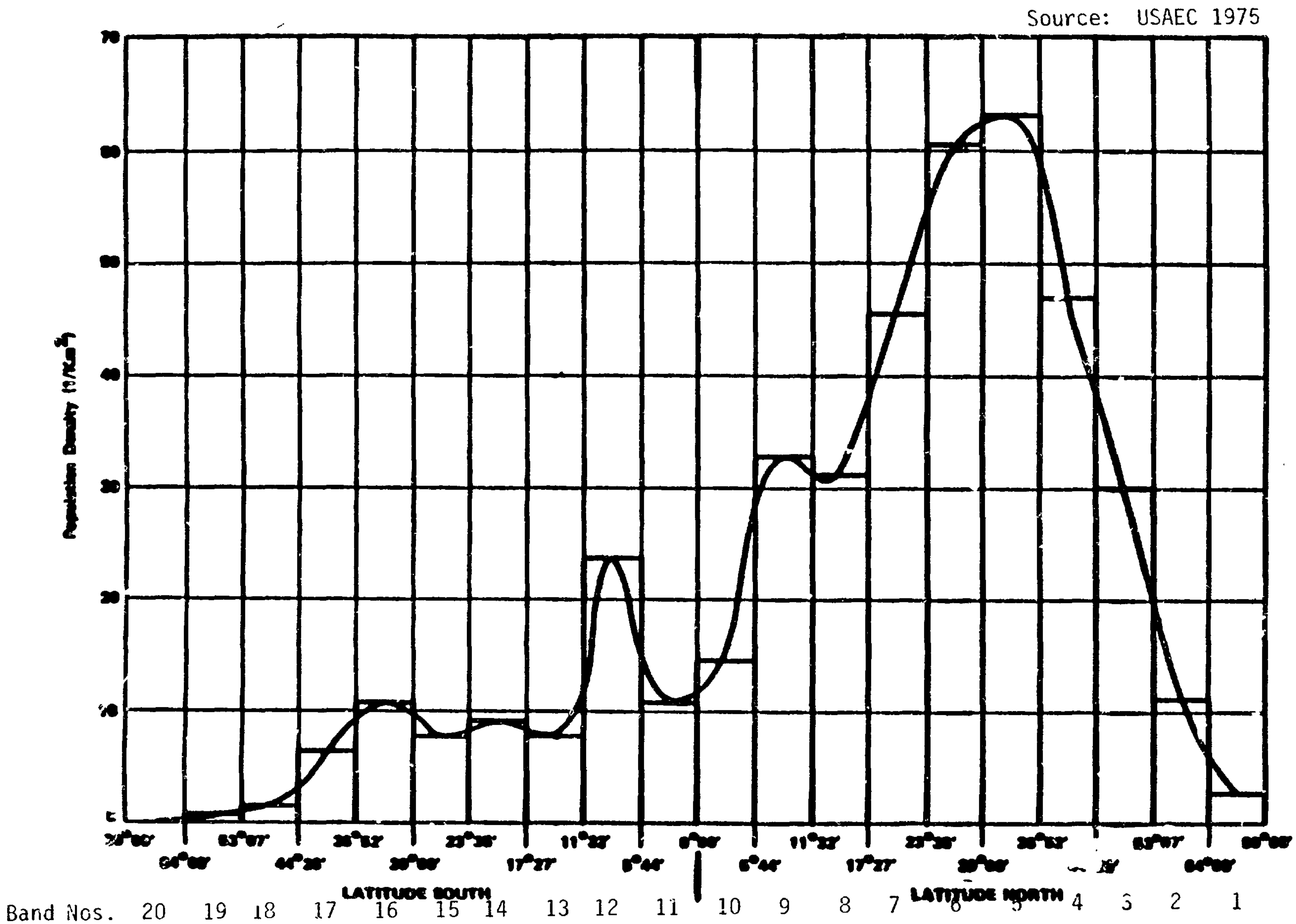


FIGURE 3-20. WORLD POPULATION (BAND LAND AREA) DENSITY BY LATITUDE BANDS

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 all but the more southern bands, can be found in urban 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 4-7).

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

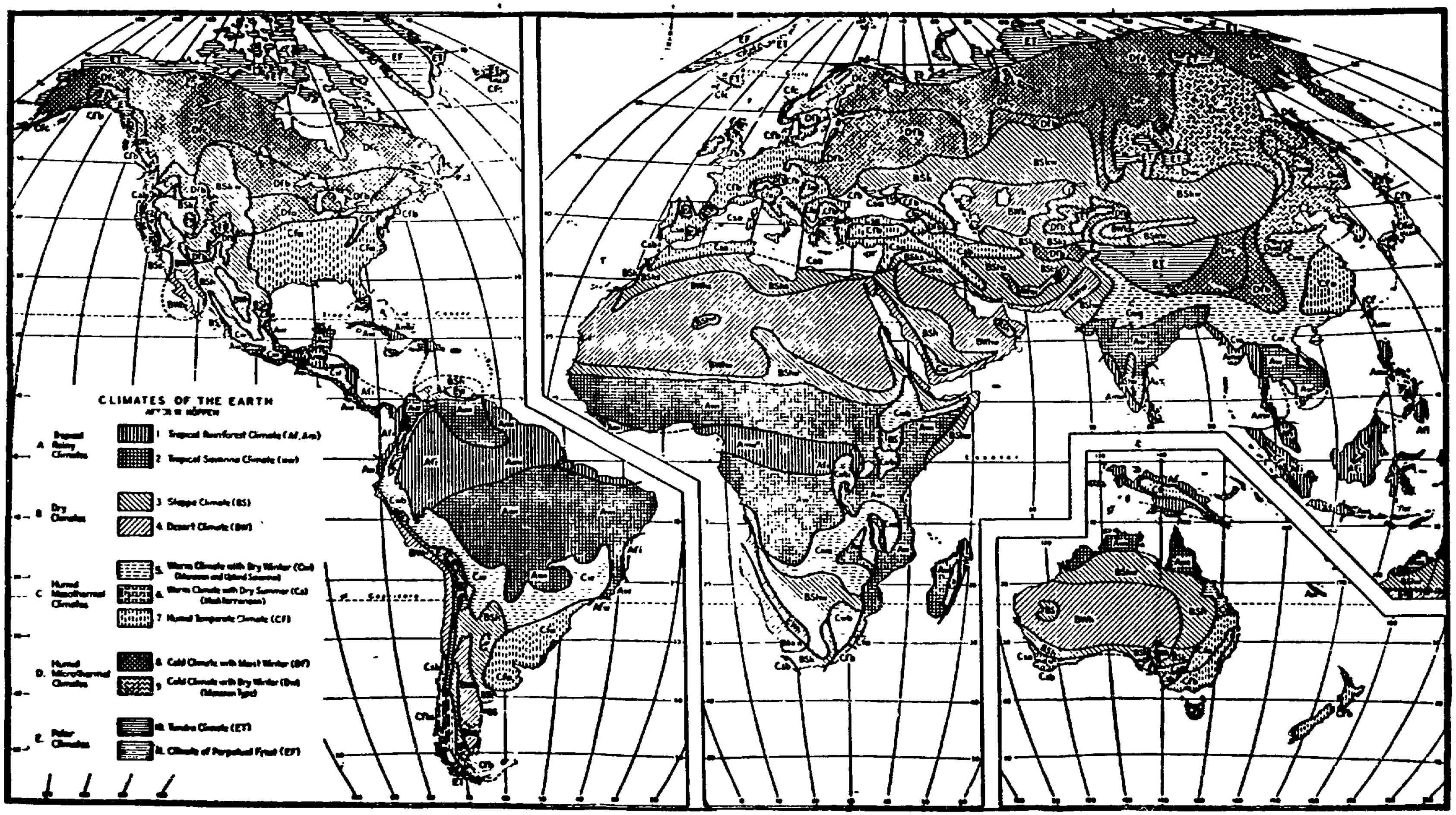
The distribution of surface types, worldwide, is an important characteristic in considering the potential consequences of accident scenarios analyzed for the Galileo mission. Table 3-5 provides a breakdown, by each of the 20 equal area latitude bands noted above, of the total land fraction and the total 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 4-7), 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 Galileo spacecraft RTGs, 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 Galileo mission accident.

Over the period 1945 through 1974, aboveground 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 of principally Pu 238 (about 9,000 curies), and Pu 241 and Pu 242. Aboveground nuclear testing thus 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 was deposited at and near the test sites, (EPA 1977). The remaining 325,000 curies was 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,



(SOURCE: USAEC 1975)

FIGURE 3-21. CLIMATES OF THE EARTH

TABLE 3-5. **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

principally 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. 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 U.S. In general, drier areas of the U.S. 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.

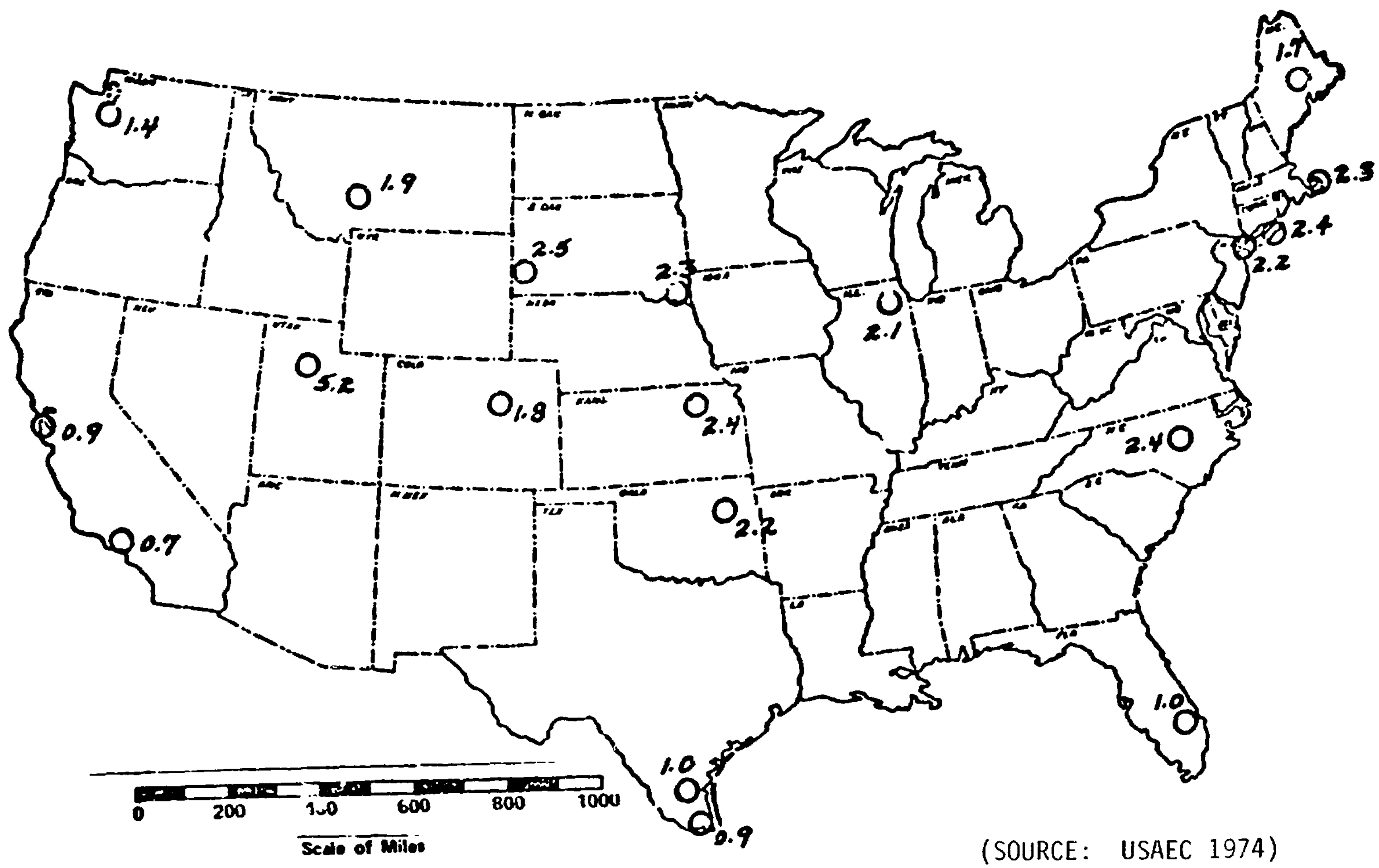
Referring to Table 3-6, it will be noted that the Pu 238 inventory from weapons tests (about 9,000 curies) was increased by a space nuclear source, specifically from the 1964 re-entry and burn-up of a SNAP-9A Radioisotopic Thermoelectric Generator. This release of plutonium into the atmosphere was consistent with the RTG design philosophy of the time. Subsequent RTGs, including those on the Galileo spacecraft, have been designed to fully contain the Pu 238 fuel to the maximum extend possible (see Section 2.2.2.2).

TABLE 3-6. 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)

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.



(SOURCE: USAEC 1974)

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

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4. ENVIRONMENTAL CONSEQUENCES

The principal purpose of this draft (Tier 2) Environmental Impact Statement (EIS) is to present information to enable a choice among the alternative actions presented in Section 2. This section discusses the potential environmental consequences that could result from the implementation of each of the alternatives available to the National Aeronautics and Space Administration (NASA) as presented in Section 2.

4.1 ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION

4.1.1 Implications of Completion of 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. The impacts associated with final launch preparations are addressed in the following subsection. There are no environmental consequences associated with the balance of the activities identified above (NASA 1988a).

4.1.2. Environmental Consequences of Normal Launch of the STS

The environmental consequences of normal operations and normal launches are summarized in this section and were discussed in detail in previously published NASA documents including EISs on the Space Shuttle Program (NASA 1978) and the Kennedy Space Center (KSC) EIS (NASA 1979), the KSC Environmental Resource Document (NASA 1986), and the Tier 1 EIS for the Galileo and Ulysses missions (NASA 1988a), and were found to be acceptable when weighed against the benefits of the space program.

Impacts on Land Use

Launch of the Galileo mission aboard the National Space Transportation System/Inertial Upper Stage (STS/IUS) would occur at Launch Complex 39 at the KSC. The launch complex and the area surrounding it are dedicated space launch land uses. The only special land uses nearby are Cape Canaveral National Seashore and Mosquito Lagoon about 2 miles to the north. Mosquito Lagoon is a designated State of Florida aquatic preserve and also an Outstanding Florida Water. Designated land uses in these areas would be unaffected by a launch of the Galileo mission.

Air Quality Impacts

A ground cloud will be formed by combustion in the Space Shuttle rocket engines during launch (NASA 1979). This cloud consists of the exhaust products from the solid rocket motors and liquid engines, the products of afterburning in the exhaust plume, the air that is mixed with the exhaust gases, and much of the heat energy that is generated. These gases have the potential for forming high concentrations of acids (hydrogen chloride mist - HCl) that can rain on and affect vegetation. This acid rain can affect the density of vegetation as described in the section on biological systems below.

Upper Atmosphere Effects

The Space Shuttle exhaust releases water, hydrogen chloride, chlorine, and aluminum oxide particles into the stratosphere and produces nitric oxide in the hot plume. The quantity of water released by the Space Shuttle is small compared to natural sources, and its effect on the ozone density will be insignificant (Cofer 1987).

During Shuttle maneuvers above an altitude of 180 kilometers (in the ionosphere), the exhaust products from the Orbital Maneuvering System (OMS) will reduce the ion concentration. This effect is localized and temporary. Effects on radio wave propagation will be insignificant. During Shuttle reentry, which will occur between a 70- and 90-kilometer altitude, some of the heated atmosphere will be converted to nitric oxide, which ionizes in ultraviolet sunlight. The length of the trail could extend to one-fourth the circumference of the Earth, but the width will be narrow. The required time for the trail to disappear has been calculated to be less than 1 day, and if wind shears are present, the trail could disappear in hours. The effects of the ionized trail on radio wave propagation are expected to be insignificant. The long-term effects of the nitric oxide on the stratosphere also have been studied and have been determined to be negligible (NASA 1978).

Sonic Boom

Launch of the STS results in three sonic booms with focal zones over uninhabited ocean waters. The Shuttle also will produce a sonic boom during reentry. Because of the large range of entry trajectories, the boom may occur partially over land. Overpressures have been calculated for these conditions, and trajectories have been tailored to minimize the effect on the ground (NASA 1986). These overpressures are not enough to cause damage or injury but are in the nuisance or annoyance range according to the report issued by the Sonic Boom Panel of the International Civil Aviation Organization in October 1970.

Hydrology and Water Quality

Each STS launch generates about 863,000 gallons of deluge and washdown wastewater (NASA 1986). Much of the deluge water is vaporized and contained in the ground cloud. Shallow impounded waters near the launch complex typically experience a sharp but short-term (about 2 hours) depression in pH immediately following launch due to the HCl scavenging from the ground cloud. About 326,000 gallons of washdown water, along with an unknown quantity of deluge water, are collected in two concrete tanks connected to the launch pad flame trench. This water is neutralized to a pH of about 8.5 after the launch and is landspread over the adjacent pad area. Groundwater studies have been unable to establish a cause/effect relationship between launches and periodically detectable quantities of aluminum, cadmium, chromium, iron, lead, and volatile organic compounds in the groundwater.

Biological Systems

Information on the impacts of launch events to the local environment has been documented from a 54-acre area outside of the perimeter of Launch

Complex 39A (LC-39A). Described as within the near field environment, this tract has experienced significant changes in vegetative community structure (NASA 1986). Overall, total vegetative cover in the near field have been reduced and unvegetated areas have expanded.

Impact analyses indicate that thin-leafed herbaceous species, and shrubs with succulent leaves, are more sensitive to launch cloud deposits than are typical dune grasses (NASA 1986). Dune community species exhibiting sensitivity to launch cloud effects include camphorweed (Heterotheca subaxillaris), inkberry (Scaevola plumieri), beach sunflower (Helianthus debilis), and marsh elder (Iva imbricata). Dune species exhibiting resistance to launch cloud effects include sea oats (Uniola paniculata), beach grass (Panicum amarum), and slender cordgrass (Spartina patens).

Shallow impounded waters in the vicinity of Launch Complex-39A have experienced fish kills following the launch of the Space Shuttle (NASA 1986). These waters can experience sharp depressions in pH as a result of launch cloud rainout. Reductions in pH of four units within 30 minutes of a launch event are possible. The sudden acidification of surface waters is believed to be responsible for the fish kills accompanying launch events. Species of fish collected from the near field impact area exhibit symptoms of severe ionic imbalance and anoxia, resulting from extensive gill damage (NASA 1986). Fish kills have ranged from small (less than 100 individuals) to major (greater than 1,000 individuals) (NASA 1979).

While the impact on the near field flora and fauna is measurable following each launch event, these impacts are localized and are not likely to extend significantly from the near field environment.

Endangered and Threatened Species

Some protected species, principally colonial nesting birds such as snow egret, white ibis and yellow-crowned night heron, are known to inhabit at least the Picnic Island nesting area about 1 mile to the west of Launch Complex 39. Of these three species, the snowy egret is listed by the State of Florida Game and Freshwater Fish Commission as a "species of special concern". The ibis and heron are listed by the Florida Committee on Rare and Endangered Plants and Animals as "species of special concern". An osprey nesting site is also located in the Picnic Island area. The osprey is listed by the Convention on International Trade in Endangered Species of Wild Flora and Fauna which was implemented by the Endangered Species Act of 1973. The nearest bald eagle (Federally endangered) nesting site is over 5 miles from the launch complex. Banana Creek, about 1 mile west of the launch complex, is listed as critical habitat for the Federally endangered Florida manatee. (See Appendix D-4 for more detail and figures showing locations inhabited by these species.) No endangerment of these species will result from a normal launch.

In addition to the above, the potential exists for other listed species such as the roseate spoonbill (State species of special concern) as well as some listed plants to occur in the vicinity of the launch complex.

Birds would be subject to a startle/flight reaction with ignition of the STS engines and would probably avoid the area and the exhaust cloud, thus should not experience any significant adverse impact. Protected plant species that may exist in the area could be exposed to the ground cloud and its high levels of acid mist and particulates. Given that the near-field area around the launch complex (out to about 930 feet) has been impacted by previous and future launch activities, it is unlikely that the Galileo mission would result in any additional impact on listed plants.

Socioeconomic Factors

Launch of the Galileo mission aboard the STS/IUS from KSC should have no significant adverse effects on the socioeconomic environment surrounding KSC. In fact, given the Nation's interest in the Space Program and general public viewing of planned launches from KSC, the launch of the Galileo mission should have a short term beneficial effect on the economy of the nearby area from the influx of tourists who come to view a launch. Such tourists can number over 100,000 people who add temporarily to traffic and congestion in the area at launch times.

Radiation Exposure

Exposures of occupational personnel to minor external radiation could occur during the normal movement and handling of the Radioisotope Thermoelectric Generators (RTGs) before launch at KSC. Radiation from the RTG and Radioisotope Heater Unit (RHU) components has a very short range, and all such operations occur under strict conditions and supervision. Therefore, there is no health effect on occupational personnel or the public from these activities.

4.1.3 Implications of Balance of Mission

The balance of a normal mission will have no significant adverse impacts to the environment. Recovery of the jettisoned reusable solid rocket boosters would introduce some soluble products from the small amount of residual fuels left in the boosters. The impact would be temporary and localized to an area immediately adjacent to the boosters.

With completion of its portion of the Galileo mission, the STS would return to Earth for a landing at Edwards Air Force Base in California. A normal return would result in a sonic boom during reentry from orbit and during landing. These sonic booms are not expected to adversely impact the environment.

The Galileo spacecraft, once injected into its Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory, would have no impact on the human environment given a normal trajectory. The Jupiter encounter of the Galileo spacecraft would also have no impact on the human environment.

4.1.4 Consequences of Shuttle Launch Accidents

4.1.4.1 Overview of Shuttle Accidents

Accident Scenario Definition Approach

A systematic approach was utilized to identify those credible accident scenarios that might occur. The Shuttle system was divided into its major elements: Launch Support Equipment, Payload, Orbiter, External Tank, Solid Rocket Boosters, Space Shuttle Main Engine/Liquid Propellant System (SSME), and Range Safety Destruct System. Each of these elements was further divided into its major failure components. Credible failure modes refer to those which generally cause a loss of the vehicle and may produce an environment which is a potential threat to the RTG(s). Representative accident scenarios were defined by grouping similar accident scenarios which resulted from each of the credible failure modes.

A detailed Galileo Earth Avoidance Study (JPL 1988) of possible spacecraft and mission failures has determined only three failure types which represent even a remote threat of Earth impact during Earth-gravity-assist flybys. They are: retro-propulsion module penetration by a micrometeroid, a small combination of lesser probability spacecraft failures, and multiple serial failures in the ground command system. The total probability of spacecraft re-entry and impact is less than 5×10^{-7}.

Accident Scenarios and Environment Overview

Accident scenarios and environments from NASA 1988 are treated in Appendix B and summarized in Table 4-1. For purposes of analysis, the mission was divided into mission phases generally related to vehicle configuration and/or activity.

The applicable intact abort modes, primary accident causes, and applicable environments are indicated in the Table.

The intact abort modes -- Return to Launch Site (RTLS), Transoceanic Abort Landing (TAL), Abort-Once-Around (AOA), Abort-To-Orbit (ATO), and Abort-From-Orbit (AFO) -- are explained in detail in Appendix B.2. The first four are generally caused by premature shutdown of one or more Space Shuttle Main Engines SSMEs. AFO would be a result of ATO or a problem with the 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.

The primary accident causes for each phase are generally 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 Solid Rocket Booster (SRB) fragments will achieve higher velocity if a 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 re-entry heating and subsequent ground or water impact.

TABLE 4-1. STS/IUS ACCIDENT SCENARIO AND ENVIRONMENT SUMMARY

MISSION PHASE			INTACT ABORT MODES	PRIMARY ACCIDENT CAUSES	APPLICABLE ENVIRONMENTS*					
No.	Descriptor	Time			Ground Propellant Explosion	SRB Explosion	Liquid Engine/ Tank Explosion	IUS Explosion	Re-Entry	Ground or Water Impact
0	Prelaunch Propellant Loading	T-8.5 hr to T=0s	--	Propellant Loading SSME Ignition**	X		X			X
1	SRB Ascent	T+0s to 125s	RTLS TAL	SRB SSME**	X	X	X			X
2	2nd Stage	T+125s to 514s	TAL AOA ATO	SSME**			X		X	X
3	On Orbit	T+514s to 6 hr 40 min	AFO	Shuttle					X	X
4	Payload Deploy	T+6 hr 40 min to 7 hr 28 min		IUS				X	X	X
5	VEEGA	T+7 hr 28 min to 38 months		Micrometeoroid puncture of s/c propellant tank					X	X

*NOTE: Explosion environments include shock overpressures, fireball, and/or fragments depending on source and time of accident.
**SSME = Space Shuttle Main Engine

The explosion environments can have multiple elements as seen by the RTGs or RHUs. The sudden release of energy in air will drive a shock wave that can distort or break up the RTG, depending on its strength. The same explosive energy can push fragments of structure into the RTG. Finally, the resulting fire associated with accidents on or near the ground can provide thermal stresses on the RTG elements.

STS/IUS Configuration

In the wake of the Challenger accident, NASA cancelled development of the Centaur G-Prime for flight crew safety reasons unrelated to nuclear launch safety. That rocket was an energetic liquid hydrogen/liquid oxygen upper stage launch vehicle. In its place, NASA will use the solid fueled IUS in the Shuttle for launching deep space missions such as Galileo. An IUS successfully deployed a Tracking Data Relay Satellite into Earth orbit during the successful September 1988 STS Discovery flight.

The STS/IUS configuration poses much less potential environmental risk than the STS/Centaur, which was addressed in the draft EIS of September 1985 (NASA 1985a). The earlier STS/Centaur safety analysis indicated that most accident environments were dominated by Centaur involvement irrespective of the initiating cause (e.g., a SRB rupture would generate high-velocity fragments that would cause a Centaur rupture and explosion). The IUS, a solid fueled upper stage whose fuel is more inert, is much less likely than the Centaur to explode and contribute to accident environments.

It is noteworthy that an IUS upper stage was on board during the Challenger accident in order to propel a data relay satellite to geosynchronous 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.

These findings indicate that the IUS did not contribute to the accident environment. Also, based on the general design of the RTG, it is reasonable to infer that had an RTG been on board the Challenger with an IUS, it would not have been damaged significantly in the accident, and therefore, it is expected that there would have been no release of plutonium.

Safety and Environmental Analysis Processes

The safety and environmental analysis processes are depicted in Figures 4-1 and 4-2. The analyses consist of defining potential accident scenarios and resulting environments to which the RTGs/RHUs may be exposed and the probability distributions of these accidents and environments, and then assessing the consequences of subjecting the RTGs/RHUs to those environments. The risk is then a combination of the probabilities of the

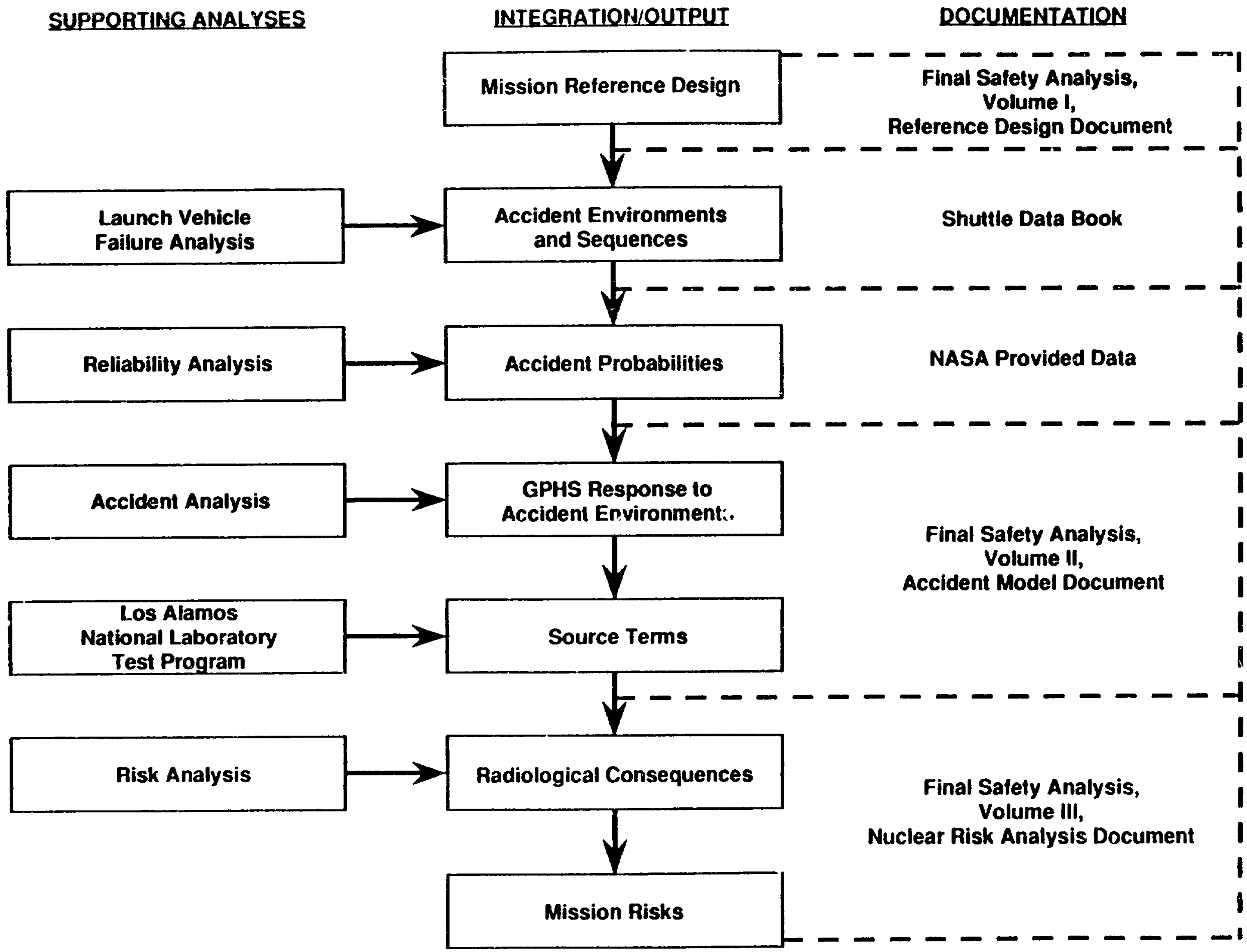
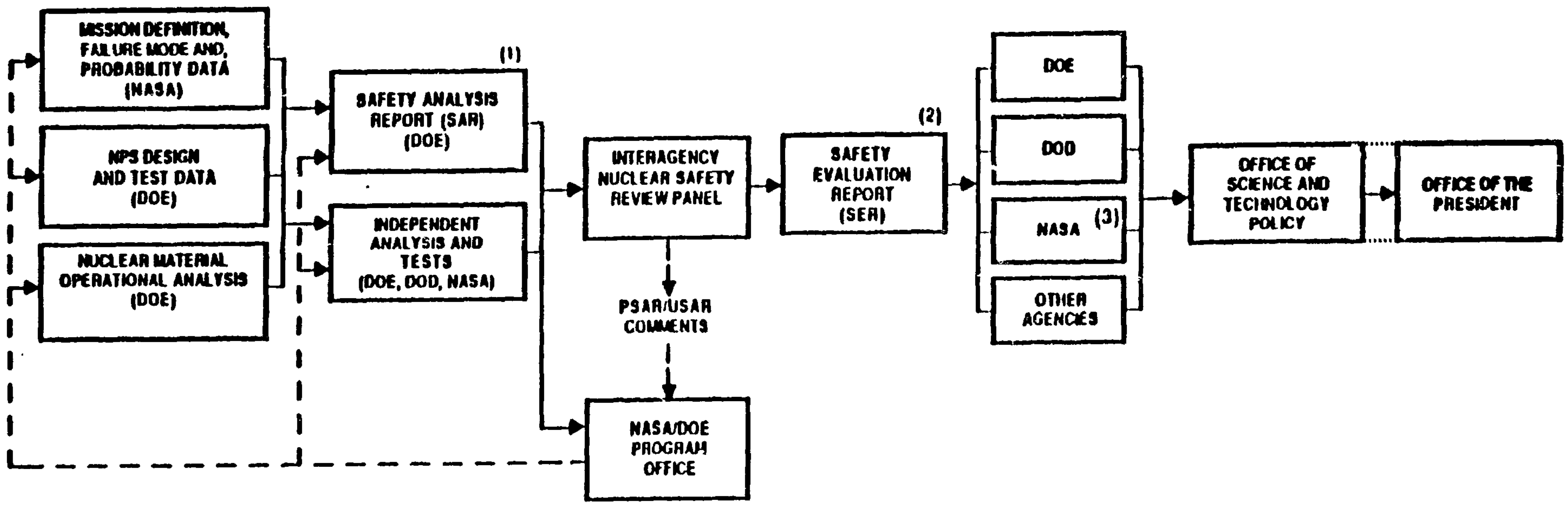


FIGURE 4-1. FINAL SAFETY ANALYSIS REPORT DEVELOPMENT PROCESS



(1) PSAR = PRELIMINARY
USAR = UPDATED
FSAR = FINAL
} SAFETY ANALYSIS REPORT

(2) SAFETY EVALUATION REPORT WRITTEN BY INSRP BASED ON FSAR REVIEW AND INDEPENDENT ANALYSIS

(3) RESPONSIBILE MISSION AGENCY MUST MAKE LAUNCH RECOMMENDATION BASED ON REVIEW OF FSAR AND SER

FIGURE 4-2. AEROSPACE NUCLEAR SAFETY REVIEW PROCESS accidents and their consequences. At this time, there is a Shuttle Data Book (NASA 1988c) that contains scenarios and environments for the STS/IUS configuration, and a Safety Analysis Report (DOE 1988).

A number of documents were developed for the planned 1986 launch of Galileo and Ulysses using the STS/Centaur. Among these documents were: the FSAR (DOE 1985a, DOE 1985b, DOE 1985c); a draft SER (INSRP 1986) prepared by the Interagency Nuclear Safety Review Panel (INSRP), but never formally completed due to cancellation of the STS/Centaur; and the "Assessment of the Safety Documentation for the Galileo and Ulysses Mission" prepared by the DOE Office of Nuclear Safety (DOE 1986).

During the interval between the completion of the FSAR (late 1985) and the present, work has been redirected to develop and to improve and refine the accident models and techniques for analyses applicable to the STS/IUS case as follows.

A new FSAR and SER are required for the STS/IUS because the analyses in the December 1985 FSAR are not applicable to the present case. The replacement of the Centaur with the IUS, and the assessment of the STS 51L and 34D-9 accident data, led NASA to develop a revised Data Book of the STS/IUS accident scenarios and possible environments. Therefore, the results of the earlier STS/Centaur FSAR are not relevant to the STS/IUS configuration.

4.1.4.2 Non-Radiological Accident Consequences

Unplanned events that might occur during Space Shuttle launch operations include explosions, fire, the release of toxic gases, crash, or mission abort. The following discussions are taken from the Shuttle Program EIS (NASA 1978).

<u>On-Pad Fire or Explosion</u>

The most serious consequence of an on-pad fire involving the entire Space Shuttle vehicle will be the release of toxic combustion products from the SRBs. The large heat release associated with the burning of the main engine's propellants will assist the cloud of combustion products in rising to a high altitude. Although the quantity of SRB combustion products released at ground level will exceed that released at or near ground level in a normal launch, the additional heat and cloud rise contributed by the main engine's propellants will compensate in terms of ground-level concentrations of hydrogen chloride and chlorine.

Explosions on the launch pad might achieve significant blast effects under special circumstances. Such circumstances would be those that lead to sudden rupture of the External Tank. Immediately prior to launch, all unprotected personnel are evacuated from the launch pad. Consequently, no injuries other than to the flight crew are anticipated, even for this worst-case event.

<u>Ascent Accident</u>

Public safety from hazards associated with the launch and early ascent of the Shuttle is the responsibility of the Range Safety Officer. For early flight, this is exercised through the capability for ground-commanded flight termination (vehicle destruct) to prevent impact on land should the vehicle depart radically from its nominal flight path. This protection of the public is provided until the vehicle achieves orbit.

External Tank Jettison

In a normal mission, the External Tank will be jettisoned to impact in a preplanned ocean area remote from shipping zones. Additionally, the impact area will be announced to air transporters and shippers before the flight. This practice is identical to that used in current spaceflight activity to protect aircraft and ships from re-entry of suborbital rocket stages. In case of an early mission abort, the External Tank may be jettisoned into the ocean near the launch site. A portion of the possible impact area coincides with the launch corridor where warnings are issued to aircraft and ships before the launch and which is under surveillance during launch operations. Because the External Tank will not contain toxic materials, the hazard to the environment from impact either in the preplanned area or elsewhere will be confined to physical effects at the impact point.

Jettison of the Solid Rocket Booster

Damage to the environment would be limited to the physical effects of the impact, as the SRBs are inert after burnout. In a normal flight or in an abort, the SRBs will descend to the preplanned ocean area recovery zone by parachute. The location of the recovery area is announced to aircraft and ships before launch, and the area is maintained under surveillance.

If the SRB parachute were to fail, the SRB would still impact within the preplanned zone. The SRB might be damaged beyond further usefulness or sink and be lost, but no long-term environmental hazards would result.

Orbiter Landing

Upon successful completion of its mission the Shuttle orbiter will return to Earth and land at Edwards Air Force Base (EAFB).

Should the Shuttle crash, the consequences would be similar to those of any large aircraft crash, except for the fire which frequently follows the crash of conventional aircraft. Because the Shuttle will contain only minimal quantities of propellants, any postcrash fire will be more confined, less intense, and briefer than fires accompanying the crash of conventional aircraft.

In conventional aircraft operations, which should closely resemble Shuttle atmospheric flight operations, the most probable location of a crash on landing is near or on the runway. The Shuttle will land at the remote EAFB.

Effect of Unplanned Events on the Marine Environment and Water Quality

The potential impact of unplanned Space Shuttle operational events on the marine environment and water quality are limited to the following: in-flight failures which may result in vehicle hardware and propellant landing in the ocean, and on-pad accidents and propellant spills which may result in run-off of propellants to local drainage systems.

The potential sources of pollutants during unplanned events and the major pollutants are as follows:

Potential Source	Major Pollutant
Solid propellants	Ammonium perchlorate (NH_4ClO_4)
Liquid propellants	Mono Methyl Hydrazine (MMH)
	Hydrazine (N_2H_4)
	Nitrogen tetroxide (N_2O_4)
Lubricants, hydraulic fluid	Hydrocarbons

In-Flight Failures

Possibilities of pollution are primarily associated with toxic materials which may be released to and are soluble in the marine environment. Rocket propellants are the dominant source of such materials. A secondary consideration relates to oils and other hydrocarbon materials which may be essentially immiscible with water but, if released, may float on the surface of the water. The quantities of hydrocarbons used are small. In case of an in-flight failure in the early stages of flight, the Shuttle would be expected to separate intact and return to the launch site.

The SRB propellant would continue to burn with the same products of combustion from a normal launch (primarily hydrogen chloride, aluminum oxide and carbon monoxide) being dispersed into the air or absorbed into the ocean water. Any unburned solid propellant would slowly disperse.

The impact of the Shuttle's External Tank would release liquid hydrogen and liquid oxygen, which would burn or evaporate rapidly into the atmosphere. The MMH is contained in the Shuttle only and would be returned to the launch site. However, if the Shuttle were forced to abort to a water landing, this material would enter into the water. These materials are expected to dilute to nontoxic levels of concentration within the area affected by the emergency landing (NASA 1978). Small schools of fish could be affected, but no large-scale or permanent effects on marine life are expected. The compounds are all chemically active and are not expected to persist in the marine environment (NASA 1978).

On-pad Accidents and Propellant Spills

Provisions such as dikes and catch basins are in place for containing on-pad spills and disposing of the spilled propellant without contaminating the water environment. On-pad vehicle failures would normally be expected to result in a fire that consumed almost all of the propellants. Any unconsumed propellant would be treated in the same way as a spill.

4.1.4.3 Radiological Accident Analysis

The use of plutonium-238 dioxide (PuO_2) fuel, a radioactive material, in the two General Purpose Heat Sources (GPHSs) - Radioisotope Thermoelectric Generators (RTGs) and the 131 light weight Radioisotope Heater Units (RHUs) on the Galileo spacecraft necessitates evaluation of the radiological risks to persons in the launch site vicinity and the general population worldwide resulting from postulated accidents occurring during the mission. The inventory of PuO_2 fuel is 132,200 Ci in each RTG (264,400 Ci total) and 33.6 Ci in each RHU (4334 Ci total). The RTGs and RHUs are described in Section 2.2.2.1.

Only accidents that could result in damage to a RTG and possible fuel release are addressed in this section. These accidents are presented in Table 4-2 for each of the six mission phases.

The RHUs aboard the Galileo spacecraft could be subjected to a wide variety of hostile environments. A thorough, systematic assessment of the response of RHUs to these environments shows that fuel release would occur only in certain instances.

Some RTG accidents listed in Table 4-2, could result in the release of fuel. Each of these (which could result in the release of fuel) has a probability of occurrence and a predicted amount of released fuel (called a source term). The predicted release is based on the subsequent (i.e., conditional) probability that the accident will lead to a release of radioactive material.

The distribution of accidents and consequences are characterized by three parametric representations: the most probable case, the maximum credible case, and the expectation case. These cases are defined for each mission phase as follows:

- <u>Most Probable Case</u>: The single release having the highest probability.

- <u>Maximum Case</u>: The single fuel release that maximizes plutonium release coupled with meteorological assumptions giving the highest population dose. A probability limit of $1x10^{-7}$ was determined for the maximum credible accident. It is recognized that limiting probabilities of 10^{-5} and 10^{-6} have been used in safety evaluations for nuclear power plants. NASA has however adopted 10^{-7} as an added measure of conservatism because space launches to date present a smaller sample population than in the other program.

- <u>Expectation Case</u>: The probability listed for the expectation case is the total probability of all accidents for a plutonium release for that phase of the mission. The expectation case uses all of the predicted release and their probabilities (without regard to the $1x10^{-7}$ limiting value) for all of the accident scenarios in a mission phase to define a probability weighted source term - the statistically expected release.

TABLE 4-2. ACCIDENTS BY MISSION PHASE, STS

Phase	Description	Accident
0	Prelaunch to Launch	Inadvertent Range Safety System destruct Fire/explosion
1	Ascent	Solid Rocket Booster failure Range Safety System destruct Aft compartment explosion Vehicle breakup Crash landing Ocean ditching
2	Second Stage	Orbiter failure External Tank failure Space Shuttle main engine failure Payload failure Range Safety System destruct Crash Landing Ocean ditching
3	On-orbit	Orbiter failure and re-entry
4	Payload Deploy	IUS Solid Rocket Motor Case burst IUS Solid Rocket Motor no ignition, low impulse IUS Tumbling from separation or recontact IUS misaligned burns due to guidance failure IUS erratic burns
5	Venus-Earth-Earth Gravity Assist Maneuver	High-speed re-entry of the spacecraft

The radiological consequences include:

1. The short term radiation dose that results from the initial exposure by inhalation of the radioactive cloud. The doses are 70 year dose commitments resulting from the long-term retention of the material in the body.

2. The long-term radiation dose which would result from continuous exposure to materials deposited in the environment over an extended period following release. Long-term doses include those outside Kennedy Space Center boundaries and worldwide populations due to inhalation of resuspended material and ingestion of contaminated food products and water over a 70-year period. In addition, long-term doses to onsite Kennedy Space Center workers due to inhalation of resuspended material is calculated for onsite workers for a period of 35 years based on 40 hours per week.

3. Estimates of land and surface water areas contamination. This contamination results from deposition of PuO_2 from a plume or cloud created by an explosion or fire, or from surface impact of unvaporized reentering PuO_2 particles.

This information is presented in the following terms for each case:

1. Numbers of persons estimated to be subject to greater than specified levels of both short-term doses and long term doses, based on the launch area population data and worldwide population density data.

   Doses appear in terms of person-rems. A person-rem is a unit of collective dose from a given source of radiation exposure. As used here, it is the sum of all collective individual lifetime (70-year) doses in a given population from exposure to a release of plutonium-238 from a mission phase accident. To illustrate - as the released material is carried away from the point of release, it is dispersed and its concentration decreases, but the area and population exposed generally increases, as illustrated in Figures 4-3, 4-4, and 4-5. The area under the curves represents the collective lifetime exposure of the population where the atmosphere carries the material. Health impacts are assessed probabilistically based on population dose.

2. Total short-term and long-term population doses. In calculating population doses, the concept of <u>de minimis</u> has been used, meaning a dose level below concern and from which no health effects are expected. For the purpose of this document, the <u>de minimis</u> dose was taken to be 1 mrem/year and 50 mrem total dose commitment. Total population doses are reported both with and without <u>de minimis</u>.

3. The maximum short-term and long-term doses to individuals.

4. Estimates of land and surface water areas contaminated above a reference level. A "screening level" of 0.2 uCi/m2 has been recommended by the U.S. Environmental Protection Agency (EPA) for unspecified transuranic elements, including plutonium, and has been used as the reference level.

Tables 4-3 and 4-4 present the results of the accident modeling for the most probable accident in each mission Phase and the most severe "credible" accident for each mission Phase. For these presentations, accidents with probabilities less than about 1 in 10 million were considered beyond the range normally considered credible and not listed. In the detailed accident analyses presented in Appendix B and the FSAR, all accident sequences and scenarios with probabilities as low as 1 in 10 million (1×10^{-7}) were considered. It is recognized that limiting probabilities of 10^{-5} and 10^{-6} have been used in safety evaluations for nuclear power plants. NASA has however adopted 10^{-7} as an added measure of conservatism because space launches to date present a smaller sample population than in the other program.

The releases for both the most probable and maximum cases illustrate that the RTGs and RHUs survive mission accidents remarkably well and contain essentially all of the radioactive materials as designed. The releases are only a very small fraction of the available plutonium. The only accidents identified in which more than 0.01 percent of the plutonium could be released were the near launch pad accidents, where both large quantities of fuel and propellant were available in conjunction with hard surfaces for the GISs to impact, and the extremely low probability inadvertent re-entry in the VEEGA maneuver, in which essentially all of the plutonium in a graphite impact shell is assumed to be released if the impact shell hits hard rock at certain angles. The re-entry characteristics of this accident are such that flight paths of the GISs are essentially independent, implying that the probability of more than a few hitting rock and releasing plutonium is extraordinarily low.

A summary of the results of the radiological consequence analysis are presented in Tables 4-5 and 4-6. More detailed results are presented in Section B.4 of Appendix B. Consequences are expressed in terms of collective dose to the affected population and amount of land contaminated above the screening level proposed by the EPA. The population dose estimates are 70-year doses.

The most probable, maximum, and expectation cases present a representative range of accidents and consequences. The most probable case has the highest probability but the consequences could vary from those indicated in Table 4-5 because it is representative of only one set of the variables--quantity of release, location of release, particle size distribution, probability of occurrence, and meteorological conditions. A change of any one of these variables, except the probability of occurrence, could result in a different set of consequences. The maximum, presenting the highest releases, is utilized to give an upper limit and is developed primarily for emergency planning assistance. The expectation case represents a probabilistic combination of all accident scenarios resulting in a release in a phase under average meteorological conditions. These two cases together for each Phase present a range of the type and magnitude of

TABLE 4-3. SUMMARY CHARACTERISTICS OF MOST PROBABLE CASES BY PHASE

Phase	Accident Type	Curies Released	Probability of Release	Release Category	Description
0	Fire Followed by Explosion	44	$5x10^{-7}$	Fireball	o Occurs on the Launch Pad o Fueled Clads breached by steel impact inside fireball
1	Solid Rocket Booster Failure Resulting in Loss of Thrust	796 125	$3x10^{-4}$ $3x10^{-4}$	Fireball Ground Level	o Occurs on the Launch Pad o Fueled Clads breached by Concrete impact inside and outside fireball
2	Vehicle Breakup	1	$2x10^{-6}$	Ground level	o Occurs on the African Continent o One module breached by impact on rock
3	Orbiter Reentry and Breakup	4	$6x10^{-6}$	Ground level	o Occurs at 0^0 latitude o One module breached by impact on rock
4	IUS Failure	4	$4x10^{-4}$	Ground level	o Occurs at 0^0 latitude o One module breached by impact on rock
5	Inadvertent Reentry	11,568[a]	$1x10^{-7}$	Ground level	o Occurs at 0^0 latitude o Inventory of three Graphite Impact Shells released by impact on rock

a. 3,856 Curies per Graphite Impact Shell

TABLE 4-4. SUMMARY CHARACTERISTICS FOR MAXIMUM CASES BY PHASE

Phase	Accident Type	Curies Released	Probability of Release	Release Category	Description
0	Fire Followed by Explosion	44	$5x10^{-7}$	Fireball	o Occurs on the Launch Pad o Fueled Clads breached by steel impact inside fireball
1	Solid Rocket Booster Failure Resulting in Loss of Thrust	1,864	$1x10^{-4}$	Ground Level	o Occurs on the Launch Pad o Module breached by impact on concrete outside fireball
2	Vehicle Breakup	1	$2x10^{-6}$	Ground level	o Occurs on the African Continent o Fueled Clads breached following impact of one module on rock
3	Orbiter Reentry and Breakup	8	$1x10^{-7}$	Ground level	o Occurs at 33^{o}N latitude o Fueled Clads breached following impact of two modules on rock
4	IUS Failure	8	$7x10^{-6}$	Ground level	o Occurs at 33^{o}N latitude o Fueled Clads breached following impact of three modules on rock
5	Inadvertent Reentry	11,568[a]	$1x10^{-7}$	Ground level	o Occurs at 33^{o}N latitude o Fueled Clads breached following impact of three Graphite Impact Shells on rock

a. 3,856 Curies per Graphite Impact Shell and three impact points

TABLE 4-5. SUMMARY OF RADIOLOGICAL CONSEQUENCES MOST PROBABLE CASES, STS

		Population Dose, Person-rem			Area (Square Kilometers) with Deposition Above 0.2 uCi/m²			
Mission Phase	Release Probability	Total	Above De Minimis	Health Effects	Dry Land	Swamp	Inland Water	Ocean
0	5×10^{-7}	10.1	0	0	12.5	1.63	4.57	0
1	3×10^{-4}	176	.003	0	43.3	15.9	25.7	0
2	2×10^{-6}	.23	.068	0	0	0	0	0
3	6×10^{-6}	5.99	2.45	0	.058	0	.001	0
4	4×10^{-4}	5.99	2.45	0	.058	0	.001	0
5	1×10^{-7}	1280	833	.2	13.2	0	.296	0

TABLE 4-6. SUMMARY OF RADIOLOGICAL CONSEQUENCES, MAXIMUM CASES, STS

		Population Dose, Person-rem			Area (Square Kilometers) with Deposition Above 0.2 uCi/m²			
Mission Phase	Release Probability	Total	Above De Minimis	Health Effects	Dry Land	Swamp	Inland Water	Ocean
0	5×10^{-7}	179	0	0	4.13	.128	2.64	.044
1	1×10^{-4}	4,910	3,710	0.7	2.03	.688	2.53	.18
2	2×10^{-6}	7.9	1.8	0	0	0	0	0
3	1×10^{-7}	217	58.8	0	.12	0	.003	0
4	7×10^{-6}	217	58.8	0	.12	0	.003	0
5	1×10^{-7}	54,000	52,900	9.8	8.91	0	.20	0

The tables of radiological consequences should be read as follows: first column lists mission phase, see page 4-14 for descriptions; second column lists the total probability for the release in that phase; third column lists the collective lifetime (i.e., 70-year) exposure of the people resident where the atmosphere carries the material; fourth column lists the lifetime exposure de minimis; fifth column gives the statistical incremental health effect of that exposure; last four columns list areas over which the material deposits. Thus, in Phase 5 for the maximum case: the probability of the release is one in ten million; if a release occurs, then there could be a maximum 70-year exposure of 54,000 person-rem to a population of 83,000 people (52,900 above de minimis); and there would be an increment of 9.8 cancer fatalities compared to a normally expected amount of about 16,000 in a population of 83,000 people.

occurrences that could occur for each mission Phase. The impacts of the various uncertainties in the accident modeling and analysis are presented in Section 4.1.4.7.

The consequences presented in Tables 4-5 and 4-6 indicate that the collective population doses to those affected by the accidents is quite small, ranging from 0 (for wind blowing offshore) to 176 (for nominal meteorological conditions) person-rem for the Most Probable Case or to 4,900 person-rem for the Maximum Case in Phase 1. In mission Phase 5, the maximum case has a dose rate of 54,000 person-rem. The analysis for mission Phase 5 uses an exposed population of 83,000 - assuming a uniform areal population distribution. Over a 70-year period, the Maximum Case dose in mission Phase 5 equates to less than 20 percent of the average background level of 150 mrem/yr. So the exposures are seen to be small even in the Maximum Credible Case. Note that the maximum case uses meteorological conditions which would maximize the dose to persons. The consequence calculations include the onsite, launch day population of workers and visitors to KSC.

Tables 4-5 and 4-6 also include estimates of the area of material deposition at 0.2 uCi/m^2 or greater. At that level, EPA suggests one consider monitoring; below that level, monitoring was not recommended. The screening level corresponds to a dose rate of less than 1 mrem/yr, or 1 percent of the average background. This represents a sort of de minimis level. NASA's actual monitoring plans will be based on real time estimates of the amount and location of the release and updated atmospheric analyses of the advection of the released material. As discussed in Appendix B, clean up will be based upon a number of factors including the amount, particle sizes, and concentration of the deposition and the normal use of the area in question.

4.1.4.4 Impacts of Radiological Accidents to Individuals

Individual members of the KSC workforce, launch-day visitors, and members of the general population of Florida and of the world could, under some accident conditions, receive small radiological impacts. The degree of the impact would be highly dependent on the nature and point in the flight path of the accident, the characteristics of the material released, and the specific meteorological conditions prevailing. The individual doses presented throughout this document are expressed in 70-year (i.e., lifetime) dose and are the sum of two components: the initial dose due to inhalation of very small (generally less than 10 microns) particles during initial cloud passage, and the long-term dose resulting from continuous exposure to material deposited in the environment over an extended period following the release.

Figures 4-3 through 4-5 present plots of the individual dose rate (abscissa) versus the population exposed (ordinate). In general, the models calculate exposure versus area and then estimate the population within the area. As the distance from the point of maximum exposure increases the dose decreases. The population exposure is the cumulative population exposed to a dose exceeding the minimum within that area. The area under the curve with an absicca of dosage and an ordinate of population exposed represents the "population dose" which is used to assess incremental health impact.

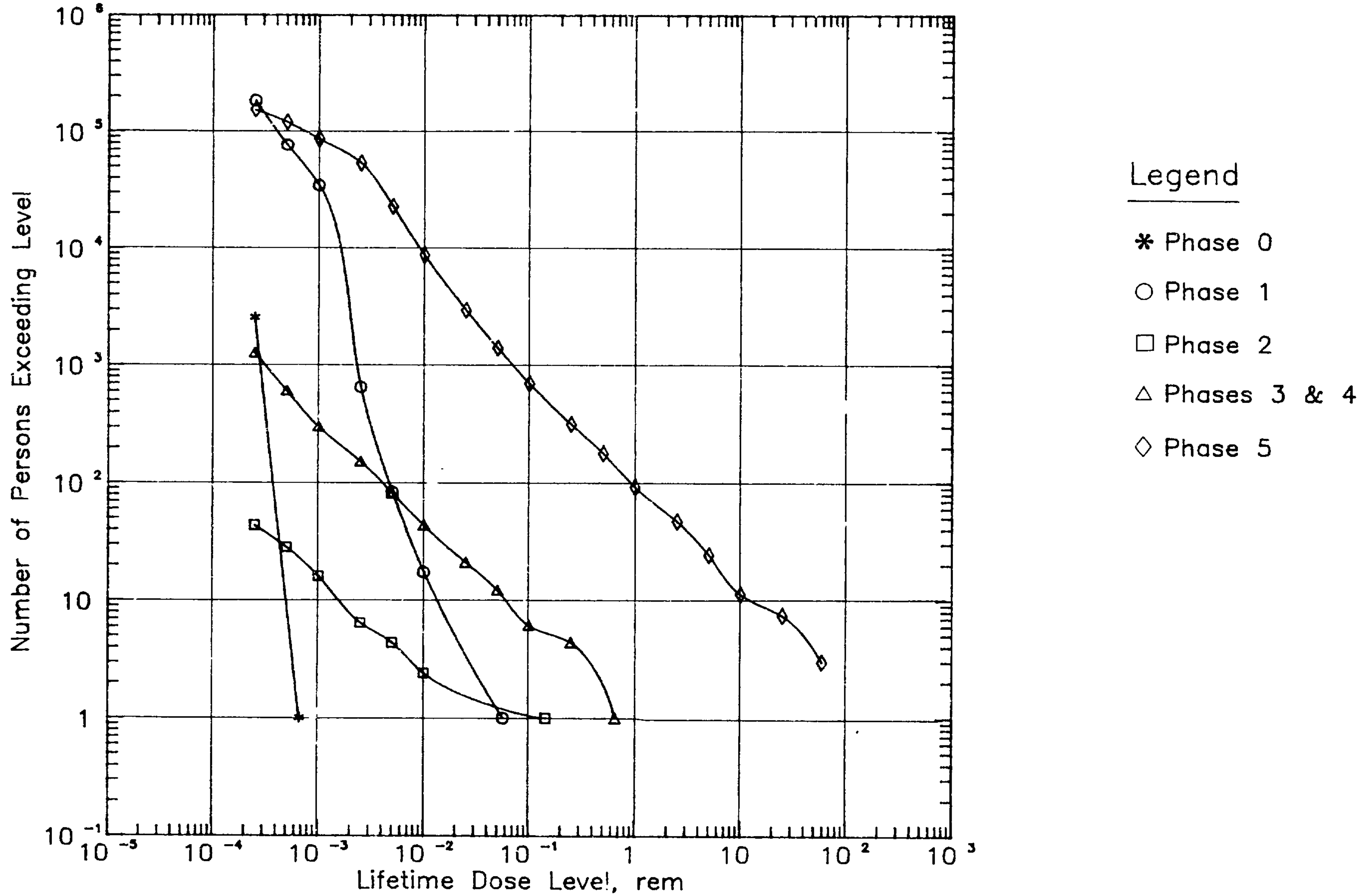


Figure 4—3. RADIOLOGICAL CONSEQUENCE SUMMARY MOST PROBABLE CASES, STS

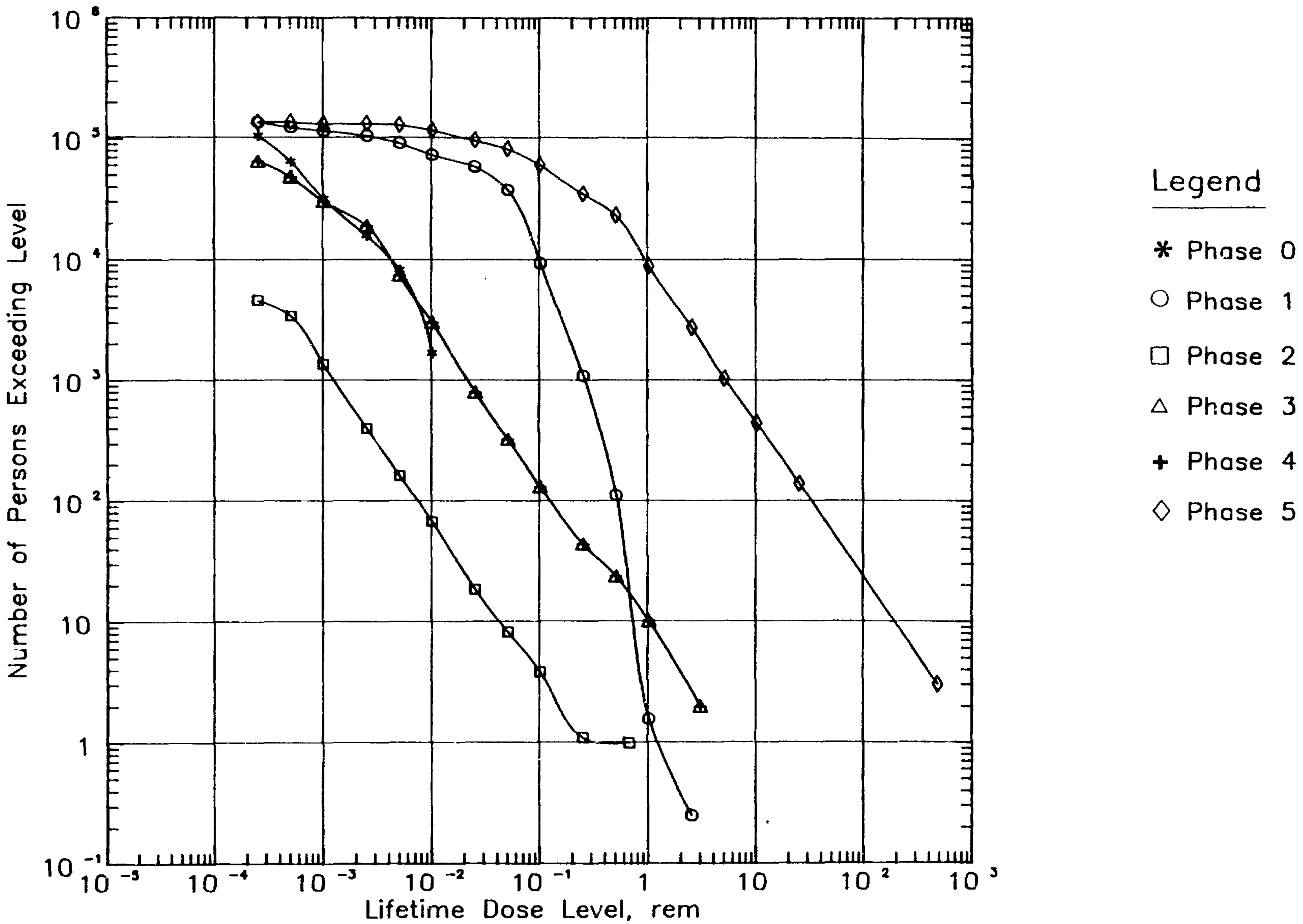


Figure 4–4. RADIOLOGICAL CONSEQUENCE SUMMARY MAXIMUM CASES, STS

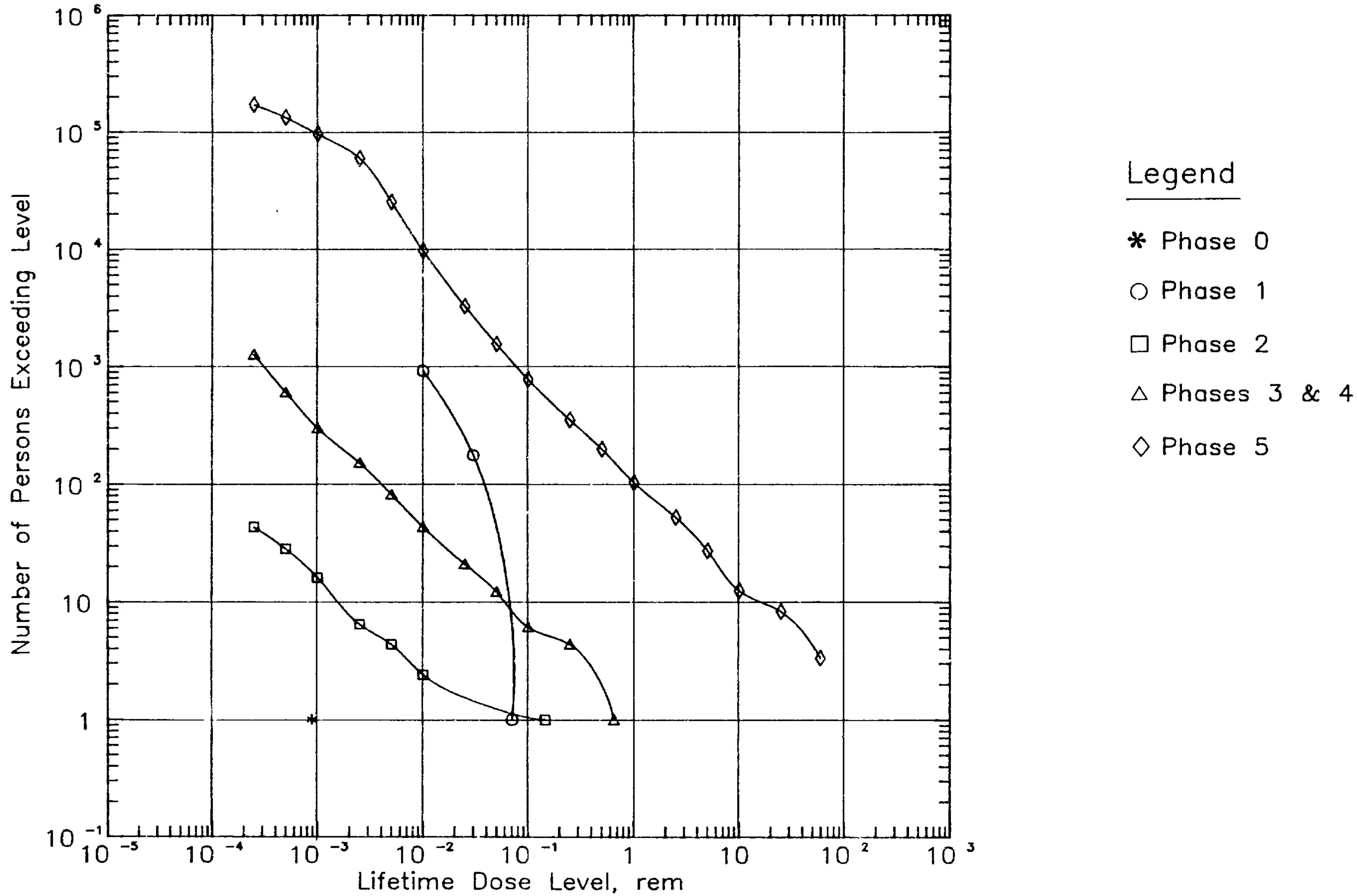


Figure 4–5. RADIOLOGICAL CONSEQUENCE SUMMARY EXPECTATION CASES, STS

The incremental health impact is presented in terms of incremental cancer fatalities on the basis of 1.85×10^{-4} cancer fatality per person-rem above the de minimis level.

The figures indicate that dose levels from possible launch accidents will be very low. For instance, in the most probable release case, which uses an average meteorology, the mission Phases 0 and 1 no individual would receive more than the de minimis dose. In Phase 2 through 5, the number of persons receiving greater than de minimis doses would be 1, 8, and 1,000, respectively. Note that mission Phases 3 and 4 are grouped as one value in the figures.

The inadvertent re-entry accident during the VEEGA operation, although extremely unlikely, has the potential for higher releases and hence higher theoretical consequences than any of the accidents identified for Phases 0 to 4. Consequences were calculated assuming worldwide average population density on land and average meteorological conditions for the most probable case, and the maximum latitude band population density (90.1 persons/km^2) and meteorological conditions that maximized radiological consequences for the maximum case. Under the most probable assumptions, less than 11,000 persons would receive more than a de minimis lifetime dose, with as many as 100 receiving 1 rem and the maximum receiving less than 100 rem lifetime dose. Under the maximum case conditions, as many as 90,000 could receive more than a de minimis dose, more than 25 could receive up to 100 rem lifetime dose, and a few could receive up to 580 rem. The few receiving the higher doses would have to be very close to the impact area and immediately downwind. About 56 percent of that dose would be received from the initial cloud passage after impact and the remaining from long-term exposure to contaminated lands and foodstuffs assuming no cleanup or mitigation measures take place. In practice, mitigation measures such as discussed in the next section would likely reduce the long-term impacts to those residing in the contaminated areas. None of the calculated individual lifetime doses are high enough that any immediate health problems due to radiation exposure would be expected although in the maximum case, some excess long-term cancers could be expected.

The radiological consequence summary for the expectation case presented in Table 4-7 indicates that when probability is factored into the calculation of the consequences and expected number of people exposed, the results are very similar to the most probable case. (It should be noted that the population dose estimates assume a 70-year exposure period.) This is because, for Phases 2 to 5, the higher consequences are the result of more GISs both hitting rock and hitting at such an angle that plutonium is released. While the consequences may double with each additional hit, the re-entry characteristics and flight paths of the GISs are essentially independent, implying the probability that more than a few hitting rock and releasing plutonium is extraordinarily low. Therefore the probability weighted consequences (and risk) for accidents in Phases 2 through 5 are dominated by the most probable accidents. For Phase 1, the expectation case is higher than the most probable case because several Phase 1 accidents were identified that could lead to about the same amount of material being released.

TABLE 4-7. SUMMARY OF RADIOLOGICAL CONSEQUENCES EXPECTATION CASES

Mission Phase	Release Probability	Population Dose in Person-rem[a]: Total	Population Dose in Person-rem[a]: Above De Minimis	Square Kilometers of Area With Deposition Above 0.2 uCi/m^2 [b]: Dry Land	Swamp	Inland Water	Ocean
0	$5x10^{-7}$	12.70	0.0	7.0	1.2	4.1	4.5
1	$4x10^{-4}$	203.0	2.7	25.7	7.3	16.3	20.8
2	$2x10^{-6}$	0.2	0.07	0.0	0.0	0.0	0.0
3	$7x10^{-6}$	5.99	2.5	0.1	0.0	0.001	0.0
4	$4x10^{-4}$	5.99	2.5	0.1	0.0	0.001	0.0
5	$5x10^{-7}$	1,430.0	927.0	14.7	0.0	0.3	0.0

a Person-rem is the cumulation of dose to the affected population.
b uCi/m^2 is microcuries per square meter.

Table 4-8 presents a summary of the risk from each phase of the mission. The excess health effects (or excess cancer fatalities) assuming the accidents for each Phase occur are quite small and indistinguishable from health effects due to natural background radiation. In the Phase 5 or VEEGA accident, less than 0.2 health effects (incremental fatalities) would be expected among the 1,550 people that statistically might be expected to receive more than a de minimis lifetime dose. Among all the people exposed to any radiation, including below de minimis levels, the total expected population dose (from Table 4-7) is 1,430 person-rem, equivalent to about 0.26 health effects (incremental fatalities) among the exposed population.

When the probability of the accidents is factored into the analysis, the risk to the exposed individuals can be calculated. The average individual risk in the Table equals the probability times health effects, divided by the population affected. This risk is quite low. The risk to members of the general population is actually quite a bit lower than the risk presented in the Table because different sets of people could be affected, depending on impact areas and meteorological conditions. These risks can be compared to the approximate individual risks of early fatalities by other causes faced by the public presented in Table 4-9. The population facing the highest risk is likely the KSC workforce. Table 4-8 implies that the most severe risk is due to Phase 1 accidents, with a maximum individual risk of early fatality of about 2 in 1 billion, much less than the ordinary risks faced.

4.1.4.5 Impacts and Mitigation of Land Deposition

This section presents the environmental consequences of an accident in which plutonium dioxide (PuO_2) is exposed to the environment. The impact analysis is divided into two major categories: 1) the potential impacts of the most probable and maximum case accidents during Phases 0 and 1; and 2) the potential impacts of the most probable and maximum case accidents during Phases 2, 3, 4, and 5. The first category are those accidents which could affect KSC and vicinity and can be represented by a specific mathematical model. The second category of accidents are those which could affect unspecified areas of the world and cannot be precisely modeled.

Results are presented for immediate impacts and long-term impacts. Immediate impacts are those that result from the deposition of PuO_2 on various environmental media. Long term impacts are those that result from leaving PuO_2 in the environment. They include impacts to natural environments, agricultural resources, man-used resources, and water bodies, along with possible mitigation measures and the impacts of mitigation. The economic cost estimates associated with the impact analyses are also presented.

Assessment of Impacts to Kennedy Space Center and Vicinity

This section presents the environmental consequences of Phase 0, Prelaunch/Launch and Phase 1, First Stage Ascent most probable and maximum case accidents. The areas affected by the accidents are primarily on Kennedy Space Center property. The land areas of deposition from the most probable, maximum, and expectation accidents in Phases 0 and 1 are presented in Table B-20 of Appendix B. Most of the radioactive material (about 94.5 percent) will remain within 10 km of the accident location and hence, primarily impact KSC property.

TABLE 4-8. MISSION RISK SUMMARY BY PHASE WITH RELEASE FROM RTG, STS

		Radiological Consequences			
Mission Phase	Release Probability	Population Dose, Person rem Above De Minimis	Excess Health Effects[a,b] (Given Accident)	Population Affected[b]	Average Individual Risk[c]
0	$5x10^{-7}$	0	0	0	0
1	$4x10^{-4}$	2.73	$5.06x10^{-4}$	86.9	$2.06x10^{-9}$
2	$2x10^{-6}$	0.086	$1.26x10^{-5}$	0.75	$3.81x10^{-11}$
3	$7x10^{-6}$	2.45	$4.53x10^{-4}$	12.2	$2.45x10^{-10}$
4	$4x10^{-4}$	2.45	$4.53x10^{-4}$	12.2	$1.33x10^{-8}$
5	$5x10^{-7}$	927.0	$1.71x10^{-1}$	1,550	$5.52x10^{-11}$

a Based on $1.85x10^{-4}$ excess cancer fatalities per person-rem (e.g., For Phase 5, $927x(1.85x10^{-4})$ = 0.1715 = less than 0.2 health effects)

b Applicable to persons receiving dose above de minimis

c Average individual risk equals probability times health effects, divided by population affected

TABLE 4-9. INDIVIDUAL RISK OF FATALITY BY VARIOUS CAUSES[a]

Accident Type	Number of Accidents for 1983	Approximate Individual Risk[c]
Motor Vehicle	44,452	2×10^{-4}
Falls	12,024	5×10^{-5}
Drowning	5,254	2×10^{-5}
Fires and Flames	5,028	2×10^{-5}
Poison	4,633	2×10^{-5}
Water Transport	1,316	5×10^{-6}
Air Travel	1,312	5×10^{-6}
Manufacturing	1,200	5×10^{-6}
Railway	1,073	4×10^{-6}
Electrocution	872	4×10^{-6}
Lightning	160	7×10^{-7}
Tornadoes	114[b]	5×10^{-7}
Hurricanes	46[b]	2×10^{-7}
All Other Accidents	9,311	4×10^{-5}
All Accidents	77,484	3×10^{-4}
Diseases	1,631,741	7×10^{-3}

Source: USBC 1986.

Notes:
a. Based on 1983 U.S. population
b. 1946 to 1984 average
c. Fatalities/Total Population

Surface contamination resulting from the Phase 0 most probable case produces a total area of 18.7 km^2 which will receive deposition above 0.2 uCi/m^2. The phase 1 most probable accident produces a total deposition area of 84.9 km^2 above the 0.2 uCi/m^2 screening level. The breakdown of these totals by the six land cover types (natural vegetation, urban, agricultural, wetlands, inland water, and ocean) is shown in Table B-19. Ocean impacts do not occur for either the Phase 0 or Phase 1 most probable accident scenarios.

The Phase 0 maximum case produces a total surface area deposition above 0.2 uCi/m^2 of 6.94 km^2. The Phase 1 maximum case produces an area of 5.43 km^2. In Phase 0, dry land receives the greatest amount of contamination, while in Phase 1, inland water receives the greatest contamination. Again, as noted earlier the areal extent of land contamination for the maximum case is smaller because the model utilizes conditions which maximize population dose. Hence, the smaller contaminated area is in the maximum case, but with higher dose.

The Phase 0 and 1 expectation cases produce total areas of 16.66 and 70.11 km^2, respectively, above the deposition screening level of 0.2 uCi/m^2. In both cases, natural vegetation is the land cover receiving the greatest contamination.

In all cases, 94.5 percent of released radioactive material is contained in particles greater than 44 um and will be deposited within 10 km of the accident/impact site. Atmospheric dispersion may scatter smaller particles beyond 10 km. Particles 10 um and smaller could travel 50 km or more; concentrations would be expected to be extremely low, as shown by the small number of health effects.

Immediate Consequences

The deposition of plutonium dioxide from the representative accidents does not physically alter land covers unless a particle produces enough heat to start a fire. However, the PuO_2 can affect the human use of these land covers and could result in a change in land cover.

Contaminated areas were analyzed to determine current land cover use and how PuO_2 would react to various environmental conditions. This analysis was used to draw the following conclusions on immediate consequences.

There is no initial impact on soil chemistry. Most PuO_2 deposited on water bodies is not expected to react chemically with the water column; therefore, no immediate consequences are expected in these waters. No significant consequences to flora and fauna are expected from surface deposition and skin contact with PuO2 (Section B.6.1, Appendix B).

Long Term Consequences

Plutonium dioxide deposited on the soil will interact with inorganic and organic ligands forming soluble or insoluble products. It is expected that over 95 percent of the PuO_2 will remain in the top 5 cm (2 in) of surface soil for at least 10 to 20 years. Mitigation required for other reasons may result in significant soil impacts (Section B.6.1, Appendix B).

Natural areas receiving deposition within 32 km (20 mi) of Launch Complex 39 could range from 1.5 km^2 (0.58 mi^2) to 32 km^2 (12 mi^2). Wetland areas receiving deposition range from .13 km^2 (.05 mi^2) to 16 km^2 (6.2 mi^2). No significant consequences to flora are expected. Minor consequences are possible through ingestion by terrestrial and aquatic fauna and inhalation by terrestrial fauna (Section B.6.1, Appendix B).

Only small amounts of PuO_2 will be available in the water columns. The amounts available are not considered to have significant impacts to the aquatic fauna that may ingest dissolved or suspended PuO_2. Bioaccumulation of PuO_2 by benthic organisms and aquatic vegetation may occur. There is a potential for the PuO_2 to travel up the food chain, however, bioaccumulation of plutonium decreases with higher trophic levels (Section B.6.2.3, Appendix B).

Mitigation of the impacts to flora and fauna in natural 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 would 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 inhalation health hazard.

Agricultural areas within 32 km (20 mi) of Launch Complex 39 include citrus groves and pastures. Agricultural areas contaminated by accidents during different phases range from 0.43 km^2 (0.17 mi^2) to 9.1 km^2 (3.5 mi^2). No pasture areas will be contaminated (Section B.6.2.3, Appendix B).

If citrus exposed to deposition is consumed, it poses a potential health effect to man. Contaminated citrus fruit surfaces are not readily washable with water. In contrast with the fruit, plutonium was readily washed away from leaf surfaces (Section B.6.2.3, Appendix B).

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 soil added around the trees. Future citrus crops could be monitored for PuO_2 contamination before sold on the market (Section B.6.2.3, Appendix B).

Surface contamination levels may 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 use the surficial aquifer as a source of water. PuO_2 could contaminate this aquifer, but analysis of groundwater flow and sediment leaching indicate it is unlikely, especially for any contamination to reach the wellheads of municipal water supplies. It is highly unlikely that any contamination on the Kennedy Space Center will reach offsite wells. Transport through the underlying aquatard to the lower Floridan aquifer is considered very unlikely (Section B.6.2.3, Appendix B).

Mitigation could include monitoring of contamination profiles of the soil in aquifer recharge areas to determine if the plutonium dioxide is migratory to the water table. If the monitoring shows a high probability of migration, areas may be scraped to below the contamination depth and the spoil disposed of properly. Private wells in the area of deposition could be monitored and alternative water supplies could be developed if water supplies are impacted.

The areas of land cover used by man (e.g., buildings, roads, ornamental vegetation, and grass areas) that are contaminated could be monitored to determine the decontamination or mitigation action necessary. Mitigation actions could prevent the immediate return of the population to their homes and workplaces. Cleanup actions could last from several days to several months. Historical and archaeological resources, both known and unknown, could receive deposition. Kennedy Space Center facilities that have historical significance, and are not damaged in the blast, could also receive deposition. Presently unknown archaeological sites could be affected by the cleanup actions undertaken in those areas. Plutonium dioxide also has a long-term affect on future investigation at any archaeological site (Section B.6.2.3, Appendix B).

Plutonium dioxide is generally considered highly insoluble, therefore it is not expected to react chemically with the water column. As a result, the 15 pC/l water quality standard (applicable to all Florida waters, NASA 1986) is not expected to be exceeded for the waters surrounding Merritt Island. Some of the waters surrounding Merritt Island are considered Outstanding Florida Waters (OFW). Waters with this classification are subject to water quality standards based upon either existing water quality or the designated surface water standard, whichever is higher. This level of protection is intended to prohibit land and/or water use activities which would degrade the water quality of the resource so designated.

Mitigation of PuO_2 impacts could include monitoring small and shallow water bodies close to human activity, and draining and removing sediment if a threat to man is identified. Larger bodies of ponded water could be monitored and skimmed to remove surficial film, if necessary. Additional monitoring to determine the need for water and/or sediment removal could be required. Recreational water activities could be restricted in larger water bodies until monitoring results indicate it is safe for them to be resumed.

The bounding economic cost of each representative case accident for Phases 0 and 1 are presented. In all cases the minimum cost would be the monitoring program. This program is estimated to cost $1 million in the first year, $500,000 in the second year, $250,000 in the third year and $100,000 per year after the third (Appendix B, Table B-18). These numbers may be somewhat less for Phase 0 and somewhat more for Phase 1 since the areas contaminated in the Phase 1 accidents are greater (Section B.6.2.3, Appendix B).

Finally, the low probability of these consequences must also be considered. For instance, considering the risk to be the product of the probability of contamination and the cost of cleanup, then the risk of the largest cleanup cost (i.e., the most probable case for Phase 1) one would have $\$762 \times 10^6$ (cleanup cost) $\times 3 \times 10^{-4}$ (release probability) or a risk of $228,000. This is the order of magnitude of expenditure that one would incur to obviate the risk. That amount is small compared to the $800 million investment in the Galileo mission to date.

Assessment of Global Impacts

This section presents the environmental consequences of Phases 2, 3, 4 and 5. Since the exact location of areas of deposition cannot be determined, location specific impacts are not described. A general discussion of the impacts and possible mitigation measures are presented.

Global impacts vary from one module impacting land for the most probable accidents in Phases 2, 3, and 4, and one, two, and three modules impacting land in the maximum case for Phases 2, 3 and 4 respectively. For Phase 5, three Graphite Impact Shells could impact for the most probable maximum cases (Section B.4.2, Appendix B).

A reentry accident during Phases 3 and 5 would involve spacecraft failure and breakup. Atmospheric reentry speed and spacecraft breakup rate will likely result in PuO_2 modules or Graphite Impact Shells being released at different locations during reentry. These independent release points will result in impact areas that may be separated by many thousands of kilometers. Except for Phase 5, the areas involved are less than 1 km^2 (0.36 mi^2). For Phase 5, each impact area would average 4 to 5 km^2 (1.4 to 1.8 mi^2). Mitigation would include recovery and cleanup of areas contaminated at 25 mrem/yr or greater.

Deposition from the Phase 2 cases does not exceed the screening level so no cleanup costs have been estimated. The estimated economic costs of Phases 3 and 4 are presented in Table B-23, Appendix B. The only deposition that exceeds the screening levels occurs on dry land. The areas of impact vary from 0.06 km^2 for the most probable and expectation cases to 0.1 km^2 for the maximum case. Since none of the deposition in these areas equal or exceed the cleanup level (25 mrem/yr or greater), no cleanup costs are associated with these phases.

The estimated economic costs of Phase 5 are presented in Table B-22, Appendix B. The deposition that exceeds the screening level occurs on dry land and inland water. The areas of impact vary from 9.1 km^2 for the maximum case to 15.03 km^2 for the expectation case. Areas which could equal or exceed the cleanup level (25 mrem/year or greater) range from 0.2 km^2 for the most probable case, to 1.4 km^2 for the maximum case. Costs for the cleanup of these areas for the expectation case vary from $0.5 million to $240.5 million.

4.1.4.6 Additional Mitigation Measures for Accidents

Emergency Response Planning

For missions involving space nuclear power, comprehensive radiological contingency plans must be developed to address all launch/landing phase accidents involving the RTGs and RHUs. These plans are developed through the combined efforts of various government agencies, including NASA, DOE, the Department of Defense (DOD), the EPA, and the State of Florida, and are formulated to conform to the Federal Radiological Emergency Response Plan (FRERP) (NASA 1985b). These plans will be updated for the Galileo missions based on the results of the new FSAR and SER. 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 material, 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 RTGs. 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.

Other Methods of Limiting the Potential Consequences of Accidents

In addition to post-launch activities, there are other options available to NASA to mitigate the consequences of prelaunch and launch-ascent (Phase 0 and 1, respectively) accidents. For instance, further restrictions on spectator location and meteorological launch criteria could further reduce the already low consequences. NASA has studied both types of restriction and has found them to be unnecessary. Most spectator locations are off of KSC property and are in public areas, making further access restrictions difficult without legislation. Meteorological conditions are highly variable, and wind conditions close to the surface are generally different from those aloft, so further meteorological launch constraints were deemed impractical.

In general, in view of the low probability of adverse consequences, further launch constraints have not been imposed.

4.1.4.7 Limitations and Uncertainties of the Accident Analyses

The safety analyses performed in support of the launch of the Galileo spacecraft with RTGs and RHUs on board are unquestionably some of the most detailed and elaborate ever performed in support of a spacecraft launch. Significant effort went into the analyses to ensure that they were both reasonable and conservative. Even so, there are still uncertainties in the estimation of the probabilities of releases, the amount of material released, and the consequences to man and the environment from those releases. As a part of the safety analysis process, an attempt was made to identify the degree of confidence with each of the major assumptions, the limitations of the analyses, and the impacts of these uncertainties and limitations on the overall probabilities and consequence estimates. This uncertainty analysis is included as Appendix H of Vol. III of the FSAR (DOE 1988b) and is summarized in Section B.4.2 of Appendix B.

The factors affecting estimates of radiological consequences and mission risks that were evaluated include:

- Accident scenario
  - Accident environment
  - Accident probability

- Release characterization
  - Conditional source term probability
  - Source term
  - Modifications to the source term and particle size distribution because of mechanical, chemical and physical interaction prior to deposition
  - Particle size distribution
  - 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 dose and health effects
  - Internal dose factors
  - Health effects estimator.

Estimates were made of the uncertainty of each of these factors and then combined to determine the overall uncertainty associated with the various types of radiological consequences and mission phase risks. Table 4-10 presents the overall mean uncertainty factors and the associated ranges for both the consequences and mission risks. The uncertainty analysis implies, for example, that the best estimate for the mean total population dose for the expectation case is actually about 23 percent of the value quoted earlier in Table 4-7. Referring to Table 4-7, the population dose for Mission Phase 1 was 203 person-rem. The best estimates mean total population dose utilizing the uncertainty factor from Table 4-10 then becomes 0.23 x 203 = 46.7 person-rem, or 23 percent of 203 person-rem. The 5 percent to 95 percent uncertainty range for that mean total population dose best estimate varies from 0.67 percent to 790 percent (i.e., the 0.0067-7.90 range noted in Table 4-10), of the value quoted earlier (203 person-rem). For Phase 1 mission risk, the uncertainty range is larger with the mean total population dose from Table 4-10 being 39 percent of the estimation case estimate, and the range varying from 3.5 percent to 430 percent of that estimate. In terms of mission risk for Phase 0 and Phases 2 through 5, the mean total population dose is 23 percent of the estimation case estimate, and the range varying from 2.9 percent to 180 percent of that estimate.

TABLE 4-10. OVERALL UNCERTAINTY ANALYSIS RESULTS

Result Type	Overall Uncertainty Factor Mean	Range[b]
• Radiological consequences[a]		
- Short-term population dose	0.25	0.013-4.6
- Long-term population dose	0.22	0.0042-1.4
- Total population dose	0.23	0.0067-7.9
- Health effects	0.23	0.0063-8.5
- Surface contamination area	0.75	0.051-5.2
• Mission phase risk[b]		
Phase 1		
- Short-term population dose	0.42	0.061-2.9
- Long-term population dose	0.37	0.024-5.7
- Total population dose	0.39	0.035-4.3
- Health effects	0.39	0.032-4.8
- Surface contamination area	1.3	0.22-7.8
Phases 0, 2-5		
- Short-term population dose	0.25	0.55-1.1
- Long-term population dose	0.22	0.019-2.5
- Total population dose	0.23	0.029-1.8
- Health effects	0.23	0.026-2.0
- Surface contamination area	1.75	0.20-2.9

a. The mean uncertainty factor for radiological consequences multiplies the expectation case results (Table 4-7) to yield a best estimate mean of the expectation case results. The best estimate mean result for the expectation case should be multiplied by the uncertainty factor range to yield a best estimate of the 5- and 95-percentile values of the range of radiological consequences.

b. The mean uncertainty factor for mission phase risk multiplies the mission phase risk results (Table 4-8) to yield a best estimate mean of mission phase risk (defined as total probability times expectation case results). The best estimate result for mission phase risk should then be multiplied by the uncertainty factor range to yield a best estimate of the 5- and 95-percentile values for the mission phase risks.

These uncertainty estimates imply that the overall mission risk is still low even when the 95 percentile uncertainty estimates are included. Table 4-10 implies that at the 95 percent confidence level, the overall consequence and risk estimates presented in these sections are unlikely to be low by much more than a factor of 10.

In addition to the uncertainty analysis conducted in the FSAR, there are ongoing analyses currently being conducted by the NASA/DOE project, NASA/DOE internal review groups, and INSRP which could broaden (or narrow) the uncertainty range of accident consequences. The currently known areas of further analyses include: (1) probability of various accident scenarios, (2) SRB fragment velocities, (3) fragment/structural interactions, (4) RTG impact response models, (5) RTG response to VEEGA re-entry, and (6) radiological transport models. It is impossible to quantify the results of these further assessments, a priori, but it is likely that there will be some change to the uncertainty results in the Final EIS.

4.2 ENVIRONMENTAL CONSEQUENCES OF DELAYING COMPLETION AND OPERATION OF THE GALILEO MISSION UNTIL 1991

4.2.1 Delay to 1991 and Use of STS/IUS as Launch Vehicle

The types of consequences associated with a normal launch of the Galileo Mission on the STS/IUS in 1991 are not expected to differ from those described for the proposed action (4th Quarter 1989 launch aboard the STS/IUS) in Section 4.1.2. Given that a 1991 launch would most likely occur in May, the ground cloud (launch exhaust emissions) would initially be forced to the north by the configuration of the launch pad structure, and then would probably drift towards the northwest and west due to the prevailing spring winds (see Section 4.1.2).

In 1991, the VEEGA fly-by altitudes would be greater than in 1989, but the probability of inadvertent re-entry still remains at 5×10^{-7}.

4.2.2 Delay to 1991 and Use Titan IV/IUS as Launch Vehicle

The U.S. Air Force (USAF) has informed NASA that a Titan IV launch vehicle will not be available for the May 1991 launch opportunity. Consequently, the Titan IV/IUS launch configuration is no longer a reasonable alternative to the STS/IUS in the delay alternative. Nevertheless, since the analyses were done, the data on the Titan IV/IUS are presented in Appendix C to this document, and thus will be available to decision-makers.

4.3 NO-ACTION ALTERNATIVE

There are no environmental impacts associated with the No-Action alternative; however, there are major economic, programmatic, and geo-political consequences of such a cancellation. Through FY 1988 (i.e., through September 30, 1987), NASA will have expended approximately $800 million on the Galileo program. Cancellation would mean the abandonment of that investment and a loss of the anticipated scientific gains.

Currently, the United States has a clear lead in the exploration of the outer planets. Programmatically, there are currently no back-up missions that could achieve Galileo's scientific goals within this century, as there are no other approved U.S. missions to the outer planets. Thus, the United States would forego detailed scientific knowledge of the unique environments of Jupiter.

Galileo was started in 1977 and many scientists, engineers, and technicians have devoted a large share of their professional lives working on this project. From a human standpoint, it would be unfortunate to cancel the program when there is no clear evidence of adverse environmental impacts that would justify such a cancellation.

4.4 SUMMARY OF ENVIRONMENTAL CONSEQUENCES

The environmental consequences that could result from the implementation of each of the programmatic alternatives available to NASA are expected to be similar. The specific act of implementing any of the choices has no near-term environmental impact. However, there are significant programmatic, economic, scientific, and geopolitical consequences associated with the alternatives.

If the modifications of the spacecraft were delayed a year or more until the 1991 launch opportunity, there would be major programmatic impacts. Attempting to retain critically skilled personnel on a standby basis would be inordinately expensive. On the other hand, releasing such personnel and later attempting to hire replacements undoubtedly would lead to delays that would threaten the 1991 launch opportunity. Although NASA could regain the skills, NASA would lose the experience base of the current staff.

The only significant potential environmental consequences are expected to be associated with launch. The environmental impacts of normal launches are associated with the STS or Titan IV vehicles and would be similar to other NASA launches of non-RTG missions.

4.5 ADVERSE ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED

During the normal launch, hydrogen chloride will be produced by the solid rocket boosters. This will produce some acid conditions in the ponds near the launch pad and deposition on nearby vegetation. The concentrations will be below levels of exposure considered hazardous by the National Academy of Sciences. The deposition could result in some vegetation damage near the launch pad, and possible fish kills in onsite ponds near the launch pad.

In the event of an accident, it is possible that some areas could be contaminated by plutonium. The probability of this occurring is predicted to be less than 1 in 10 million. If such an accident did occur, decontamination of land, vegetation, and buildings could be required, and costs would be incurred.

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

4.6.1 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.

4.6.2 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.

4.7 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

4.7.1 Iridium

A total of 270 troy ounces of iridium are contained in the two Galileo RTGs. This amount represents approximately 0.0001 percent of the discovered reserves of this metal in the world. Based on a cost of $600 per troy ounce, the 1982 market price of iridium (DOI 1982), approximately $162,000 worth of iridium would be irreversibly committed to the Galileo and Ulysses missions.

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, at the end of 1973, had an inventory of 17,000 troy ounces (NASA 1985b). Although the amount of iridium lost in the successful implementation of the missions would represent about 1.6 percent of the current U.S. stockpile, this amount could easily be replaced from the world supply through current sources.

4.7.2 Plutonium-238

Each RTG contains approximately 17.8 pounds of plutonium-238 in the form of plutonium dioxide. Successful implementation of the Galileo mission therefore would result in the loss of approximately 35.6 pounds of plutonium-238.

The element plutonium is produced in nuclear reactors on an as needed basis by DOE. Therefore, although the launching of the RTGs represents a commitment of plutonium-238 resources that will never be recovered, additional plutonium-238 can be manufactured in nuclear reactors.

4.7.3 Other Materials

The total quantities of other materials in the payloads that would be irreversibly and irretrievably committed to the Galileo missions 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 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.

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TABLE 5-1. CONTRIBUTORS TO THE EIS

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

Responsible Person	Summary	Chapter 1	2	3	4	5	6	7	8	Appendix A	B	C	D
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ALFRED MOWERY Ph.D Physics			X		X						X	X	

6. AGENCIES AND INDIVIDUALS CONSULTED

This Draft Environmental Impact Statement (EIS) will be available for review for a period of 45 days by Federal, state, and local agencies and the public, as applicable. All information received will be considered during preparation of the Final EIS. Comments are 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-Center 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

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
- Center for Law and Social Policy
- Christic Institute
- Common Cause
- Concern, Inc.
- Environmental Policy Institute
- Federation of American Scientists
- Friends of the Earth

Florida Defenders of the Environment
Natural Resources Defense Council
National Wildlife Federation
Physicians for Social Responsibility
The Committee to Bridge the Gap
The Planetary Society
Sandia National Laboratory
SANE
Sierra Club
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8. INDEX

APPENDICES

APPENDIX A

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

APPENDIX A

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AFO	Abort From Orbit
AOA	Abort Once Around
ATO	Abort To Orbit
ASE	airborne support equipment
BOM	beginning of mission
BACT	best available control technology
CCAFS	Cape Canaveral Air Force Station
CELV	Complementary Expendable Launch Vehicle, or Titan IV
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
Ci	Curie
cm	centimeter
DEIS	Draft Environmental Impact Statement
DOC	Document
DOD	Department of Defense
DOE	Department of Energy
EA	Environmental Assessment
EIS	Environmental Impact Statement
ELV	Expendable launch vehicle
EOM	End of mission
EPA	Environmental Protection Agency
ESA	European Space Agency
ESMC	Eastern Space and Missile Center
FAST	Failure/Abort Sequence Tree
FC	Fueled clad

FEIS	Final Environmental Impact Statement
FDER	Florida Department of Environmental Regulations
FR	Federal Register
FRERP	Federal Radiological Emergency Response Plan
f/s	feet per second
FSAR	Final Safety Analysis Report
FTS	flight termination system
FWPF	fine weave, pierced fabric
g	gram
GGS	Global Geospace Science
GIS	Graphite impact shell
GPHS	General purpose heat source
HGA	High gain antenna
IIP	Instantaneous Impact Point
IP	Implementation Plan
INSRP	Interagency Nuclear Safety Review Panel
IUS	Inertial Upper Stage
JOI	Jupiter orbit insertion
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
km/s	kilometers per second
LANL	Los Alamos National Laboratory
lbf	pounds of force
LES 8/9	Lincoln Laboratory Experimental Satellite 8 and 9
LWRHU	Light Weight Radioisotope Heater Unit
MECO	main engine cutoff

MET	Mission elapsed time
MHW	Multihundred Watt
mi/s	miles per second
MMH	Monomethyl hydrazine
m/s	meters per second
N	Newton
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NRC	Nuclear Regulatory Commission
NSTS	National Space Transportation System
OMS	Orbital Maneuvering System
OSTP	Office of Science and Technology Policy
PAM	Payload Assist Module
ppm	parts per million
PSAR	Preliminary Safety Analysis Report
psi	pounds per square inch
Pu	Plutonium
RCRA	Resource Conservation and Recovery Act (1978)
RHU	Radioisotope heater unit
Rj	Jovian radii
ROD	Record of Decision
RPM	Retropulsion module
RSO	Range Safety Officer

RTG	Radioisotope thermoelectric generator
RTLS	Return to Launch Site (abort)
SAR	Safety Analysis Report
SER	Safety Evaluation Report
SNAP	Space nuclear auxiliary power
SRB	Solid rocket booster
SRM	Solid Rocket Motor
SSME	Space Shuttle main engine
STS	Space Transportation System
TAL	Transoceanic Abort Landing
USAR	Updated Safety Analysis Report
VAFB	Vandenberg Air Force Base
VEEGA	Venus-Earth-Earth Gravity-Assist
VEGA	Venus-Earth-Gravity-Assist
VOC	volatile organic compounds
W	Watt
WIND	Weather Information Network Display

APPENDIX B

LAUNCH VEHICLE ACCIDENT ANALYSIS AND RTG ACCIDENT ANALYSIS/CONSEQUENCES ASSESSMENT FOR THE STS

APPENDIX B

LAUNCH VEHICLE ACCIDENT ANALYSIS AND RTG ACCIDENT ANALYSIS/CONSEQUENCES ASSESSMENT FOR THE STS

B.1 LAUNCH VEHICLE AND PAD DESCRIPTION

B.1.1 General Description

The Galileo spacecraft is planned for launch by the Space Transportation System/two-stage Inertial Upper Stage (STS/IUS) combination. The STS configuration consists of the Shuttle Orbiter, its main external tank and two solid propellant rocket boosters (SRBs) (see Figures B-1 and B-2). The main External Tank (ET) contains liquid oxygen and hydrogen propellants. The STS configuration produces approximately 6,925,000 pounds of thrust at sea level.

The shuttle orbiter is launched from pad 39A which is located in a wetlands environment at the Kennedy Space Center (KSC) in Florida. (See Chapter 3 for a detailed description of the launch area environment.) As shown in Figures B-3 and B-4, the launch pad is bordered by a paved, roughly circular roadway approximately 1,200 feet from the center of the pad. The surface of the launch pad is constructed of concrete and stands approximately 48 feet above the ground. An approximately 14,000 square foot steel launch platform, called the service structure, supports the shuttle. This structure consists of a fixed portion (called the launch tower) and a movable portion which rotates clear of the shuttle during pre-launch operations. Two steel structures, the liquid hydrogen and oxygen facilities, are located northeast and northwest of the pad, respectively. Inside the 1,200-foot radius roadway surrounding the pad are a series of concrete roads and support buildings that extend radially from the pad. The remainder and majority of the launch complex area consists of sand.

A flame trench and exhaust channel are located under the launch platform and terminate at an exhaust deflector structure (see Figure B-4). To the northeast, approximately 300 feet from the pad, lies an elevated water tank. This tank supplies water to protect the pad from the high temperatures generated during main engine and SRB ignitions.

B.1.2 Launch/Flight Sequence

The Shuttle orbiter, along with its External Tank and two SRBs, are launched in the following sequence. At 6 seconds before launch -- denoted "T-6" or "T-6 MET" (Mission Elapsed Time) -- the main engines will be ignited. At T-40 milliseconds, the two SRBs will be ignited. At T+7 seconds the Shuttle will clear the launch tower. The SRBs will burn out and separate from the External Tank at T+128 seconds.

The main engines will continue to provide thrust until T+500 seconds at which time they will shut down. After the ET is released (at approximately T+528 seconds), the Shuttle's Orbital Maneuvering System (OMS) engines will be fired to establish and circularize the Shuttle in orbit. Approximately 9 hours after launch and in approximately the sixth orbit of Earth, the Galileo spacecraft and its IUS will be deployed from the Orbiter.

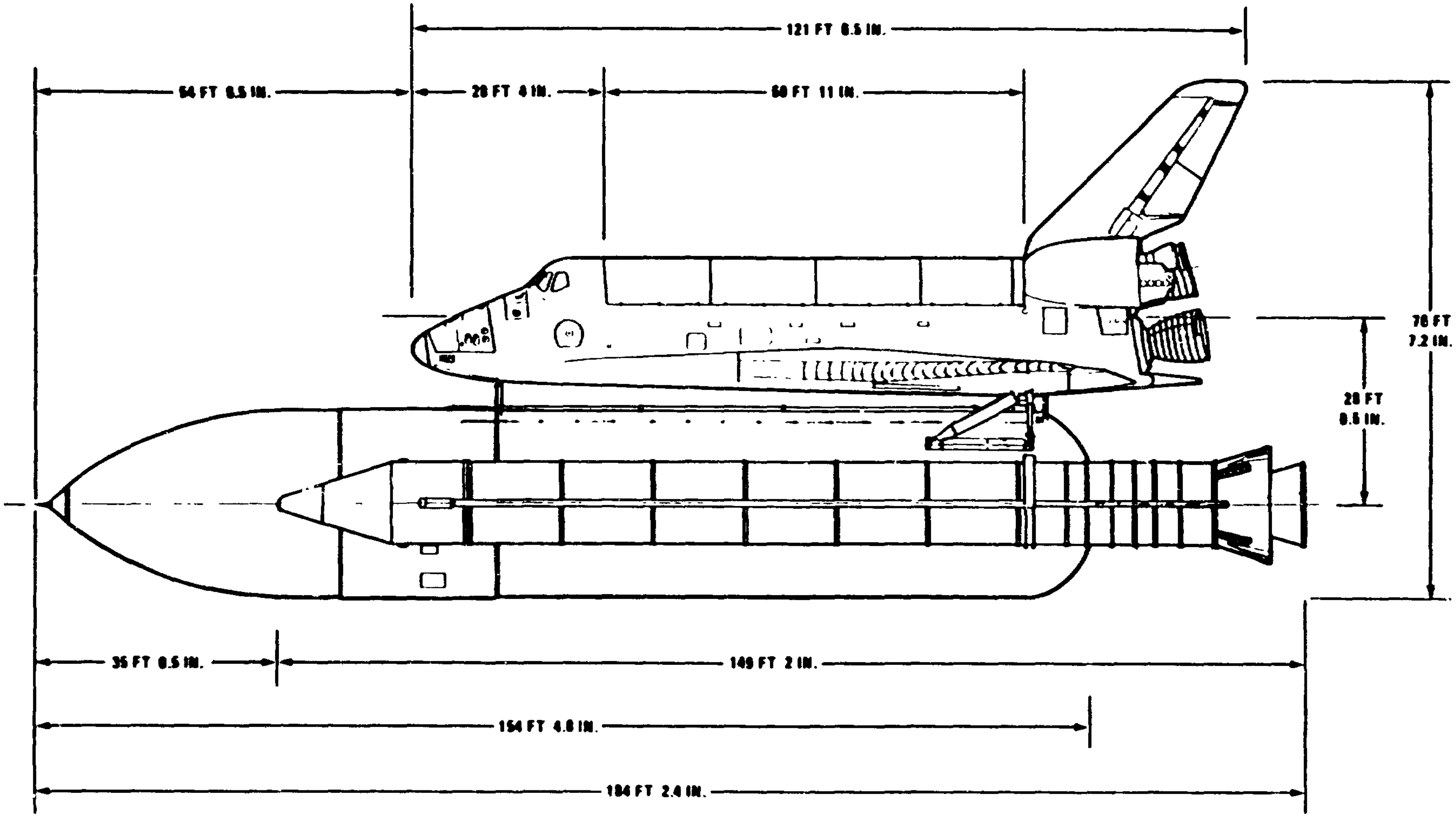

FIGURE B-1. SHUTTLE VEHICLE, SIDE VIEW

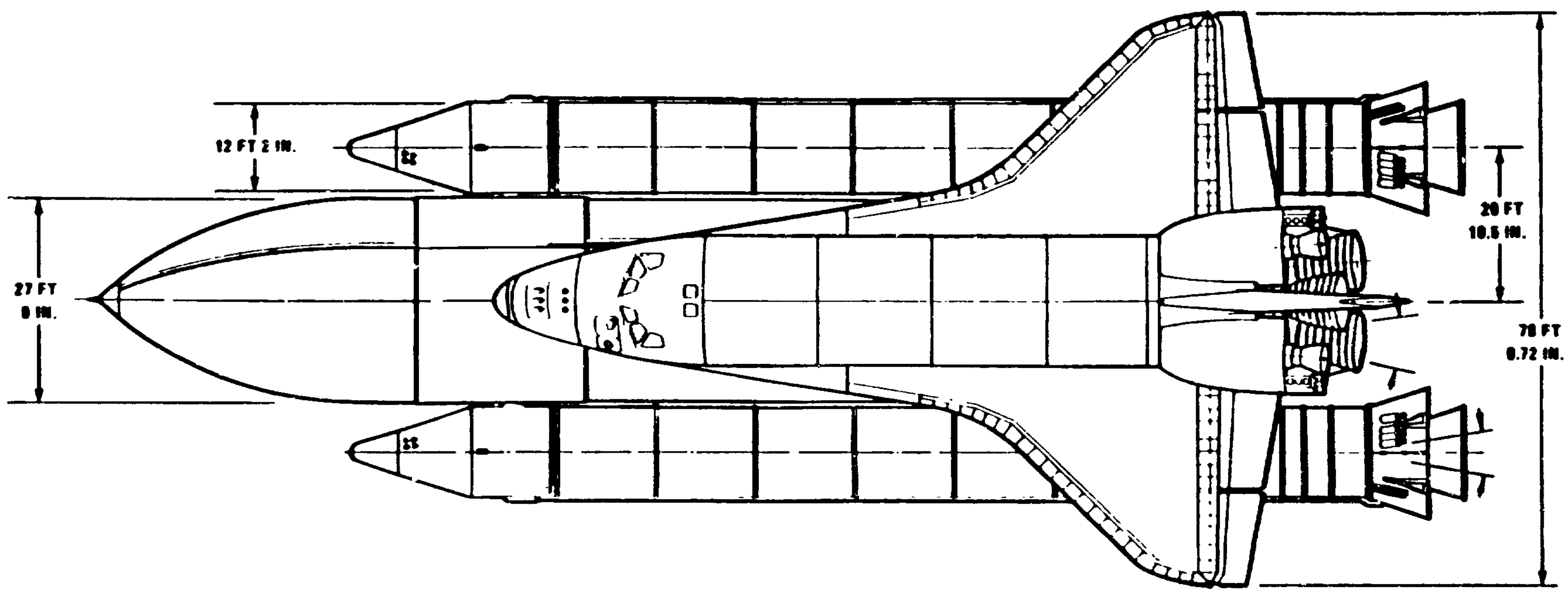

FIGURE B-2. SHUTTLE VEHICLE, TOP VIEW

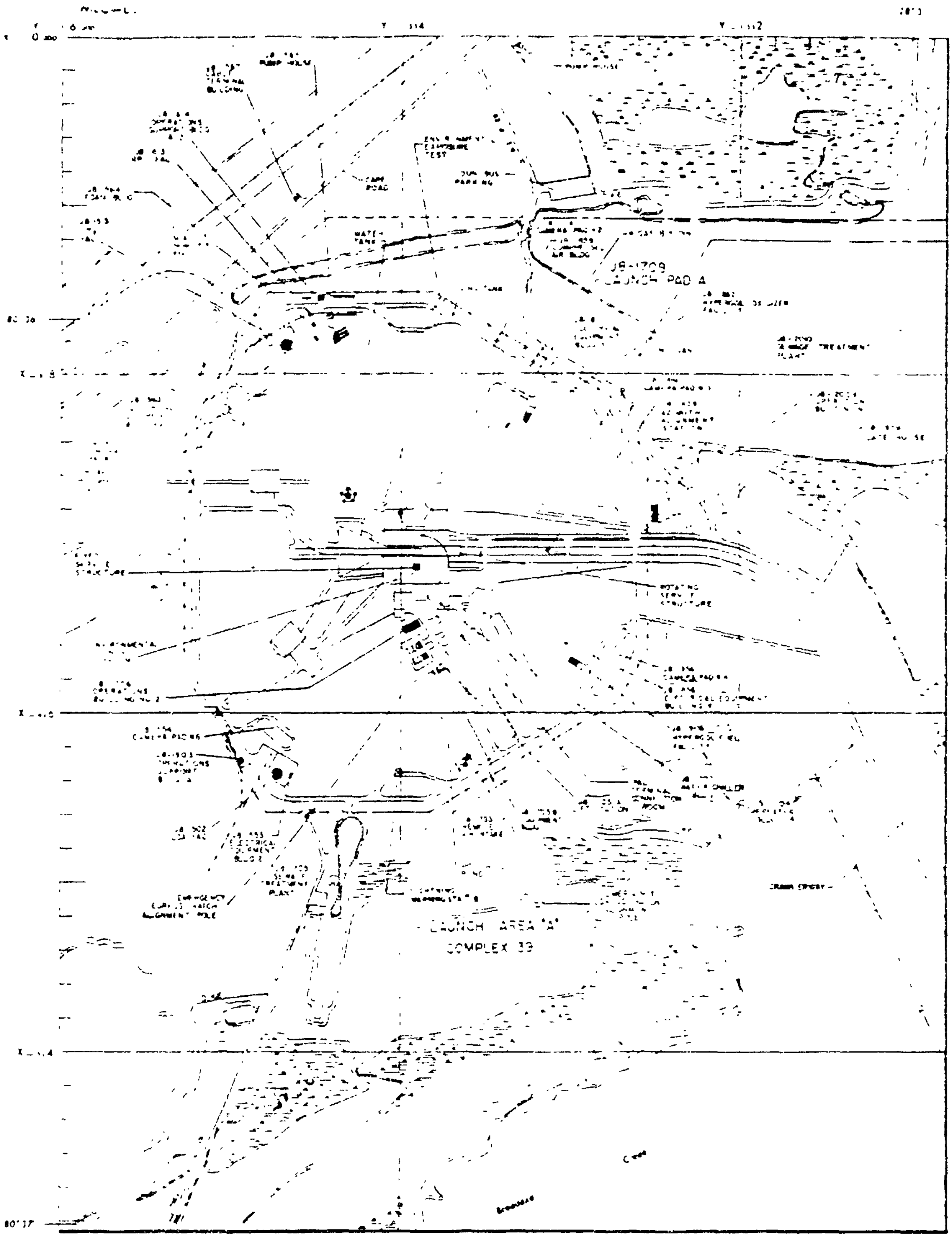

FIGURE B-3. LAUNCH PAD 39A AT KSC

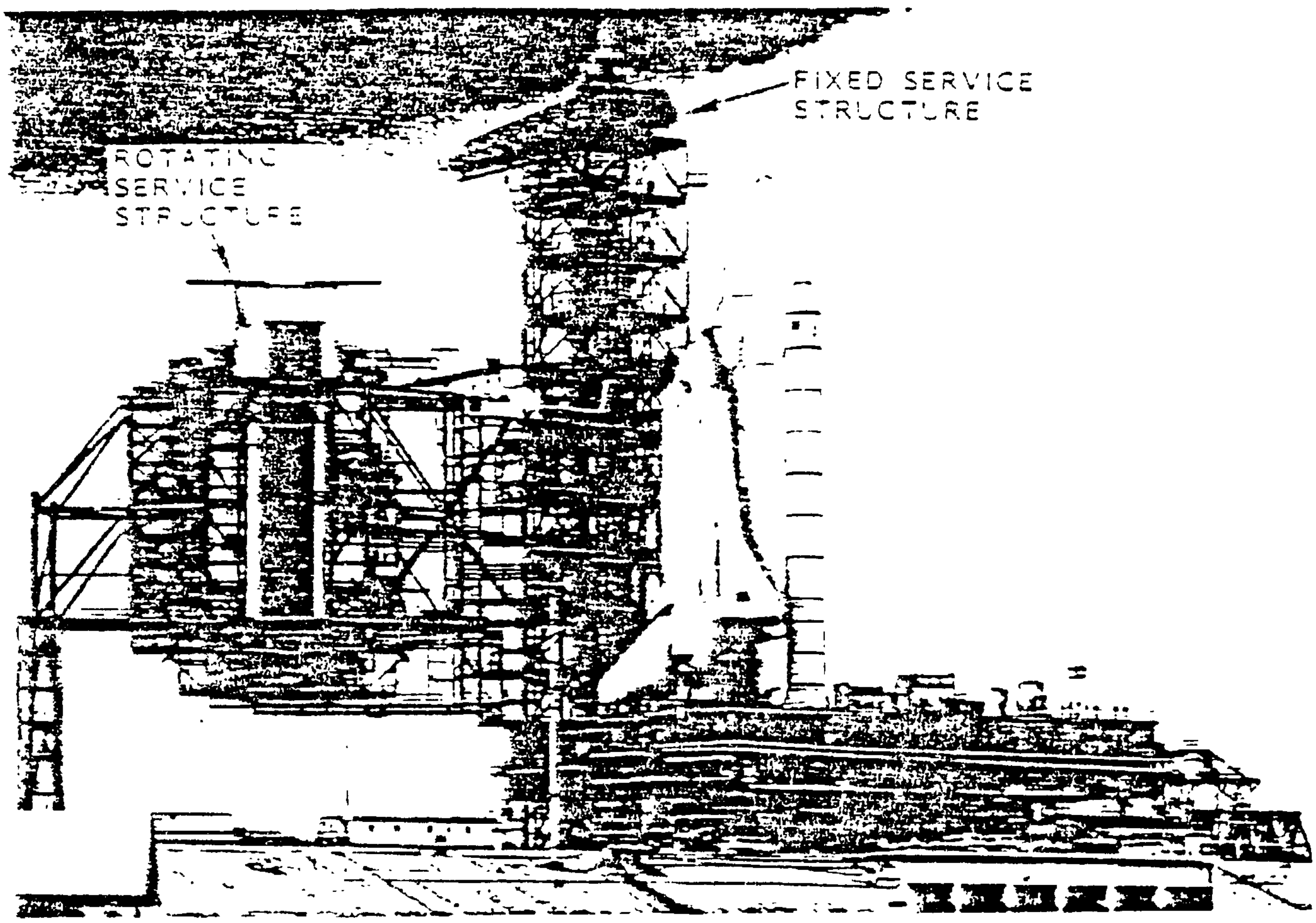

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FIGURE B-4. LAUNCH PAD PHOTHGRAPH SHOWING SPACE SHUTTLE AND BOTH FIXED AND MOVEABLE SERVICE STRUCTURES

Once the Orbiter has moved a safe distance away, the IUS will be ignited. The sequential ignition and burn of the two stages of the IUS will take the Galileo spacecraft out of Earth orbit and places it on a trajectory for Venus. Once the Radioisotope Thermoelectric Generator (RTG) booms have been deployed and the spacecraft stabilized, the Galileo spacecraft will separate from the IUS and continue on its trajectory.

Table B-1 lists the normal sequence of events that lead to placement of the Galileo spacecraft on its planned interplanetary trajectory; with reference to the mission phases used for accident analyses.

TABLE B-1. NOMINAL MISSION SEQUENCE (CONDENSED)

Phase	Sequence	Time
	Start Propellant Loading	T-8.5 hours
	Auto Launch Sequence Begins	T-31 seconds
0	Orbiter Main Engines Ignition	T-6.6 seconds
	SRBs Ignition	T-40 milliseconds
	Launch	T-0 seconds
	Orbiter Clears Tower	T+7 seconds
1	Orbiter Over Water	T+34 seconds
	SRBs Burnout	T+119 seconds
	SRBs Separation	T+125 seconds
2	Orbiter Main Engine Cutoff	T+514 seconds
	First OMS Burn (To Orbit)	T+634 seconds
3	Begin Ascent Coast	T+802 seconds
	Second OMS Burn (Orbit Circularization)	T+2,770 seconds
	Spacecraft/IUS Deployment	T+6 hours, 40 minutes
4	Interplanetary Injection	T+7 hours 28 minutes
5	2nd Earth Flyby	T+38 months

B.1.2.1 Trajectory/Flight Characteristics to Orbit

The Shuttle orbiter containing the Galileo spacecraft and its IUS will be launched with an approximate 70-degree azimuth. This means that the Shuttle's initial ground-track (i.e., the path it flies over the surface of the Earth) will be 70 degrees from true north. A 70-degree launch azimuth will give the Shuttle an orbital inclination of approximately 34 degrees as measured from the equator; in other words, the 70-degree launch azimuth will allow the Shuttle to fly as far north as points along the 34-degree north parallel (i.e., Cape Canaveral's latitude) and as far south as points along they 34-degree south parallel.

B.1.3 <u>Range Safety</u>

The primary range safety objective is to preclude the ground impact of intact launch vehicles or their component parts which could endanger human life or cause damage to property. All Shuttle launches carry a flight termination system which allows the Range Safety Officer through monitoring systems, ground transmitters, and tracking systems to determine whether the launch vehicle poses an imminent threat to people or property. In the event that the launch vehicle violates established flight safety criteria, the Range Safety Officer can control the launch vehicle's flight path by destroying the vehicle.

B.1.3.1 Flight Vehicle Range Safety System

The Space Shuttle Flight Termination System allows the intentional destruction of the SRBs and external tank if the flight deviates too far outside the nominal or established flight limits. On radio command from the Range Safety Officer, linear shaped charges rupture the two tanks in the External Tank as well as the cases of the SRBs. The onboard systems for the three elements (one external tank and two SRBs) are all interconnected so that, if either SRB receives a destruct, all three receive it.

Based on past experience and the combined functioning of the ground and flight portions of the Safety System, a delay of at least 4 and 1/2 seconds will occur between the time a Shuttle vehicle could require destruct action and when the destruct event actually occurs.

B.2 MISSION ACCIDENTS

B.2.1 Accident Scenario Definition Approach

A systematic approach was utilized to identify those credible accident scenarios that might occur. The Shuttle system was divided into its major elements: Launch Support Equipment, Payload, Orbiter, External Tank, Solid Rocket Boosters, Space Shuttle Main Engine (SSME)/Liquid Propellant System, and Range Safety Destruct System. Each of these elements was further divided into its major failure components. Credible failure modes refer to those which generally cause loss of the vehicle and may produce an environment which is a potential threat to the RTG(s). These are generally single point failures in systems or 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. Representative accident scenarios were defined by grouping similar vehicle responses which resulted from each of the credible failure modes for the six major phases of the STS/Galileo mission. The potential accident scenarios are listed in Table B-2 and described below as summarized from NASA 1988.

B.2.2 Phase 0 Accident Scenarios (Pre-Launch)

Phase 0 accidents can occur between propellant loading and launch, typically from T-8 hours to T-0 seconds or launch. 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 destruct activation. The latter accident could occur only after destruct arming in the last 20 seconds before launch.

TABLE B-2. VEHICLE CATASTROPHIC ACCIDENTS EVALUATED IN SAFETY ANALYSIS

Phase	Description	Accident
0	Prelaunch to Launch	Inadvertent Range Safety System destruct Fire/explosion
1	Ascent	Solid Rocket Booster failure Range Safety System destruct Aft compartment explosion Vehicle breakup Crash landing Ocean ditching
2	Second Stage	Orbiter failure External Tank failure Space Shuttle main engine failure Payload failure Range Safety System destruct Crash Landing Ocean ditching
3	On-orbit	Orbiter failure and reentry
4	Payload Deploy	IUS Solid Rocket Motor Case burst IUS Solid Rocket Motor no ignition, low impulse IUS Tumbling from separation or recontact IUS misaligned burns due to guidance failure IUS erratic burns
5	Venus-Earth-Earth Gravity Assist Maneuver	High-speed reentry of the spacecraft

B.2.3 Phase 1 Accident Scenarios (SRB Burn)

Phase 1 accident scenarios represent the period in which the SRBs are a 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 0-10 seconds, a release of ET propellants can cause a ground surface pool explosion which is explained in the following paragraphs. After about 20 seconds, the trajectory of the launch vehicle, if thrust were stopped, would lead to water impact rather than land impact.

In addition to vehicle breakup by instantaneous failures of the SRBs or SSME's aft compartment explosions, Range Safety System 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 Space Shuttle Main Engines during Phase 1 can lead to a Return to Launch Site (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.

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. A Shuttle failure on touchdown can result in a crash landing.

B.2.4 Phase 2 Accident Scenarios (SSME Burn to MECO)

This phase of flight starts when the SRBs separate from the vehicle until SSME cutoff (MECO). The primary vehicle catastrophic accidents during this period result in vehicle breakup or in failure to achieve orbit, leading to uncontrolled re-entry.

At altitudes exceeding 150,000 feet, explosions and fragment environments are no longer a threat to the RTGs. The SRBs are no longer attached and formation of explosive mixtures of liquid oxygen and liquid hydrogen cannot result in explosion overpressures, considering the rarefied atmosphere. Ballistic re-entry of the spacecraft will result in breakup of the vehicle and release of the RTGs.

Non-catastrophic shutdown of one or more SSMEs during this phase can lead to a variety of intact or contingency abort modes. The Transoceanic Abort-Landing (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 Abort Once Around (AOA) or Abort to Orbit (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. TAL sites for NSTS-34 (Galileo) are:

- Primary - Ben Guerir, Morocco
- Alternate - Moron, Spain.

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 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 Abort from Orbit.

Contingency abort conditions are defined when two Space Shuttle Main Engines fail prior to single engine TAL capability, or when three engines fail prior to achieving an AOA capability. These results 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.

B.2.5 Phase 3 Accident Scenarios (MECO to IUS deployment)

Accidents in this phase would occur after vehicle orbit has been achieved but prior to deployment of the Galileo/IUS. The accidents of primary concern are those associated with the Shuttle failures that would result in orbital decay and eventual uncontrolled re-entry. The entry would be very shallow at a velocity of 26,000 feet per second.

If problems are found with either orbital parameters, the Galileo spacecraft, or the IUS 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 given in the AOA section above may be employed in this abort mode.

Although abort landing accidents are theoretically possible from Abort From Orbit (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.

As pointed out in Section 2.2.5, if a healthy spacecraft is left in Earth orbit, the spacecraft propulsion system can be used to boost the spacecraft to a long-life orbit in excess of 2,000 years.

B.2.6 Phase 4 Accident Scenarios (IUS Deployment to Earth Escape)

Accidents in this phase would occur between Galileo/IUS separation from the Shuttle and Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory insertion. The accidents of primary concern are IUS propulsion or guidance failures which could result in vehicle breakup and/or in re-entry from orbit.

Re-entry conditions can range from speeds of 14,000 to 36,000 ft/sec at angles of -0.5 to -36.0 degrees.

B.2.7 Phase 5 Accident Scenarios (VEEGA)

A detailed Galileo Earth Avoidance Study (JPL 1988) of possible spacecraft and mission failures has determined only three failure types which represent even a remote threat of Earth impact: retro-propulsion module penetration by a micrometeroid, a small number of lesser probability spacecraft failures, and multiple serial failures in the ground command system.

The total probability of spacecraft re-entry and impact is less than 5×10^{-7}. In the remote event that any of these accidents resulted in the spacecraft being placed on an Earth-impacting trajectory and recovery attempts failed, the spacecraft would break up as it re-entered the atmosphere at a velocity of 45,600 to 49,300 ft/sec at angles of 0 to 90^{0}. The resulting thermal and dynamic environment would be very severe with peak heating rates around 11,000 Btu/ft^2-sec and peak dynamic loads of 17,700 lb./ft.^{2} at decelerations of approximately 600 g's.

B.3 ACCIDENT ENVIRONMENTS

The following paragraphs summarize the key accident environments which were addressed in the Department of Energy (DOE) safety analysis of Shuttle accidents and the possible threat to the RTGs and Radioisotope Heater Units (RHUs).

B.3.1 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 solid rocket boosters 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 MET at the time of initial case fracture.

Typical estimated peak SRB fragment characteristics for SRB random failure are shown as a function of MET in Table B-3. This table also shows estimates of the probability of a large fragment hitting a RTG and the effects of intervening Orbiter structure on fragments flying toward the Shuttle cargo bay. The peak fragment velocities for range destruct are comparable to the random values, but the high velocity range destruct fragments represent a lessor threat to the RTGs because of their location near the motor destruct charge.

TABLE B-3. PEAK SRB FRAGMENT ENVIRONMENTS: SRB RANDOM FAILURE

MET (s)	Fragment Velocity (fps)	Maximum Spin Rate (HZ)	Fragment Hit Probability	Intervening Structure Velocity Reduction (%)
0-20	135-370	12	~.17	10-19
20-70	135-340	11	~.17	10-19
70-105	180-365	13	~.17	10-19
105-120	265-765	21	~.17	6-18

B.3.2 <u>ET Propellant Explosion Environments</u>

B.3.2.1 Blast Environments

The hazards imposed by explosions can be characterized for purposes of safety analysis by specifying, in probabilistic terms, values for the blast wave parameters, peak overpressure, overpressure impulse, peak dynamic pressure, dynamic pressure impulse, and peak reflected pressure. The definition of these blast loading parameters are:

Static Overpressure is defined as the peak crushing pressure, exceeding the ambient pressure, which occurs in the blast pulse from an explosion. The variation of the overpressure with time at a fixed distance from the explosion depends largely on the amount and rate of the energy release of the explosion. The peak overpressure at a fixed distance is the maximum value sensed at that location and is experienced at the instant the front of the blast pulse just passes the location.

Static Overpressure Impulse is defined as the area under the curve of overpressure versus time over the interval between the time of arrival of the blast front at the fixed location to the time at which the overpressure returns to zero at the same location.

Peak Reflected Pressure is defined as the magnitude of the reflected blast wave front that would result upon striking a rigid body placed in the path of a blast front. Since the peak reflected pressure can be quite high, it can deform the body and accelerate it.

Dynamic Pressure is a measure of the strength of the "wind" following the front of the blast pulse. Peak dynamic pressure occurs just behind the front and decays rapidly with distance behind the front.

Dynamic Pressure Impulse is defined analogously to static overpressure impulse. Peak dynamic pressure and dynamic pressure impulse control the drag of the blast wind and along with body shape and weight determine the final velocity of a body if it is free to move.

Pre- and Early-Flight Ground Pool Explosions

A significant explosion source for the Shuttle is from the possible massive spill of the liquid oxygen and hydrogen ET propellants. 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 RTGs within the Orbiter. It is also possible that, as the blast wave fails the structure, the RTGs will be directly exposed to the blast environment. Thus, not only Orbiter fragmentation but also blast loading (acceleration) hazards are presented to the RTGs.

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 RTGs.

Typical blast and Orbiter fragmentation environments estimated to result from these ground-pool explosions at several distances above the pad surface are shown in Tables B-4 and B-5, respectively.

TABLE B-4. BLAST ENVIRONMENTS* DUE TO DESTRUCT OR GROUND POOL EXPLOSIONS STS/IUS

Height (ft)	Over-Pressure	Pressure (psi) Dynamic	Pressure (psi) Reflected	Impulse (psi-s) Static	Impulse (psi-s) Dynamic
In-pool	2,075	810	5,300	0.58	0.058
Just Above Pool	659	1,720	5,169	2.01	0.33
20	106	123	552	0.71	0.19
100	21	18	78	0.41	0.20

*Upper 10 percentile estimates for on-pad explosions of respective liquid bipropellants (except for in-pool and just above pool).

TABLE B-5. FRAGMENT VELOCITIES* FROM DESTRUCT OR GROUND POOL EXPLOSIONS: STS/IUS

Height (ft)	Flyer Plate Velocity (fps)	Shrapnel Velocity (fps)
In-pool	679-2,186	1-92
Just Above Pool	1,079-2,661	2-122
20	429-1,096	0-70
100	184-356	0-58

*Upper 10 percentile estimates for on-pad explosions of respective liquid bipropellants (except for in-pool and just above pool).

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 an 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 an explosive mixture. The burning SRBs provide an ignition source to ignite the mixture. A hydrodynamic computer code is used to compute the blast loading parameters of a fast-moving, spherically-expanding, blast pulse.

The estimated blast environment from this explosion is shown in Table B-6 for the breakup starting at two different times as the Shuttle accelerates during its early launch trajectory. As the ET breakup, propellant dump, and mixing require an elapsed time on the order of a second, the increased speed of the Shuttle between the two initiating times shown in Table B-6 has allowed an increased distance (Shuttle inertia) 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.

The potential Orbiter fragment velocities associated with the airborne blast environments in Table B-6 are shown in Table B-7.

TABLE B-6. BLAST ENVIRONMENTS DUE TO IN-FLIGHT EXPLOSIONS FROM DESTRUCT OR MASSIVE STRUCTURAL FAILURES: STS/IUS

MET (s)	Pressure (psi)			Impulse (psi-s)	
	Over-pressure	Dynamic	Reflected	Static	Dynamic
10	298	122	1,991	3.23	1.60
30*	14	5	53	1.13	0.48

*Over-water threshold.

TABLE B-7. FRAGMENT VELOCITIES FROM IN-FLIGHT EXPLOSIONS DUE TO DESTRUCT OR MASSIVE STRUCTURAL FAILURES:

MET (s)	Flyer Plate Velocity (fps)	Shrapnel Velocity (fps)
10	958 - 1949	6 - 354
30*	200 - 285	2 - 83

*Over-water threshold.

B.3.3 Fireball Environment From ET Propellants

The updrafts and high temperatures within the fireball produced by a large liquid propellant ground fire are hazards 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.

The fireball characteristics and thermal environment that would result from a massive spill of ET propellants at the launch pad can be specified by: (1) maximum fireball diameter, (2) fireball lift-off time, (3) duration of the fireball, (4) temperature inside the fireball, and (5) total heat flux produced within the fireball.

Using available experimental and analytical information, and assuming a full ET load of propellant is involved (1,595,000 pounds), a maximum fireball diameter of 1,000 feet is predicted. The fireball is also predicted to have a total duration of 30 seconds and to lift completely off the ground after about 10 seconds.

The temperatures to which an RTG could be exposed range from approximately 4,000 degrees Fahrenheit at fireball inception down to 3,500 degrees Fahrenheit at fireball lift off. The total heat flux ranges from about 300 to 100 Btu/second/feet^2 over the same time span.

B.3.4 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-8.

TABLE B-8. RTG IMPACT VELOCITIES DUE TO ABORT CRASH: STS/IUS

Crash Scenario	RTG Impact Velocity (fps)
Ditch No Flare	65-125
Ditch With Flare	50-110
Landing Pre-Flare	60-120
Landing Post-Flare	50-65

B.3.5 Environments For Re-entry From Orbit

Aerodynamic and heat transfer analysis of the uncontrolled, accidental re-entry 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 re-entry and will not reach the surface intact.

2) For MET less than 495 seconds, the RTGs or General Purpose Heat Source (GPHS) modules reach the surface over the Atlantic Ocean.

3) For MET between 128 and 155 seconds, the RTGs reach the surface intact and without case melting.

4) For MET between 155 and 210 seconds, the RTGs may reach the surface without case melting, or the GPHS modules may be released prior to reaching the surface.

5) For MET greater than 210 seconds, the GPHS modules are released prior to surface impact.

B.3.6 Inertial Upper Stage and Payload Environments

The IUS vehicle itself does not significantly add to any of the accident environments produced by the main launch vehicle. The solid propellant is not detonable under credible accident conditions for the Galileo mission. Although IUS 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 Galileo/IUS from the Orbiter result in errant re-entry within the design capability of the RTGs. Earth impact conditions are similar to those for re-entry from orbit.

The only IUS failure that can cause a direct threat to the RTGs 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.

The Galileo spacecraft also does not significantly add to any of the accident environments produced by the launch vehicle accident scenarios.

B.4 RADIOLOGICAL ASSESSMENT

The use of plutonium-238 dioxide (PuO_2) fuel, a radioactive material, in the two General Purpose Heat Source - Radioisotope Thermoelectric Generators (RTGs) and the 131 Light Weight Radioisotope Heater Units

(LWRHUs) on the Galileo spacecraft necessitates evaluation of the radiological risks to persons in the launch site vicinity and the general population worldwide resulting from postulated accidents occurring during the mission. The inventory of plutonium dioxide fuel is 132,200 Ci in each RTG (264,400 Ci total) and 33.6 Ci in each LWRHU (4334 Ci total). The RTGs and LWRHUs are described in Section 2.2 of this EIS.

Final Safety Analysis Reports have been prepared by the U.S. Department of Energy (DOE) addressing the safety aspects of the RTGs (USDOE 1988a, USDOE 1988b, USDOE 1988c) and the LWRHUs (USDOE 1988d, USDOE 1988e, USDOE 1988) on the Galileo mission using the Space Shuttle as a launch vehicle. The Final Safety Analysis Reports present the results of safety assessments, including analyses and testing, of launch and deployment of the RTGs and LWRHU for the Galileo mission. The objective of this section is to summarize the results of the Final Safety Analysis Reports in terms of potential accidents and resulting radiological consequences and risks.

The RTG Final Safety Analysis Report consists of three volumes as follows:

Volume 1: Reference Design Document

Contains reference design information that provides a basis for Volumes II and III. It contains descriptions of the RTG, the Galileo spacecraft and mission profile, the Space Shuttle, the Inertial Upper Stage (IUS), the trajectory and flight characteristics, and the launch site.

Volume II: Accident Model Document

Summarizes the potential accident environments and associated probabilities as described by NASA in the Shuttle Data Book (NASA 1988). Presents a summary of failure sequences and any resulting fuel releases (source terms) based on analyses and test data characterizing the response of an RTG to different accident environments.

Volume III: Nuclear Risk Analysis Document

Summarizes the radiological consequences of postulated accident scenarios by mission phase. Mission risks, by mission phase, are also quantified. The radiological consequences and risks are reported in terms of the radiation dose and health effects incurred by the affected population, and levels of deposition of radioactive material on the ground.

The analysis is supported by a series of appendices which present in detail the methodology utilized in risk assessment; biomedical aspects of PuO_2; meteorological data; land use, oceanographic and water characteristics at the Kennedy Space Center; worldwide demographic, land use, and oceanographic data; particle size considerations; and an uncertainty analysis.

The process of information flow and analyses used in the RTG Final Safety Analysis Report is summarized in Figure B-5. The LWRHU Final Safety Analysis Report consists of an analogous three volume set.

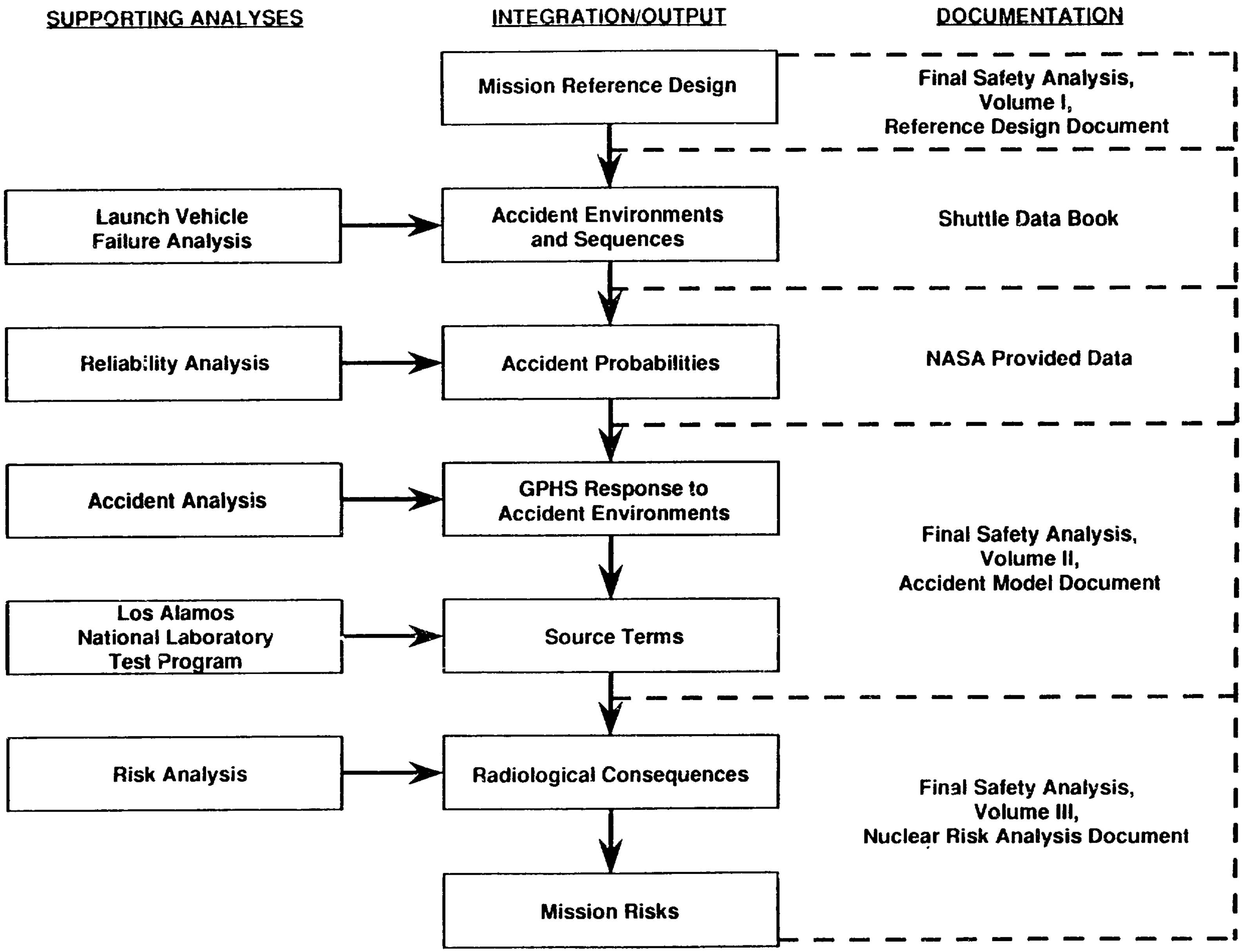

FIGURE B-5. FINAL SAFETY ANALYSIS REPORT DEVELOPMENT PROCESS

The remainder of this section summarizes the source terms based on the Accident Model Document (Section B.4.1), the radiological consequences methodology (Section B.4.2), the accident consequences (Section B.4.3), and integrated mission risks (Section B.4.4) based on the Nuclear Risk Analysis Document and its appendices.

B.4.1 Source Terms

This section summarizes the accident scenario and accident environment that could result in a fuel release from the LWRHUs. The accident scenarios and accident environments that could result in fuel release from the RTGs are presented in Sections B.2 and B.3. Considerations and conclusions of evaluating the damage to fuel containment structures are summarized.

The fuel release from an accident is called a source term. A source term consists of the quantity of fuel released (expressed in curies of PuO_2), 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.

The radiological consequences of an accident are dependent on several variables. These are the accident scenario, release characterization, exposure pathway parameters, and meteorological conditions. Each accident case is a combination of the variables. The total number of combinations is very large, making analysis of all accident cases impractical. Three cases for each mission phase are developed and analyzed. The method of selection and the source term for the selected cases are described.

For the accident scenarios and the associated environments specified by NASA, the considerations and conclusions of evaluating the damage to fuel containment are summarized as follows:

1) Explosion of external tank propellants on or near the launch pad, with the subsequent implosion of the Orbiter payload bay walls around the RTGs do not result in breach of the Fueled Clads. Distortions of the clads generally are less than the threshold for breach.

2) In a small percentage of cases, external tank propellant explosions could result in release of Fueled Clads. The secondary impact of the Fueled Clads on the concrete and steel surfaces around the launch pad could result in breach of some clads.

3) Based on tests simulating range destruct or Solid Rocket Booster case rupture, Solid Rocket Booster fragments at velocities up to 695 ft/sec in the face-on impact attitude will not breach the Fueled Clads when struck in the full RTG configuration.

4) The results of Solid Rocket Booster fragment interaction tests with Orbiter structure indicate that attenuation by passage through the wing and payload bay wall can reduce fragment velocity up to 46 percent and spin rate up to 100 percent. Passage through only the payload bay wall can reduce velocity up to 20 percent. These data, coupled with the results of the large Solid Rocket

Booster fragment tests, indicate that Solid Rocket Booster fragments in the face-on attitude at impact during the first 105 seconds of mission elapsed time will not cause a breach of the Fueled Clads. A range destruct of the vehicle during the 105-128 seconds of mission elapsed time are of the face-on impact type.

5) Solid Rocket Booster fragments impacting in an edge-on attitude can breach the fuel clads at velocities in the range of 130-370 ft/sec depending on the fuel and iridium characteristics, and the location of impact with respect to the clads, and the position of the Fueled Clads in the stack of modules.

6) If re-entry occurs as a result of a spacecraft failure during the VEEGA Maneuver phase, the aeroshells are expected to fail and release the Graphite Impact Shell with Fueled Clads. The iridium clads will fail from eutectic formation with the graphite in the Graphite Impact Shell. Impact on a hard ground surface is then assumed to release all the fuel in the Graphite Impact Shell.

7) Both intact and damaged Fueled Clads and modules may have some residence time in the fireball from liquid propellant explosions. The effects of the fireball will not result in breach of the clads; the fireball, however, will modify the particle size distribution or location of any fuel released in the fireball.

8) Modules released during On-Orbit or Payload Deploy phase accidents may release small amounts of fuel upon impact on a rock or other hard surfaces for cases involving land impact following reentry.

The LWRHUs aboard the Galileo Spacecraft can be subjected to a number of hostile environments. A systematic assessment of the response of LWRHUs to these environments shows that fuel release would occur only in certain instances during a VEEGA superorbital reentry (USDOE 1988d, USDOE 1988e). The probability of a release is 1.00×10^{-8} for the most probable case, 5.00x 10-9 for the maximum case, and 1.50×10^{-8} for the expectation case. Accidents with a probability of release of less than 1.00×10^{-7} have been dropped from consideration. Since the probabilities of release for the LWRHUs are less than this cut off limit they are not considered further.

Shuttle related launch and ascent source terms were calculated using the LASEP-2 program. LASEP-2 uses a Monte Carlo approach to simulate RTG response to a given accident environment. This is done using a minimum of 10,000 trials for each scenario or sub-scenario 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-2 model directs the calculations to arrive ultimately at Fueled Clad distortion. Correlations based on RTG component test data are then used by LASEP-2 to determine Fueled Clad crack size, the fuel release quantity and particle size distribution of the release (USDOE 1988b).

The average and maximum source terms are calculated for each accident scenario considered. One most probable and one maximum accident scenario from each mission phase are analyzed in the Nuclear Risk Assessment Document

(USDOE 1988c). In addition, an accident expectation case, which incorporates all probabilities and source terms, is presented for each phase. The definitions of these cases follow:

Most Probable Release Case

The Failure/Abort Sequence Trees for each mission phase are examined and the single release having the highest probability of occurrence is selected. All associated releases within the selected sequence branch (e.g., projectile breach and impacts on various media of both breached and unbreached Fueled Clads) comprise the source term (USDOE 1988c).The radiological consequence of the source term for each of the 42 sets of daily meteorological data, which represent the 42 days of the launch window, are then calculated. The results are ranked according to population dose, and the case that represents the 50th percentile of the ranking is selected as the most probable case.

Maximum Release Case

Within a mission phase, the maximum fuel release and the meteorology that maximizes population dose through inhalation, ingestion, and external pathways is selected. The single release and all related releases in the sequence branch comprise the source term (USDOE 1988c).

Expectation Case

The expectation case uses all of the average releases and their probabilities to define a probability-weighted source term, considering all of the scenarios postulated in a mission phase. The radiological consequences of the source term for each of the 42 meteorological sets are calculated. The results are averaged to develop the expectation case. The purpose of the expectation case is to develop the components of a risk analysis considering the whole phase duration. It represents a probabilistic combination of all accident scenarios (USDOE 1988c).

The range from zero to most probable and maximum cases present a representative range of releases that could occur. The most probable is the release of highest probability, but could be different considering it is representative of only one set of the variables - quantity of release, location of release, particle size distribution, probability of accident occurrence, and meteorological conditions. A change in any one of these, except probability of occurrence, could result in a different set of consequences. The maximum case, presenting the highest consequences, is developed primarily for emergency planning purposes.

The most probable, maximum, and expectation source terms for each mission phase are presented in Tables B-9 through B-11, respectively. Each case is described by type of accident, the curies that are estimated to be released, the probability of release, category of release, and description of the accident. For example, in the Phase 0 most probable accident, the type is a fire and explosion which results in release of 44 curies of PuO_2. The release has a probability of 5 in 10 million, and will occur in the fireball of the explosion while the Shuttle is sitting on the launch pad. The PuO_2 will come from Fueled Clads that are breached by impact with

TABLE B-9. SUMMARY CHARACTERISTICS OF MOST PROBABLE CASES BY PHASE

Phase	Accident Type	Curies Released	Probability of Release	Release Category	Description
0	Fire followed by Explosion	44	5.01×10^{-7}	Fireball	• Occurs on the Launch Pad • Fueled Clads breached by steel impact inside fireball
1	Solid Rocket Booster Failure resulting in Loss of Thrust	796 125	3.30×10^{-4} 3.30×10^{-4}	Fireball Ground level	• Occurs on the Launch Pad • Fueled Clads breached by concrete impact inside and outside fireball
2	Vehicle Breakup	1	2.27×10^{-6}	Ground level	• Occurs on the African Continent • One module breached by impact on rock
3	Orbiter Reentry and Breakup	4	6.47×10^{-6}	Ground level	• Occurs at 0° latitude • One module breached by impact on rock
4	IUS Failure	4	3.50×10^{-4}	Ground level	• Occurs at 0° latitude • One module breached by impact on rock
5	Inadvertent Reentry	11,568[a]	1.12×10^{-7}	Ground level	• Occurs at 0° latitude • Inventory of three Graphite Impact Shells released by impact on rock

Source: USDOE 1988c
a. 3856 Curies per Graphite Impact Shell.

TABLE B-10. SUMMARY CHARACTERISTICS FOR MAXIMUM CASES BY PHASE

Phase	Accident Type	Curies Released	Probability of Release	Release Category	Description
0	Fire followed by Explosion	44	$5.01x10^{-7}$	Fireball	• Occurs on the Launch Pad • Fueled Clads breached by steel impact inside fireball
1	Solid Rocket Booster failure resulting in loss of thrust	1,864	$1.39x10^{-4}$	Ground-level	• Occurs on the Launch Pad • Module breached by impact on concrete outside fireball
2	Vehicle Breakup	1	$2.27x10^{-6}$	Ground-level	• Occurs on the African Continent • Fueled Clads breached following impact of one module on rock
3	Orbiter Reentry and Breakup	8	$1.35x10^{-7}$	Ground-level	• Occurs at 33°N latitude • Fueled Clads breached following impact of 2 modules on rock
4	IUS Failure	8	$7.28x10^{-6}$	Ground-level	• Occurs at 33°N latitude • Fueled Clads breached following impact of 3 modules on rock
5	Inadvertent Reentry	11,568[a]	$1.12x10^{-7}$	Ground-level	• Occurs at 33°N latitude • Fueled Clads breached following impact of 3 Graphite Impact Shells on rock

Source: USDOE 1988c
a. 3856 Curies per Graphite Impact Shell and 3 impact points

TABLE B-11. CHARACTERISTICS OF EXPECTATION CASES BY PHASE

Phase	Accident Type	Fireball Release Probability	Fireball Curies Released	Ground-Level Release Probability	Ground-Level Curies Released	At Altitude Release Probability	At Altitude Curies Released
0	Fire/Explosion	1.35×10^{-8}	44	-	-	-	-
	Phase 0 Expectation	1.35×10^{-8}	44	-	-	-	-
1	Solid Rocket Booster Failure	5.01×10^{-7}	19	5.01×10^{-7}	45	3.77×10^{-7}	815
		5.15×10^{-7}	58	-	-	-	-
		3.30×10^{-4}	796	3.30×10^{-4}	125	-	-
		1.01×10^{-5}	796	1.01×10^{-5}	125	-	-
	Range Safety System Destruct	1.18×10^{-8}	11	1.18×10^{-8}	184	2.71×10^{-10}	372
	Aft Compartment Explosion	1.02×10^{-5}	796	1.02×10^{-5}	125	-	-
	Vehicle Breakup	1.84×10^{-6}	796	1.84×10^{-6}	125	-	-
		7.64×10^{-8}	26	-	-	-	-
	Phase 1 Expectation	3.53×10^{-5}	794	3.53×10^{-4}	125	3.77×10^{-7}	815
2	Vehicle Breakup	-	-	2.27×10^{-06}(a)	1	-	-
	Phase 2 Expectation	-	-	2.27×10^{-06}(a)	1	-	-
3	Orbiter Reentry/Breakup	-	-	6.61×10^{-06}(a)	4	-	-
	Phase 3 Expectation	-	-	6.61×10^{-06}(a)	4	-	-
4	IUS Failure	-	-	3.57×10^{-04}(a)	4	-	-
	Phase 4 Expectation	-	-	3.57×10^{-04}(a)	4	-	-
5	Inadvertent Reentry	-	-	5.00×10^{-07}(a)	12,400	-	-
	Phase 5 Expectation	-	-	5.00×10^{-07}(a)	12,400	-	-

Source: USDOE 1988c
a. Probability of one or more impacts on rock, resulting in fuel release.

steel. Each of the other phases for the most probable and maximum cases presented in Tables B-9 and B-10 can be similarly described.

Additional explanation of the Phase 1 most probable case is necessary. The accident type is a Solid Rocket Booster failure resulting in the loss of thrust. The release of PuO_2 comes from two categories, 1) Fueled Clads breached by concrete fragments in the fireball, and 2) Fueled Clads breached by impact with concrete outside the fireball. The total source term is 921 curies with a probability of occurrence of 3 in 10,000. The accident occurs on the launch pad.

The expectation cases (Table B-11) are presented in terms of accident type, the category of release, the probability of release, and the amount of PuO_2 released. For example, for Phase 0 only one accident type, a fire and explosion, make up the expectation case. The release occurs in the fireball with a probability of occurrence of 5 in 10 million. The Phase 1 expectation case is made up of seven accident types. All have releases in the fireball, six also have releases at ground level outside the fireball, and two also have releases at an altitude but outside the fireball.

The particle size distributions associated with these releases are based on aeroshell module and Fueled Clad impact tests conducted at Los Alamos National Laboratory (USDOE 1988c). For the most probable and expectation cases, the average of the particle size distributions for the tests considered was used as a starting point. Based on the Fueled Clad crack sizes calculated by LASEP-2, the particle size distributions were cut-off at a particle size equal to one-half the maximum crack size, and then renormalized. A similar approach was taken for the maximum release cases except that the particle size distribution from the test data that would maximize radiological consequences was selected as the starting point. The particle size distributions which are the bases for both cases are summarized in Figure B-6.

A detailed discussion of the particle size considerations is presented in Appendix D of the Final Safety Analysis Report, Volume III (USDOE 1988c). The results of this analysis show:

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 0.2 uCi/m^2 screening level are particles in the 10 to 20 micron range.

B.4.2 Radiological Consequences Methodology

This section summarizes the method used to determine the radiological consequences resulting from the most probable and maximum cases for each

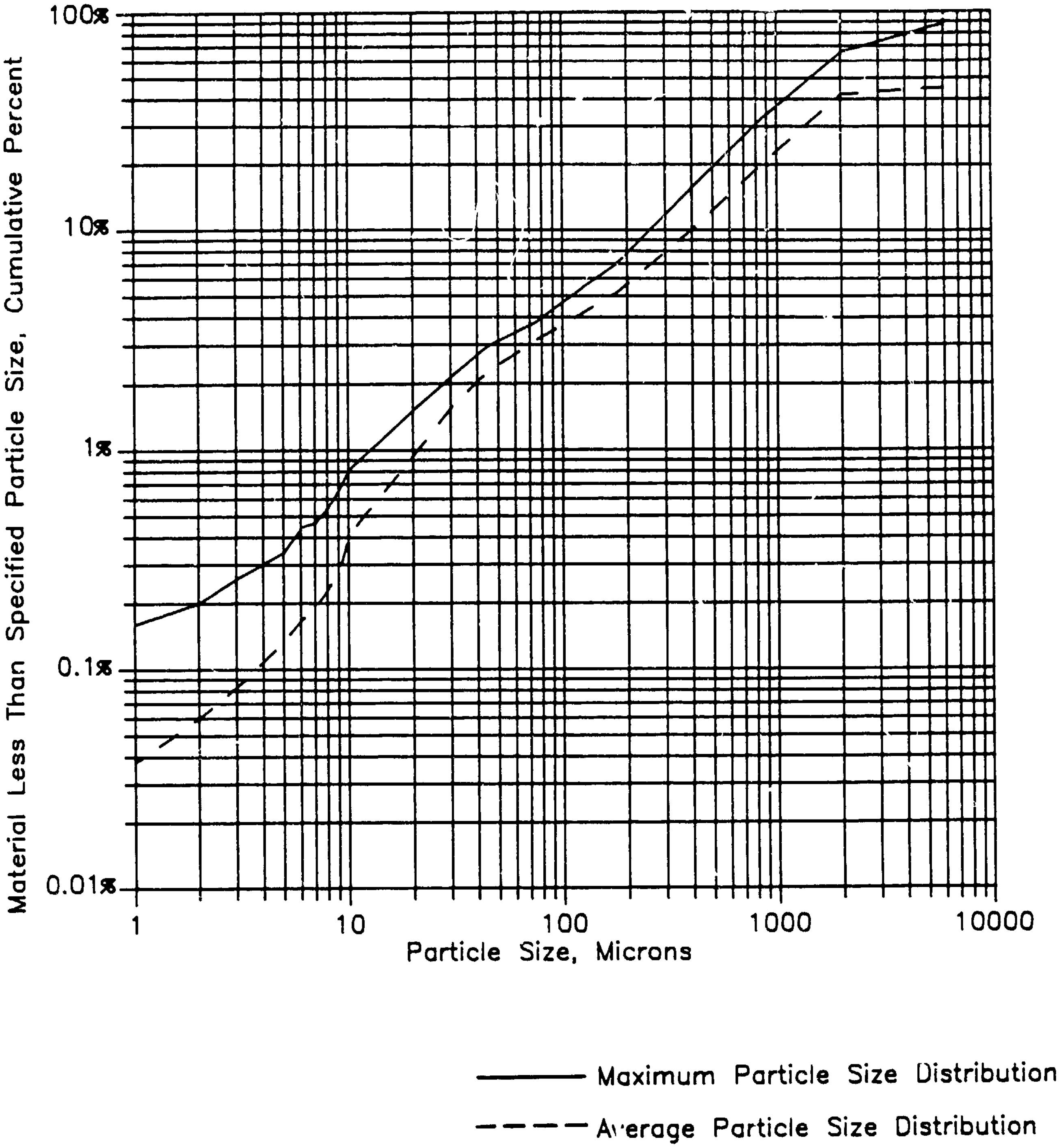

FIGURE B-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION FOR MOST PROBABLE AND MAXIMUM CASES

mission phase. 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 (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 population doses and contaminated environmental media.

The types of radiological consequences for the most probable and maximum release cases include:

1. The "short term" radiation dose that results from the initial exposure. The doses are 70-year dose commitments resulting from the extended retention of material in the body.

2. The "long-term" radiation dose which would result from continuing exposure to materials in the environment over an extended period following release. Long-term doses include those to offsite Kennedy Space Center and worldwide populations due to inhalation of resuspended material and ingestion of contaminated food over a 70-year period. In addition long-term doses to onsite Kennedy Space Center workers due to inhalation of resuspended material is calculated for an exposure period of 35 years based on 40 hours per week.

3. Estimates of land- and water-surface areas contaminated caused by deposition of radioactivity.

This information is presented in the following terms for each representative case:

1. Numbers of persons estimated to be subject to greater than specified levels of both short term doses and long term doses. The launch area population data, and worldwide population density data described in Section 3 are used as the basis.

2. Total short-term and long-term population doses. In calculating population doses, the concept of de minimis has been used, meaning a dose level below concern and from which no health effects are calculated. The de minimis dose (Davis, 1988) was taken to be 1 mrem/year and 50 mrem total dose commitment. Total population doses are reported both with and without de minimis.

3. The maximum short-term and long-term doses to individuals.

4. Estimates of land and surface water areas contaminated above specified levels. The screening level of 0.2 Ci/m^2 established by EPA, below which no further consideration need be given, has been used (USEPA 1977).

The radiological consequences for each mission phase were calculated for the most probable, maximum, and expectation cases using the KSC-EMERGE, LOPAR, and HIPAR computer models. Releases in the troposhere are treated using KSC-EMERGE and high 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). The results for the maximum and most probable cases clearly identify specific cases intended to be representative accident scenarios, while the results for the expectation case are used in the calculation of risk. Key features and assumptions of the analysis are summarized below. Details of the methodology are presented in the Final Safety Analysis Report (USDOE 1988c).

The 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 10 meters at a height of 5 meters. 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.

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 most probable case of launch pad accidents. Since lower release heights and smaller cloud dimensions result in increased radiological consequences, the cloud specification for the maximum case are based on a thermal release that is 10 percent of that used in the most probable case. This is within the range of observed variations in vertical plume configurations for a given energy release (USDOE 1988c).

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 5 m and an initial 10 m cloud diameter. Population doses should not be significantly affected. 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.

The atmospheric dispersion of postulated releases in the troposphere (altitudes less than about 10 km) in the vicinity of Kennedy Space Center is treated using the KSC-EMERGE model. KSC-EMERGE is a Gaussian puff-trajectory model that treats meteorology that varies in time and space (vertically) and accounts for vertical plume configuration; particle-size-dependent transport, deposition, and plume depletion, and sea-breeze recirculation.

Meteorology for the launch window (October-November) is treated in terms of 24-hour historical sequences of meteorological data. The launch window meteorology is represented by 42 such sequential data.

Releases at high altitude are treated by a particle trajectory model (HIPAR) in the case of large particles (greater than 10 microns) and by an empirical model (LOPAR) derived from weapons testing data in the case of small particulates and vapor (less than or equal to 10 microns).

Radiation doses to populations are calculated based on environmental concentrations. The dose conversion factors have been derived using a model developed by the Interagency Nuclear Safety Review Panel-Biomedical and Environmental Effects Subpanel for the 1986 Safety Evaluation Report. In the calculation of radiation dose, the concept of de minimis has been used, representing a dose level below concern (Negligible Individual Risk Level, or NIRL)(NCRP 1987). A de minimis dose of 1 mrem per year (50 mrem lifetime) has been used. Population dose is reported in person-rem, which is the cumulation of doses to all of the affected population.

The assumptions and features of the analyses which are 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 of ground level and elevated releases (cloud size, height) is important to the results.

4. Long-term doses contain a component due to food ingestion. It is assumed that all vegetables consumed by the population are grown locally (in home gardens). This may be true for some individuals, but is unlikely to be true for the general population.

The radiological consequences of the PuO_2 releases for the most probable, maximum and expectation cases are dependent on the characteristics of the models utilized and values selected for key model parameters. Due to the potentially large range of PuO_2 releases and environmental conditions that could affect the results, an uncertainty analysis has been performed to determine what variation from the estimated radiological consequences and mission risks might be expected (USDOE 1988c).

Important variable 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
- Modifications to the source term and particle size distribution because of mechanical, chemical and physical interaction prior to deposition
- Particle size distribution
- 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 uncertainty analysis. However, the approach taken is dependent on the type of radiological consequences under consideration which include the following:

  - Short-term population dose (with and without de minimis)
  - Long-term population dose (with and without de minimis)
  - Surface contamination levels
  - Health effects.

Population dose health effects, and risk, are the primary types of results considered in the uncertainty analysis. The other measures are discussed where appropriate, but are considered as being of secondary importance from an uncertainty viewpoint.

The detailed description of the uncertainty analysis and the methodology used are presented in Appendix H of the Final Safety Analysis Report, Volume III (USDOE 1988c). The following presents a summary of the uncertainty analysis results.

The uncertainty factors resulting from consideration of accident probabilities, release characterization, meteorological conditions, and exposure pathway parameters are summarized. Based on these uncertainty factors, the overall uncertainty associated with various types of radiological consequences and mission risk are determined.

The log-normal distributions of each of the individual uncertainty factor ranges were combined, such that the overall mean uncertainty factor was taken as the product of the individual mean uncertainty factors affecting the result type. The standard deviation of the log-normal distribution representing the overall range was determined.

Based on the methodology outlined above, the resulting overall mean uncertainty factors and associated ranges are summarized in Table B-12. The uncertainty factors represent multipliers that could be applied to the results presented in the following sections in order to describe the potential effects in more precise and realistic terms. However, in all cases but one (the Phase I mission phase risk-surface contamination area) the mean overall uncertainty factor will reduce the public health and environmental consequences. Therefore it is not as conservative as the approach used.

B.4.3 Radiological Consequence Results

The results of the radiological consequence analysis for the most probable and maximum cases are summarized in Tables B-13 and B-14. Reference should be made to Tables B.-9 and B 10 in relating accident fuel release scenarios and radiological consequences.

Tables B-13 and B-14 present the release probability, population dose in person-rem, total and above de minimis, and the area with deposition above the screening level of 0.2 uCi/m^2. The deposition areas are further divided into dry land, swamp, inland water and ocean. For example for Phase 1 most probable case the release probability is 3.30 x 10^{-4}. Total population dose is 176 person-rem with 0.003 person-rem above de minimis. Areas with deposition are 43.3 square kilometers of dry land, 15.9 square kilometers of swamp, 25.7 square kilometers of inland water, and no ocean areas.

The results for the most probable case show the population doses varying from a total person-rem range of 0.23 in Phase 2 to 1,280 in Phase 5. The population dose above de minimis ranges from 0 person-rem in Phase 0 to 83[illegible] person-rem in Phase 5. The total person-rem for the maximum case ranges from 8 in Phase 2 to 54,000 in Phase 5. The population dose above de minimis ranges from 1 person-rem in Phase 2 to 52,900 person-rem in Phase 5.

TABLE B-12. OVERALL UNCERTAINTY ANALYSIS RESULTS

Result Type	Overall Uncertainty Factor Mean[a]	Overall Uncertainty Factor Range[b]
• Radiological consequences[a]		
- Short-term population dose	0.25	0.013 - 4.6
- Long-term population dose	0.22	0.0042 - 1.4
- Total population dose	0.23	0.0067 - 7.9
- Health effects	0.23	0.0063 - 8.5
- Surface contamination area	0.75	0.051 - 5.2
• Mission phase risk[b]		
Phase 1		
- Short-term population dose	0.42	0.061 - 2.9
- Long-term population dose	0.37	0.024 - 5.7
- Total population dose	0.39	0.035 - 4.3
- Health effects	0.39	0.032 - 4.8
- Surface contamination area	1.3	0.22 - 7.8
Phases 0, 2-5		
- Short-term population dose	0.25	0.55 - 1.1
- Long-term population dose	0.22	0.019 - 2.5
- Total population dose	0.23	0.029 - 1.8
- Health effects	0.23	0.026 - 2.0
- Surface contamination area	0.75	0.20 - 2.9

a. The mean uncertainty factor for radiological consequences multiplies the expectation case results (Table B-15) to yield a best estimate of the expectation case results. The best estimate result for the expectation case should be multiplied by the uncertainty factor range to yield a best estimate of the 5- and 95-percentile values of the range of radiological consequences.

b. The mean uncertainty factor for mission phase risk multiplies the mission phase risk results (Table B-16) to yield a best estimate of mission phase risk (defined as total probability times expectation case results). The best estimate result for mission phase risk should then be multiplied by the uncertainty factor range to yield a best estimate of the 5- and 95-percentile values of the best estimate for the mission phase risk.

TABLE B-13. SUMMARY OF RADIOLOGICAL CONSEQUENCES MOST PROBABLE CASES

	Population Dose in Person-rem[a]				Square Kilometers of Area With Deposition Above 0.2 uCi/m^2[b]			
Mission Phase	Release Probability	Total	Above De Minimis	Health Effects	Dry Land	Swamp	Inland Water	Ocean
0	5.01×10^{-7}	10.10	0.00	0	12.5	1.7	4.6	0.0
1	3.30×10^{-4}	176.00	0.003	0	43.3	15.9	25.7	0.0
2	2.27×10^{-6}	0.23	0.07	0	0.0	0.0	0.0	0.0
3	6.47×10^{-6}	5.99	2.45	0	0.06	0.0	0.001	0.0
4	3.50×10^{-4}	5.99	2.45	0	0.06	0.0	0.001	0.0
5	1.12×10^{-7}	1,280.00	833.00	0.2	13.2	0.0	0.3	0.0

Source: USDOE 1988c
a. Person-rem is the cumulation of dose to the affected population.
b. uCi/m^2 is microcuries per square meter.

TABLE B-14. SUMMARY OF RADIOLOGICAL CONSEQUENCES MAXIMUM CASES

	Population Dose in Person-rem[a]				Square Kilometers of Area With Deposition Above 0.2 uCi/m²[b]			
Mission Phase	Release Probability	Total	Above De Minimis	Health Effects	Dry Land	Swamp	Inland Water	Ocean
0	$5.01x10^{-7}$	179	0	0	4.1	0.1	2.6	0.04
1	$1.39x10^{-4}$	4,910	3,710	0.7	2.0	0.7	2.5	0.2
2	$2.27x10^{-6}$	8	1	0	0.0	0.0	0.0	0.0
3	$1.35x10^{-7}$	217	59	0	0.1	0.0	0.003	0.0
4	$7.28x10^{-6}$	217	59	0	0.1	0.0	0.003	0.0
5	$1.12x10^{-7}$	54,000	52,900	9.8	8.9	0.0	0.2	0.0

Source: USDOE 1988c
a. Person-rem is the cumulation of dose to the affected population.
b. uCi/m^2 is microcuries per square meter.

Individual impacts are expressed in terms of individual dose and the number of persons exceeding the lifetime dose level. These are presented for the most probable, maximum, and expectation cases in Figures B-7 through B-9.

These figures show for the most probable, maximum and expectation cases the number of persons who will exceed different levels. For example for Phase 1 most probable case (Figure B-7) approximately 1 person will receive a lifetime close of 50 mrem.

B.4.4 Integrated Mission Risks

The mission risks associated with the use of the RTGs and LWRHUs on the Galileo mission have been assessed based on the source terms for the expectation cases. The resulting radiological consequences arising from the expectation cases are summarized in Table B-15. The overall mission risks associated with the RTGs are presented in Table B-16.

These results are based on the average source terms from all the postulated accidents and their probabilities. The release, dispersion, and dose calculation conditions for these (many) components of the expectation source terms were the same as those assumed for the most probable release cases. Since these are probability weighted conditions, they are representative of no specific scenarios. Only the "bottom line" risk results have any significance.

Risk, in terms of individual risk of cancer fatality within the affected population receiving doses can be compared with other risks due to natural and man-made hazards, as summarized in Table B-17.

B.5 ENVIRONMENTAL ASSESSMENT METHODOLOGIES

The plutonium dioxide (PuO_2) releases for the most probable, maximum and expectation cases are described in Section B.4. Since the most probable and maximum cases are developed to identify population dose impacts and therefore do not necessarily represent maximum environmental consequences. They represent an emphasis on impacts to population areas and tend to minimize impacts to natural and water areas. The expectation case more accurately reflects potential environmental impacts because it is not designed to emphasize population dose but rather to represent the average of all releases within a mission phase, combined with the average meteorology without regard to population dose. In general this will result in a decrease in deposition on land ares and increase in deposition in water areas when compared to the most probable and maximum cases. Areas of radioactive deposition resulting from the most probable, maximum, and expectation cases are presented in Section B.4, Tables B-13 through B-15.

Accidental releases can occur in the Kennedy Space Center vicinity during Phases 0 and 1 and at unspecified areas worldwide during Phases 2 - 5. Section 3 of the EIS presents a description of the environments that could be affected by radioactive deposition. Two different impact assessment methodologies were developed to analyze these releases. Both methodologies use the most probable, maximum, and expectation cases. One is for the Kennedy Space Center vicinity during Phases 0 and 1. The other is

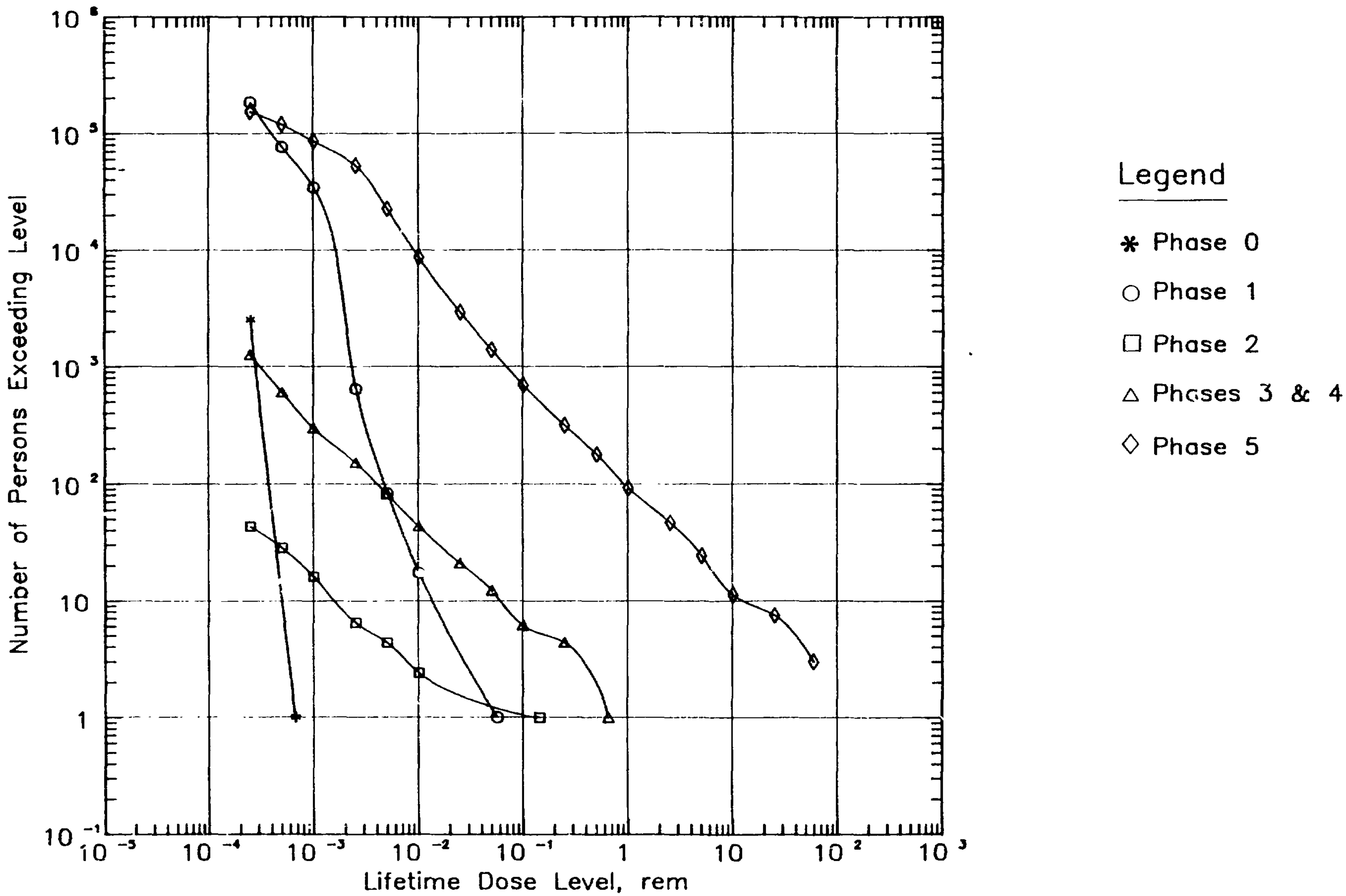

Figure B-7. RADIOLOGICAL CONSEQUENCE SUMMARY MOST PROBABLE CASES, STS

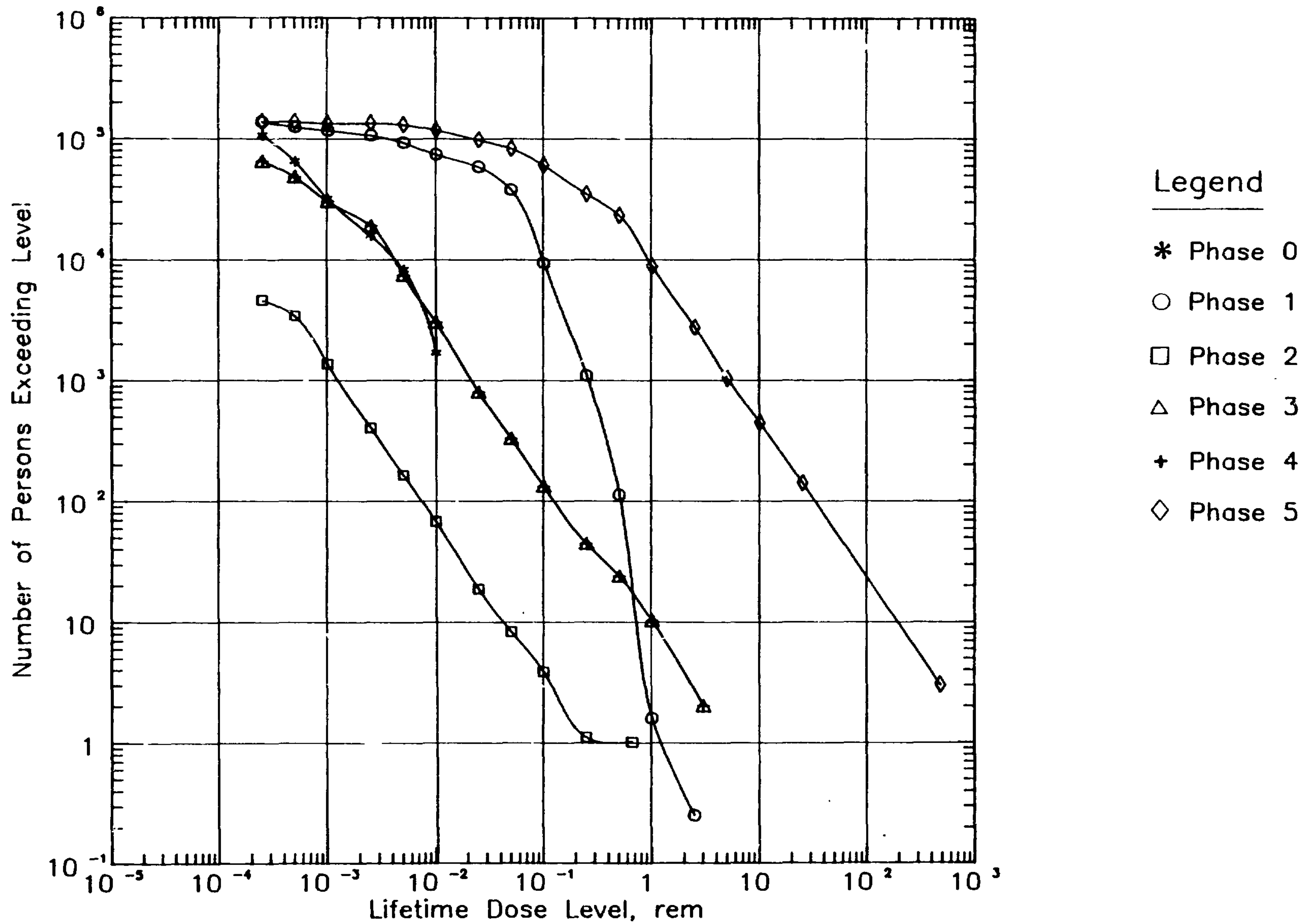

Figure B–8. RADIOLOGICAL CONSEQUENCE SUMMARY MAXIMUM CASES, STS

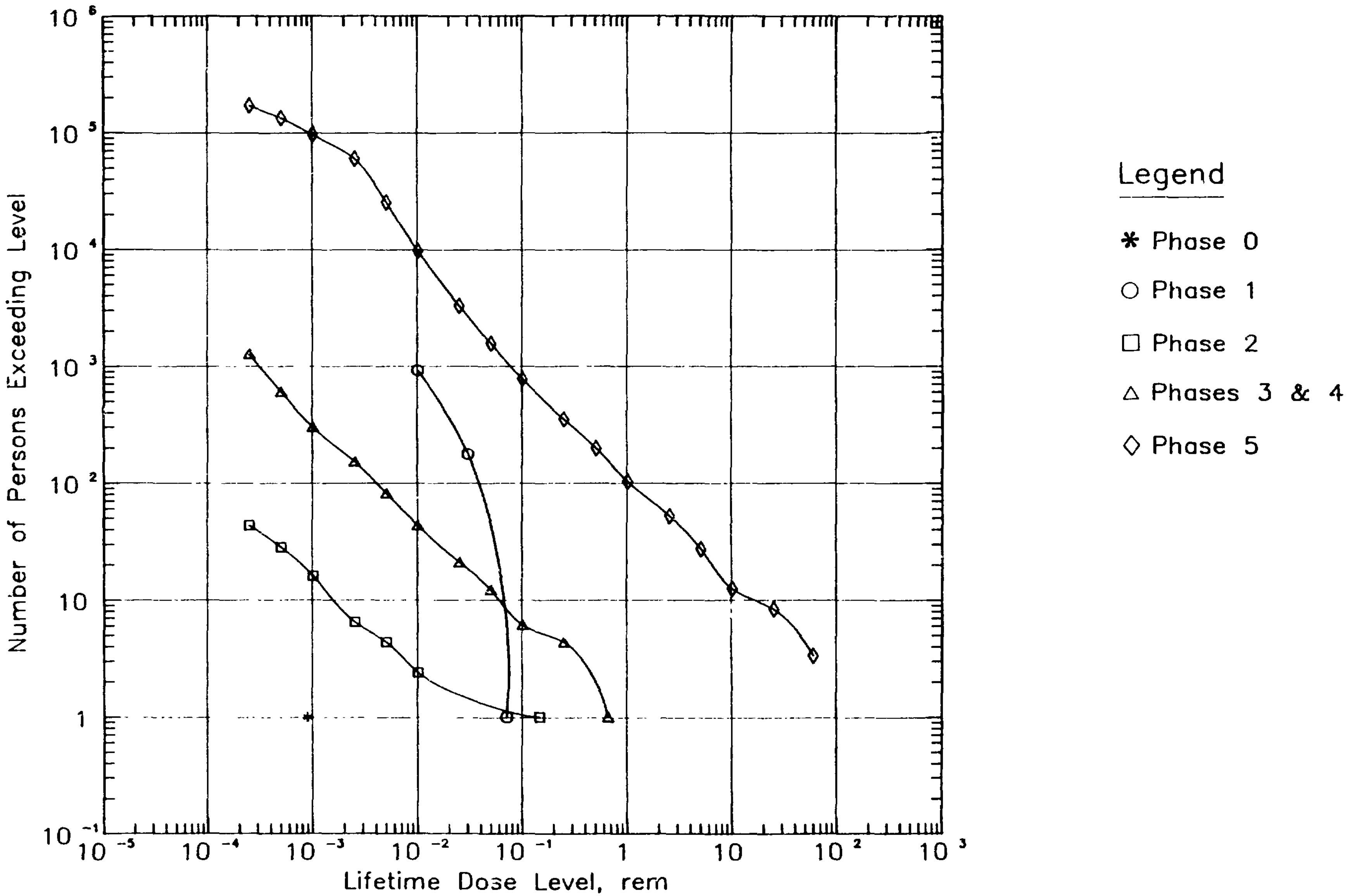

Figure B–9. RADIOLOGICAL CONSEQUENCE SUMMARY EXPECTATION CASES, STS

TABLE B-15. SUMMARY OF RADIOLOGICAL CONSEQUENCES EXPECTATION CASES

Mission Phase	Release Probability	Population Dose in Person-rem[a]		Square Kilometers of Area With Deposition Above 0.2μCi/m2[b]			
		Total	Above De Minimis	Dry Land	Swamp	Inland Water	Ocean
0	5.01×10^{-7}	12.70	0.0	7.0	1.2	4.1	4.5
1	3.53×10^{-4}	203.0	2.7	25.7	7.3	16.3	20.8
2	2.27×10^{-6}	0.2	0.07	0.0	0.0	0.0	0.0
3	6.61×10^{-6}	5.99	2.5	0.1	0.0	0.001	0.0
4	3.57×10^{-4}	5.99	2.5	0.1	0.0	0.001	0.0
5	5.00×10^{-7}	1,430.0	927.0	14.7	0.0	0.3	0.0

Source: USDOE 1988c

a. Person-rem is the cumulation of dose to the affected population.

b. $\mu Ci/m^2$ is microcuries per square meter.

TABLE B-16. MISSION RISK SUMMARY BY PHASE WITH RELEASE

Mission Phase	Release Probability	Population Dose in Person-rem Above De Minimis	Excess Health Effects[a]	Population Affected[b]	Average Individual Risk[c]
0	$5.01x10^{-7}$	0.0	0	0	no risk
1	$3.53x10^{-4}$	2.7	.00051	86.9	2 in 1 billion
2	$2.27x10^{-6}$	0.09	.00001	1	4 in 100 billion
3	$6.61x10^{-6}$	2.5	.00045	12	2 in 10 billion
4	$3.57x10^{-4}$	2.5	.00045	12	1 in 100 million
5	$5.00x10^{-7}$	927.0	.171	1,550	6 in 100 billion

Source: USDOE, 1988c
a. Based on 1.85x10-4 excess cancer fatalities per person-rem.
b. Applicable to persons receiving dose above de minimis.
c. Average individual risk equals probability times health effects, divided by population affected.

TABLE B-17. INDIVIDUAL RISK OF FATALITY BY VARIOUS CAUSES FOR THE UNITED STATES[a]

Accident Type	Number of Fatal Accidents for 1983	Approximate Individual Risk Per Year[c]
Motor Vehicle	44,452	2 in 10 thousand
Falls	12,024	5 in 100 thousand
Drowning	5,254	2 in 100 thousand
Fires and Flames	5,028	2 in 100 thousand
Poison	4,633	2 in 100 thousand
Water Transport	1,316	5 in 1 million
Air Travel	1,312	5 in 1 million
Manufacturing	1,200	5 in 1 million
Railway	1,073	4 in 1 million
Electrocution	872	4 in 1 million
Lightning	160	7 in 10 million
Tornadoes	114[b]	5 in 10 million
Hurricanes	46[b]	2 in 10 million
All Other Accidents	9,311	4 in 100 thousand
All Accidents	77,484	3 in 10 thousand
Diseases	1,631,741	7 in 1 thousand

Source: USBC 1986

a. Based on 1983 U.S. population
b. 1946 to 1984 average
c. Fatality/Total Population

global for Phases 2 - 5. 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.

B.5.1 Kennedy Space Center and Vicinity

The method to assess impacts from Phase 0 and Phase 1 accidents involves 3 main steps. The first step is the identification of areas where there could be deposition above a specified level for each of the three cases by mission phase (Tables B-13 through B-15). 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 (uCi/m^2). This EPA screening level is 0.2 uCi/m^2 at particle sizes less than 2 mm. The EPA suggests that areas contaminated above the 0.2 uCi/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, areas which do not exceed the 0.2 uCi/m^2 screening level are considered to have negligible potential for significant environmental impact, and are not analyzed.

The data presented in Tables B-13 through B-15 identify the area contaminated above 0.2 uCi/m^2 for four categories: dry land, swamp, inland water, and ocean. The dry land category includes all non- wetland inland land cover classes, such as, upland forest, urban, and agricultural areas. The swamp category includes all wetland types, such as coastal marshes and mangrove, and freshwater marshes and swamps. The inland water category includes all estuarine (brackish) and fresh open water. The ocean category is any marine waters.

The second step is to adjust the dry land area category to reflect the types of land uses that occur within this category. For example, potential impacts to natural habitats, within the dry land category, are likely to be quite different from potential impacts to urban areas, also within the dry land category. To estimate environmental resources 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.

The percentages for Brevard County are used as an approximation of the relative amounts of these land cover types in any area contaminated by a Phase 0 or 1 release. A database obtained from the East Central Florida Regional Planning Council (ECFRPC 1988) was used to determine the percentage of urban area and natural vegetation. Data on the percentage of agricultural lands were obtained from another study (USDOE 1983), which included identification and tabulation of land uses within 32 kilometers of Launch Complex 39 at Kennedy Space Center, and overlayed on the East Central Florida Regional Planning Council database 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, and 5 percent agricultural. These percentages, represented as decimal numbers, are then multiplied with the dry land total presented in Tables B-13 through B-15 to estimate the area of these cover types that is affected for each Phase 0 and Phase 1 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 B.6. 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 B.6 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.

B.5.2 Global Assessment

Because areas of impacts in the latter phases (2 - 5) are unknown, the environmental impacts are discussed in general terms. The relative percentages of natural vegetation, urban, and agricultural land cover types elsewhere in the world are unlikely to match the percentage for the Kennedy Space Center vicinity. Therefore, no distinctions are made within the dry land class presented in Tables B-13 through B-15 for Phases 2 - 5.

B.5.3 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 an accident. 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 the 0.2 uCi/m^2 level. 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 as part of the Federal Radiological Emergency Response Program (FRERP) Federal Radiological Monitoring and Assessment Center and Radiological Control Center operations. 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: 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. Consultations with experts in the radiological monitoring field have provided the costs for a radiological monitoring program. The cost estimates are presented in Table B-18.

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

- Location - affecting ease of access to the deposition, eg. a steep hillslope could be more expensive to cleanup than a level field, also 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, for example 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 methods, such as wetland restoration is 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 material to a distant repository
- Cleanup standard.

In setting the level at which specific mitigation efforts will be taken, one must take into account the characteristics of the material deposited. As has been stated, PuO2 is 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. Finally, the recommended screening level of 0.2 uCi/m^2 results in a potential dose rate of about 0.25 mrem/yr, so mitigation steps other than monitoring may not be warranted or below that level.

TABLE B-18. 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

C-3

At this time, while contingency planning is actively underway, it is not yet complete. Planning to date is as follows:

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

Guidance under discussion at EPA and DOE indicate the need to reduce dose rates to below 100 mrem/yr and as-low-as-reasonably-achievable (ALARA). The draft guidance does not indicate cleanup for dose levels of 10 mrem/yr or less. For the purpose of this EIS, an estimate of area cleanup to 25 mrem/yr is used to indicate ALARA.

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

While the actual cost of cleanup associated with a potential accident can not be predicted with great precision due to the number of factors involved (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 ($1000 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 1988 dollars, these costs should be doubled. (Cleanup without removal and disposal would range from $500,000 to $5,000,000; and with disposal, 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.

In order to determine the magnitude of these secondary effects, results from a nuclear reactor risk assessment model were used. A U.S. Nuclear Regulatory 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% of the total economic cost of an accident. In other words, the total cost of 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 B.5.1.

Using the two sources of information above, in conjunction with the surface deposition data, a range of economic costs resulting from the decontamination and mitigation of most probable, maximum, expectation cases can be estimated. At the lower end of this range are decontamination and mitigation activities that stabilize the deposition in place, with no removal of vegetation or soils and a lesser degree of environmental and secondary impacts. At the high end of the range, vegetation and soil are removed, the most highly contaminated structures are demolished, and all of these material are placed in a geological repository. These actions would have significant environmental and secondary impacts. Table B-19 presents hypothetical decontamination and mitigation actions represented in the low and high range of cleanup costs.

In order to determine the estimated dollar cost of the range of cleanup options for Phase 0 and 1 accidents, the area of deposition for each land cover type is multiplied by the lowest and highest unit cost for cleanup discussed above, $500,000 and $95,000,000 per square kilometer respectively. For urban and agricultural areas, this value is then increased by a factor of five, representing the input of the secondary costs mentioned above. For Phase 2 -5 accidents, the deposition data are multiplied by the low and high dollar values above. As a conservative estimation of secondary costs, the entire dry land total is increased by a factor of five to capture these secondary costs.

B.6 ENVIRONMENTAL CONSEQUENCES

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 impact analysis is divided into two major categories, 1) the potential impacts of the representative most probable, maximum and expectation cases during Phases 0 and 1; and 2) the potential impacts of the representative most probable, maximum and expectation cases during Phases 2, 3, 4, and 5. These cases are described in Section B.4. The description of the affected environment in Section 3 of this EIS is also used.

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. The economic cost estimates associated with the impact analyses are also presented. The methods described in Section B.5 are used in this assessment.

TABLE B-19. POTENTIAL RANGE OF DECONTAMINATION METHODS FOR 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 years 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 and 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

B.6.1 Plutonium Dioxide in the Environment

The exten and magnitude of potential environmental impacts caused by PuO_2 releases resulting from STS/IUS 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 (surface contact, ingestion, and inhalation), that determine the impacts on 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. Depending upon the surface area per unit mass of these particles, the effect of gravity may be counter balanced by a resulting air resistance. Consequently, turbulence from air currents can cause these particles to remain suspended for long periods of time.

Particle sizes have been predicted for the Phase 0 fireball accident. Distribution of the PuO_2 aerosol is shown as a function of particle size and is also shown as a corresponding percentage of the total source term of the accident (the source term value can vary for each accident).

Particle size is correlated with deposition range. For a fireball accident, approximately 94.5 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 1.5 percent of the released curies will be deposited as particles in the range of 30 - 44 microns, and the greatest number of these particles will fall in an area from 10 to 20 km from the accident. Approximately 2.5 percent of the release curies will be deposited as 10 - 30microns particles, and the majority will fall within the range of 20 -50km from the accident. The smallest particles, those less than 10 microns, account for approximately 1.5 percent of released curies, and the majority will travel greater than 50 km.

For both the fireball and ground level accidents, larger particles will tend to settle quickly out of the air close to the accident location. Smaller particles will remain in the air longer and may be transported some distance by winds. These finer particles could also be more easily resuspended by subsequent wind action.

In 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 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 (such as swimming, boating and fishing), as well as by the feeding activity of 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 solute (water) chemistry including pH, Eh, and temperature. Mass to surface area ratios of particles affect reactivity and solubility, with solubility being inversely related to particle size. The solubility of plutonium in water has been measured at 10-13 moles/L (Looney, et. al. 1987). Although this measurement was made under mildly oxidizing conditions at a pH of 5.0, it serves to illustrate the low solubility of plutonium in aqueous systems.

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

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

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

The solid/solute distribution coefficient (K_d) for plutonium has been estimated at 10^1 to 10^6 (Looney, et. al. 1987, Bartram et. al., 1983). This means that plutonium 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 K_d for plutonium 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 groundwater bodies, Pu^{4+} would tend to be dominant, and the K_d would be approximately 10^6 (Bartram 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 groundwater aquifers which are used as drinking water supplies. The opportunity would most likely occur where surface contamination is deposited on primary aquifer recharge zones. Plutonium appears to be extremely stable, however, once deposited on soils. Soil profile studies have shown that generally more than 95 percent of the plutonium from fallout remained in the top 5 cm of surface soil after 10 to 20 years of residence time in undisturbed areas (USDOE 1987).

Direct contamination of an aquifer where it reaches the surface is possible although 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 runoff containing PuO_2 could directly contaminate drinking water supplies from surface water bodies (USDOE 1988c). The danger from this type of contamination is greatest due to suspended PuO_2 and not from dissolved PuO_2. Because of this, filtering of the surface water before chemical treatment may be enough to reduce the concentration of total plutonium to an exposure level of less than 4 mrem.

The availability of PuO_2 to biota in 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 inhalation by aquatic and terrestrial fauna. The route of PuO_2 exposure differs between the two basic categories of biota, flora and fauna. Flora, in both 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 et al. 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 (Bartrum et al. 1983, Cataldo et al. 1976, Schulz et al. 1976).

The significance of ingesting PuO_2 can vary between terrestrial and aquatic fauna. Most plants have limited uptake and retention of PuO_2 and the digestive tracts of the animals studied tend to discriminate against transuranic elements (Bartrum et al. 1983, Cataldo etal. 1976, Schulz et al. 1976). However, ingestion may be significant for small fauna in terms of total exposure. These fauna, especially those that burrow, ingest 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.

The impact of ingesting PuO_2 by 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 indicated that the bioaccumulation of PuO_2 was 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 which include 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 et al. 1980, Thompson et al. 1980). However, resuspended material available for inhalation is on the order of $1x10^{-6}$ of the ground deposition, thus high levels of ground concentration would be required to constitute a risk to animals through this route.

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 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 organism's offspring. Any of these three physical effects could cause increased mortality to exposed organisms. Although maximally exposed individual organisms could die as a result of these effects, overall ecosystem structure is not expected to change, and therefore no significant ecological consequences are anticipated.

B.6.2 <u>Assessment of Impacts to Kennedy Space Center and Vicinity</u>

This section presents the environmental consequences of Phase 0, Prelaunch/Launch and Phase 1, First Stage Ascent accidents. Phase 0 includes the time period of 8 hours before launch until launch. Included in this period is the loading of the liquid propellants, firing of the Orbiter main engines, and firing of the solid rocket boosters. Phase 1, First Stage Ascent includes the period from launch to 128 seconds of mission elapsed time. Included in this phase are lift off, clearing of the tower, clearing of land, and burnout and jettison of the solid rocket boosters.

B.6.2.1 Surface Areas Contaminated by Representative Accidents

The land areas contaminated from the most probable, maximum, and expectation accidents in phases 0 and 1 are presented in Table B-19.

The source term ranges indicate that most radioactive material (94.5 percent) will remain within 10 km of the accident location (within controlled area).

Surface contamination resulting from the Phase 0 most probable case produces a total area of 18.70 km^2 which will receive deposition above 0.2 uCi/m^2. The phase 1 most probable accident produces a total deposition area of 84.90 km^2 above the 0.2 uCi/m^2 screening level. The breakdown of these totals by the six land cover types (natural vegetation, urban, agricultural, wetlands, inland water, and ocean) is shown on Table B-20. Ocean impacts do not occur for either the Phase 0 or Phase 1 accident scenarios.

The Phase 0 maximum case produces a total surface area deposition above 0.2 uCi/m^2 of 6.94 km^2. The Phase 1 maximum case produces as area of 5.43 km^2. In both phases, inland water receives the greatest amount of contamination (Table B-19).

The Phase 0 and 1 expectation cases produce total areas of 16.66 and 70.11 km2, respectively, above the deposition screening level of 0.2 uCi/m2. In both cases, natural vegetation is the land cover receiving the greatest contamination.

Areas of deposition for the expectation and most probable cases are greater than the area of deposition for the maximum case because the maximum case maximizes dose to persons. Hence, the meteorology tends to be more concentrated.

In all cases, 94.5 percent of released radioactive is contained in particles greater than 44 um and will be deposited within 10 km of the accident/impact site. The extra energy imparted to the released material by the explosion and fireball may scatter smaller particles beyond 10 km. Particles 10 um and smaller could travel 50 km and more.

B.6.2.2 Exposure Effects

Deposition of PuO_2 from Phase 0 and 1 most probable, maximum, cases 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 from the most probable, maximum, and expectation cases do not have any direct effects on historical or archaeological resources. It will not physically alter nor chemically degrade historical or archaeological resources.

B.6.2.3 Long Term and Mitigation Effects

Long term effects from the deposition of PuO_2 on the Kennedy Space Center and vicinity are discussed for the six land covers: natural vegetation, urban agricultur, wetlands, inland, water, and ocean. A description of potential mitigation measures and related consequences is also presented. It is assumed that any area with surface contamination will be monitored to determine the specific degree of impact.

Table B-20. Phase 0 and Phase 1 Areas of Deposition

	Phase 0 (km2)			Phase 1 (km2)		
	Most Probable	Maximum	Expectation	Most Probable	Maximum	Expectation
Natural Vegetation	9.25	3.06	5.16	32.0	1.50	19.0
Urban	0.62	0.20	0.35	2.2	0.10	1.28
Agriculture	2.63	0.87	1.46	9.1	0.43	5.40
Wetlands	1.63	0.13	1.16	15.9	0.69	7.33
Inland Water	4.57	2.64	4.08	25.7	2.53	16.3
Ocean	0	0.04	4.45	0	0.18	20.8
	18.70	6.94	16.66	84.9	5.43	70.11

Areas of deposition for the expectation and most probable cases are greater than the area of deposition for the maximum case because the maximum case maximizes dose to persons. Hence, the meteorology tends to be more concentrated.

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 will remain in the top 5cm (2 in) of surface soil for at least 10-20 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 B.6.1, surface contamination and skin contact does not pose a significant danger 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} 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} of the concentration of PuO_2 deposited in the bottom sediment. Thus, for any wetland area contaminated at 2.0 uCi/m^2 of PuO_2, approximately 2×10^{-5} uCi/m^2 of PuO_2 will 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 (USDOE 1987, USDOE 1988c).

Overall, the major potential impacts to the natural vegetation and wetland biotic resources of the Kennedy Space Center and vicinity resulting from Phases 0 and 1 most probable and maximum release case 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 chain. However, bioaccumulation of plutonium decreases with higher trophic levels. 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.

Agricultural

Citrus groves on the Kennedy Space Center will be contaminated with PuO_2 at or above 0.2 uCi/m^2 from Phase 1 most probable, maximum and expectation cases. A study on PuO_2 contaminated citrus groves 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 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 believed to occur because splash up generally does not reach a height greater than 1 m (3ft) above the ground. Most orange tree leaves are over 1 m (3ft) 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

The areas of land cover used by man (e.g., buildings, roads, ornamental vegetation, and grass areas) contaminated above the 0.2 uCi/m^2 level would be monitored to determine if decontamination or mitigation actions might be necessary. It is possible that monitoring would indicate no cleanup is necessary. If mitigation actions are 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 which may receive deposition by Phase0 and 1 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, and might be affected by the cleanup actions undertaken in those areas.

The deposition also has a long term affect on future investigation 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 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, PuO_2 is deposited in these waters, this threshold level is not expected to be exceeded.

Some of the waters surrounding Merritt Island are considered Outstanding Florida Waters (OFW). These waters are designated to receive protection which supersedes any other water classifications and standards, and as such prohibits any activity which reduces water quality parameters below existing ambient water quality conditions. A Phase 0 or Phase 1 accident 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 uCi/m^2 could impact an area of conditionally approved shellfish harvesting.

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 uCi/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 which are 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 given the fact that 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 developed if contamination occurs.

B.6.2.3 Economic Impacts

The bounding economic cost of each accident for Phases 0 and 1 are presented using the methods described in Section B.5.3. In all cases the minimum cost will be the cost of the monitoring program. This program is estimated to cost $1 million in the first year, $500,000 in the second year, $250,000 in the third year and $100,000 per year after the third. These numbers may be somewhat less for Phase 0 and somewhat more for Phase 1 since the areas contaminated in the Phase 1 accidents are greater.

The majority of contamination resulting from Phase 0 most probable and maximum case accidents is confined to the Kennedy Space Center site. The economic impacts from these accidents will therefore be confined to Kennedy Space Center facilities and operations. Cleanup, as a mitigation measure applies to areas contaminated at 25 mrem/yr or above. The model yielded no areas contaminated at this level, thus cleanup costs are noted as zero.

The Phase 1 most probable case accidents have the highest level of impacts on the Kennedy Space Center and vicinity. Table B-21 provides a breakdown of economic cost associated with the Phase 1 cases. The costs for the most probable case range from $7.6 million to $762 million. The maximum case has costs of $0.8 million to $65 million.

The expectation case represents deposition on an area of 7.2 km^2. The cost of cleanup ranges from $5.3 million to $392 million. Of the six dry land cover categories, agriculture has the lowest minimum cost of $.04 million. The maximum cost of $317.2 million is for the clean up of urban lands. Since the majority of the deposition is estimated to occur on Kennedy Space Center property, the costs are estimated to be toward the low end of the cost range. Secondary costs for agricultural and urban uses on the Kennedy Space Center probably will not be 5 times the clean up costs. All agriculture on the Kennedy Space Center is citrus production on leased land and the urban areas are industrial areas. Impacts to wetlands and natural areas on the Kennedy Space Center could be isolated by controlling access rather than removal and restoration. Ocean clean up costs are limited to search and removal of large particles. This is also estimated to be at the lower end of the cost range.

B.6.3 Assessment of Global Impacts

This section presents the environmental consequences of Phases 2, 3, 4, and 5 as described in Section B.2. The methodology of impact assessment presented in Section B.5.2 is used to determine and describe impacts. Mitigation techniques that may be used are described along with the impacts that may result from mitigation.

The contamination from Phases 2 through 4 will result from accidents in which modules impact a hard surface. For phase 5, the contamination will come from the impact of Graphite Impact Shells. The number of modules or shells is presented in Tables B-9 and B-10.

Each of the modules or Graphite Impact Shells involved in the accidents will release PuO_2 at a different location separated by kilometers to hundreds or thousands of kilometers. Each release point is independent of the other.

Deposition from the Phase 2, 3, and 4 cases did not exceed the cleanup level so no costs have been estimated.

The estimated economic costs of Phase 5 are presented in Table B-22.

The deposition that exceeds the screening level occurs on dry land and inland water (Figures B-13, B-14, and B-15). The areas of impact vary from 0.2 km^2 for the most probable case to 1.4 km^2 for the maximum case. Costs for the maximum case vary from $3.5 million to $657 million.

Table B-21. Estimated Economic Costs of Phase 1 Accidents

Land Cover Type	Most Probable Case			Maximum Case			Expectation Case		
	Area[a]	Minimum Cost[b]	Maximum Cost[b]	Area[a]	Minimum Cost[b]	Maximum Cost[b]	Area[a]	Minimum Cost[b]	Maximum Cost[b]
Natural Vegetation	4.50	2.30	--	0.40	0.20	--	2.40	1.20	--
Urban	1.30	3.20	615.50	0.10	0.30	52.40	0.70	1.70	317.20
Agriculture	0.30	0.80	146.50	0.03	0.07	12.50	0.20	0.40	75.50
Wetland	0.50	0.20	--	0.00	0.00	--	0.40	0.20	--
Inland Water	2.10	1.10	--	0.60	0.30	--	2.00	1.00	--
Ocean	0.00	0.00	--	0.00	0.00	--	1.60	0.80	--
Total	8.7	7.6	762.0	1.2	0.8	64.9	7.3	5.3	392.7

a In square kilometers
b In millions of 1988 dollars

Table B-22. Estimated Economic Costs of Phase 5 Accidents

Land Cover Type	Most Probable Case			Maximum Case			Expectation Case		
	Area[a]	Minimum Cost[b]	Maximum Cost[b]	Area[a]	Minimum Cost[b]	Maximum Cost[b]	Area[a]	Minimum Cost[b]	Maximum Cost[b]
Dry Land	0.20	0.09	16.40	1.40	3.50	656.90	0.20	0.50	240.50
Swamp	0.00	0.00	--	0.00	0.00	--	0.00	0.00	--
Inland Water	0.001	0.01	--	0.01	0.005	--	0.004	0.002	--
Ocean	0.00	0.00	--	0.00	0.00	--	0.00	0.00	--
Total	0.2	0.1	16.4	1.4	3.5	656.9	0.2	0.5	240.5

a In square kilometers
b In millions of 1988 dollars

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APPENDIX C

ANALYSIS/CONSEQUENCES ASSESSMENT FOR THE TITAN IV LAUNCH VEHICLE

C.1 LAUNCH VEHICLE AND PAD DESCRIPTION

An overall description of a Titan IV/IUS configuration for the Galileo mission, accident scenario, environments and probabilities was compiled for the Safety Analysis below (Martin Marietta 1988).

C.1.1 General Description

The Galileo spacecraft and its Inertial Upper Stage (IUS), when launched on a Titan IV, is protected by a 56-foot long payload fairing (PLF). The integrated flight vehicle (stack) consists of the spacecraft, its adapter, upper stage, PLF, and the Titan IV launch vehicle (shown in Figure C-1). The launch vehicle consists of the two-stage hypergolic liquid-propellant core vehicle and the two solid propellant rocket motors (SRMs) attached to opposite sides of the core vehicle. The SRMs are located well below (behind) the spacecraft.

The total length of the integrated flight vehicle (stack) is about 174 feet (exit of SRM nozzles to nose of PLF). The diameter of the core vehicle and each of the SRMs is about 10 feet (120 inches); the diameter of the PLF is about 200 inches. The total weight of the integrated flight vehicle just prior to ignition of the SRMs is nearly 2 million pounds; about 62 percent is in solid rocket fuel of the two SRMs; the liquid propellant of the core vehicle is only about 22 percent of the total weight. The solid fuel weight in the two-stage IUS is only a little over 2 percent of the solid fuel of the SRMs; the liquid propellant weight of the space-craft is less than one-half percent of that of the two stages of the core vehicle.

C.1.2 Launch Complex

Launch Complex 41 is used at Cape Canaveral to launch the Titan IV (see Figure C-2). It includes a ready building, complex support building, fuel holding area, protective clothing building, oxidizer holding area, gas storage, paint-oil-lubricant building, emergency power shelter, launch stand, exhaust duct, umbilical tower, aerospace ground equipment building, mobile service tower, air conditioning shelter, camera pads, and television towers.

At the launch complex, the stack is readied for launch next to the permanent umbilical tower (see Figure C-3). The umbilical mast, permanently mounted on the transporter, accompanies the launch vehicle from the vertical integration building. The transporter consists of the transporter frame which serves as the launch platform and undercarriage assemblies which are moved from the launch complex prior to the actual launch. The mobile service tower, which surrounds the launch vehicle, is moved away shortly before launch.

The launch pad is a concrete deck with fixed foundations to support the launch transporter with the mounted Titan IV launch vehicle, the mobile service tower, and the umbilical tower. A concrete exhaust duct is an integral part of the launch pad and deflects solid rocket motor exhaust

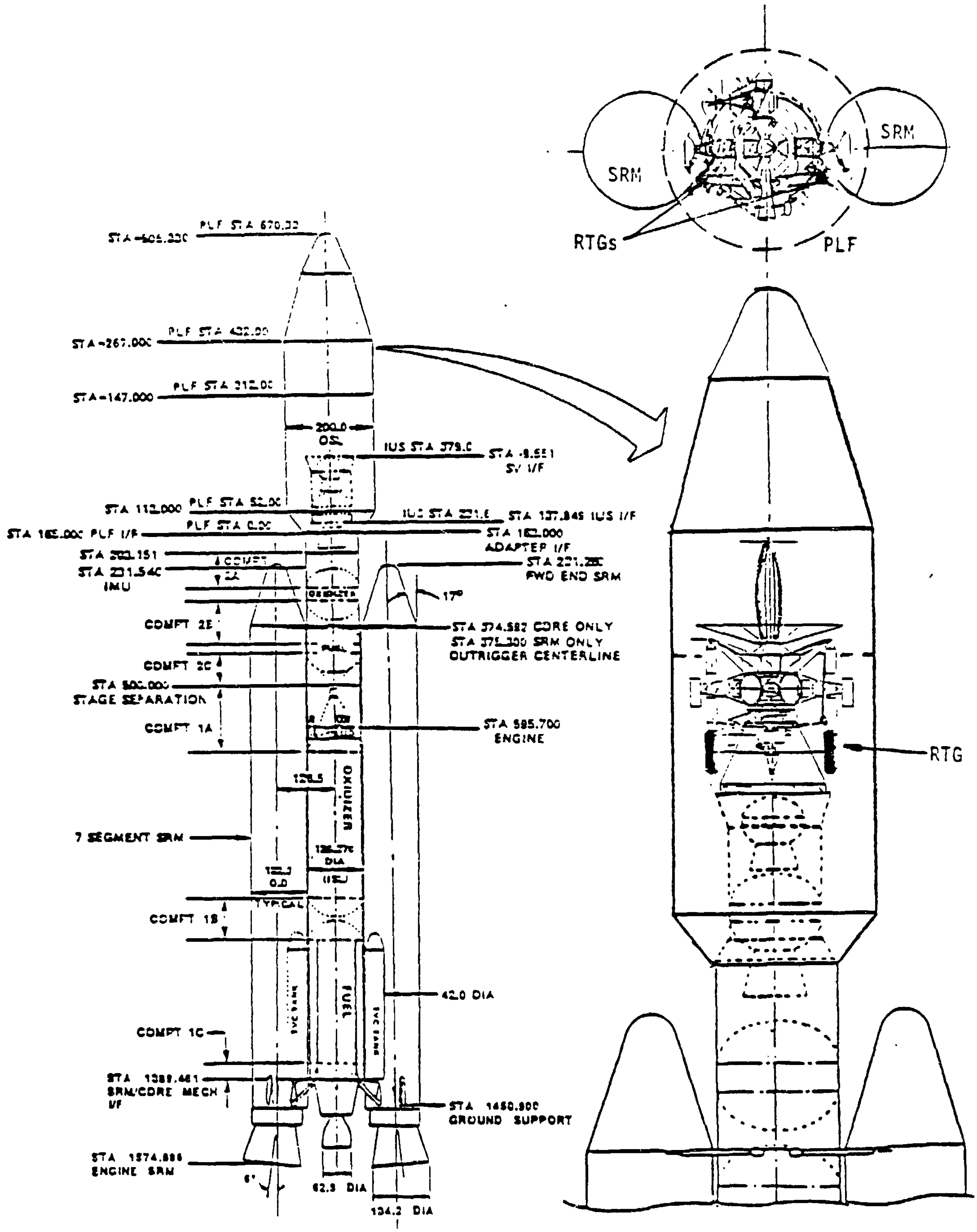

FIGURE C-1. DIAGRAM OF TITAN IV CONFIGURATION

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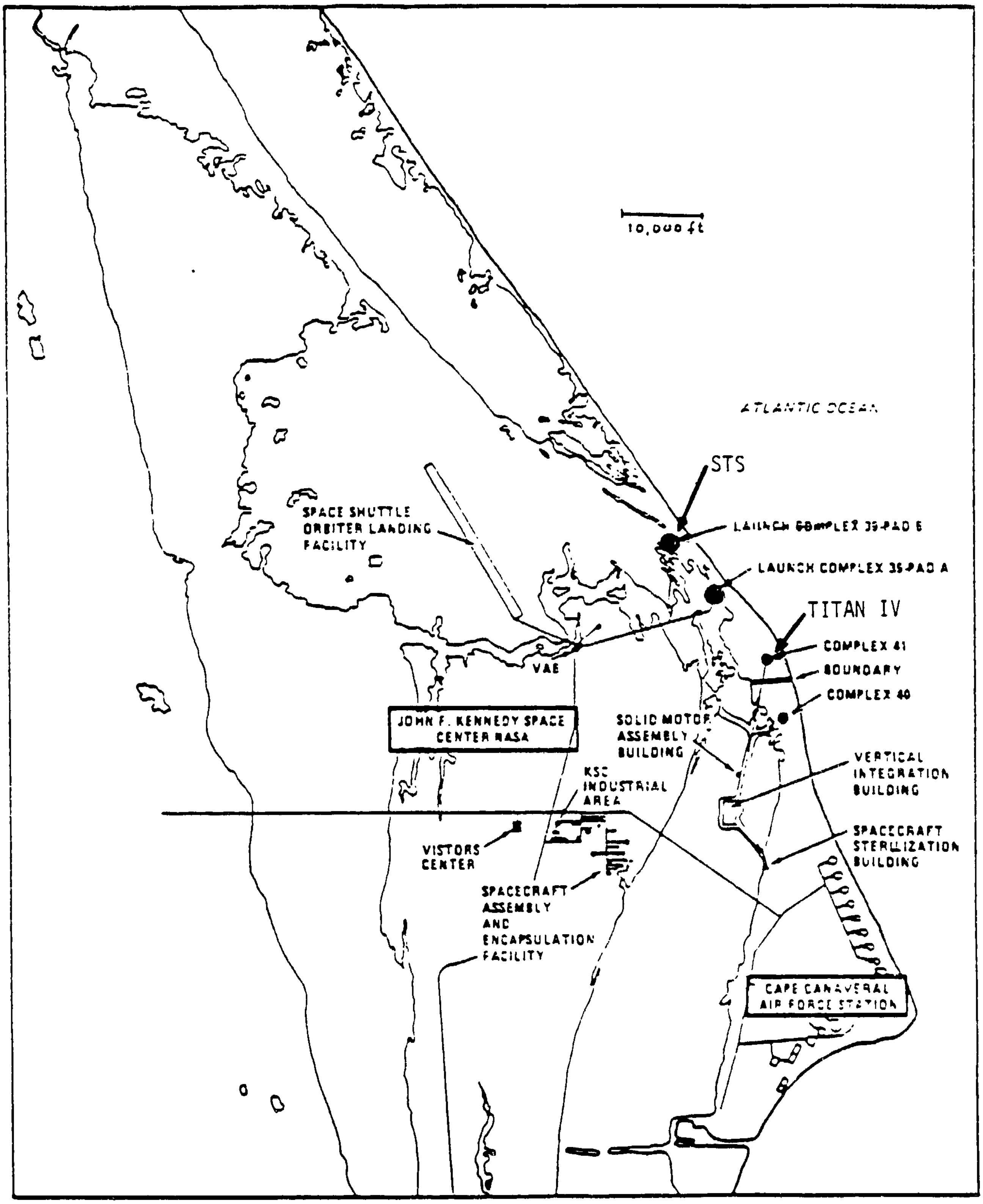
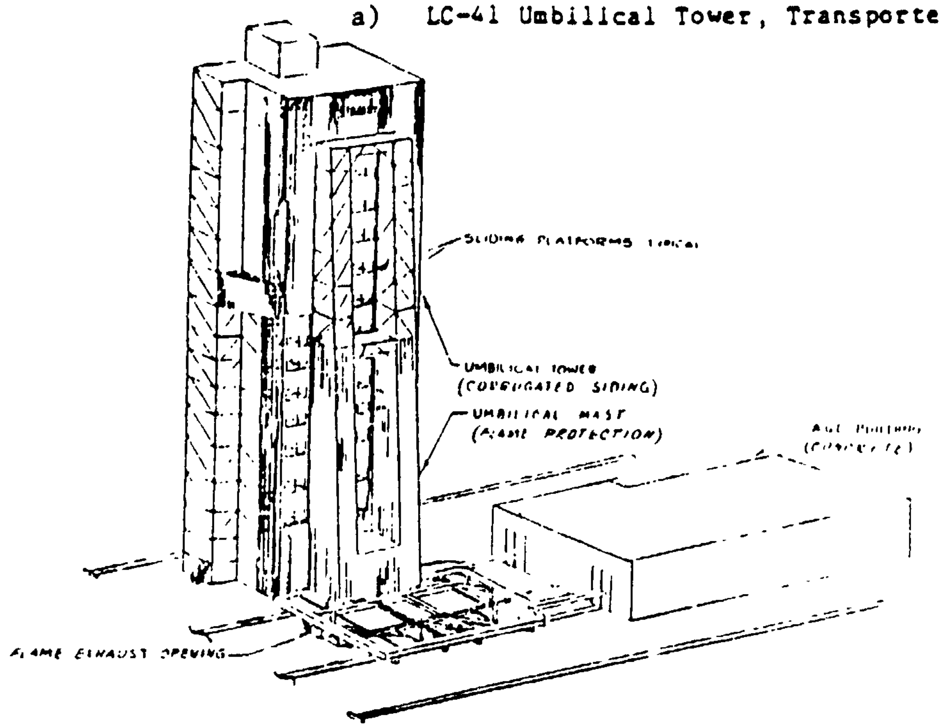


FIGURE C-2. MAP OF KSC AND CCAFS

a) LC-41 Umbilical Tower, Transporter, and AGE Building



b) Mobile Service Tower

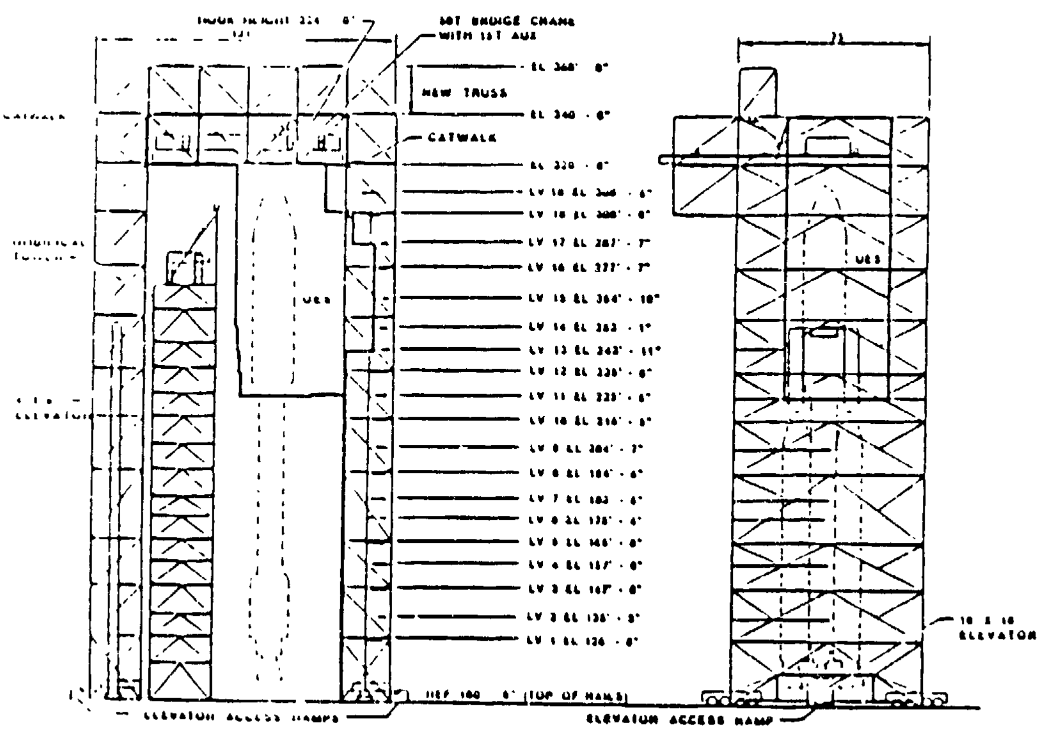


FIGURE C-3. DIAGRAM OF UMBILICAL TOWER AND MOBILE SERVICE TOWER gases away from the launch pad to reduce the acoustic and overpressure launch environments.

For range safety consideration, the relative areas of hard and soft surfaces have been determined within a 600-foot radius circle of the position of the launch vehicle. Sand occupies 70 percent of the total area, asphalt occupies 23 percent, and concrete occupies about 7 percent. All major buildings are included in the concrete portion as each is built on a concrete slab and has either a reinforced concrete roof or one of steel beam covered with corrugated steel. With past Titan launches, no personnel have been allowed within 8,000 feet of the launch pad at the time of launch. This distance may be increased for Titan IV launches.

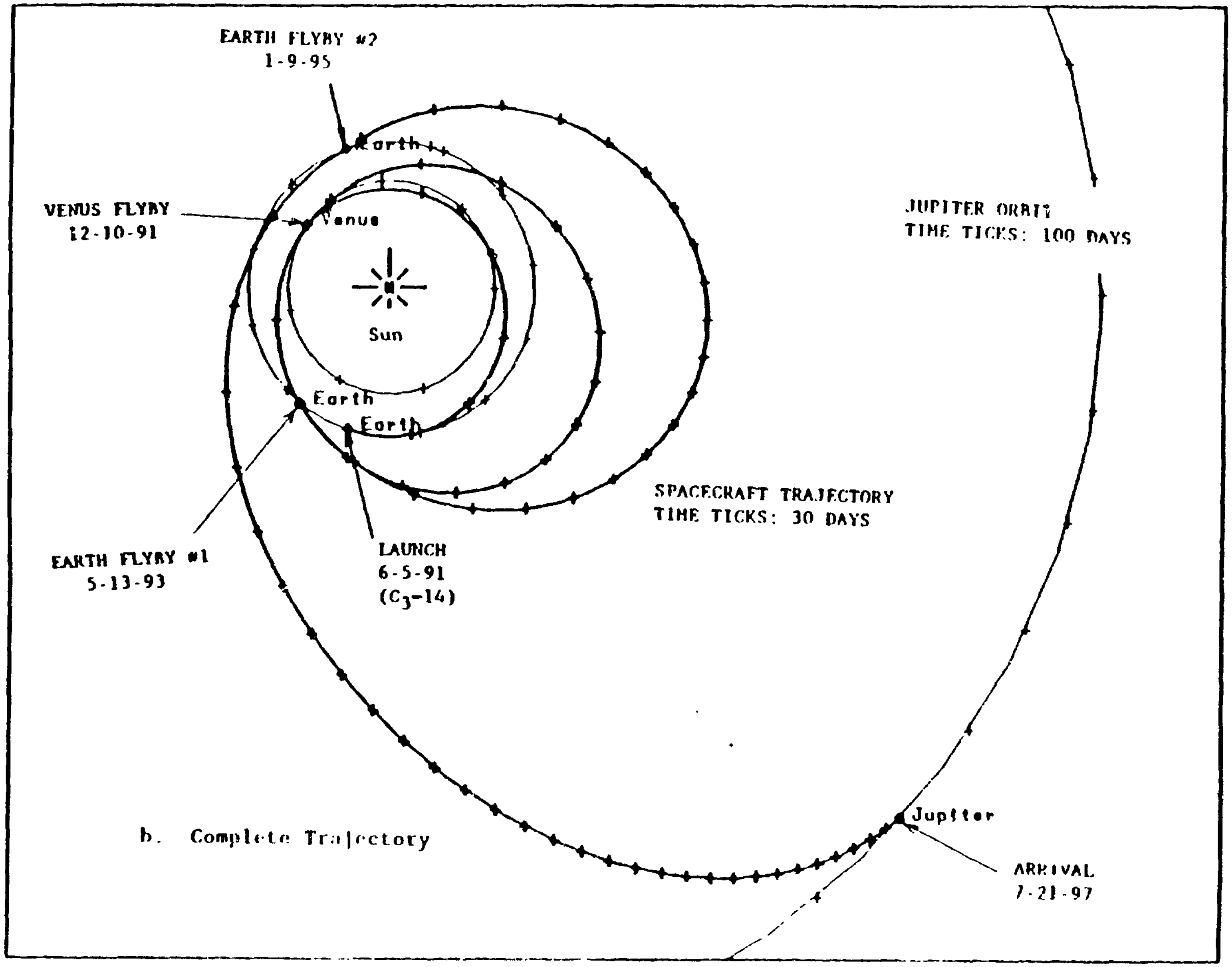
C.1.3 Launch/Flight Sequence

Lift off of the integrated flight vehicle is accomplished solely by use of the SRMs firing together, generating around 3 million pounds of thrust. Maximum aerodynamic forces are encountered approaching the mid-point of the SRM burn. The first stage of the core vehicle is started just before the SRM burn is completed (at which time the SRMs are jettisoned). Toward the end of the first stage burn, the PLF is jettisoned (as soon as the atmosphere is sufficiently tenuous so that aerodynamic heating to the spacecraft and upper stage is acceptably low. When the first stage (liquid) has used up its propellant, the second stage (also liquid) of the core vehicle is started; this process separating the first stage. Upon completion of the second stage firing, a very low Earth orbit (with a minimum altitude of 85 n mi.) is achieved (lifetime is estimated to be up to about a day), and the IUS-spacecraft combination is separated from the second stage of the core vehicle. Time sequence information of the nominal launch process is listed in Table C-1. At an appropriate time/location in Earth orbit, the first stage of the IUS is fired, followed by the second stage, sending the separated 5,700-pound spacecraft on its inter-planetary trajectory to swing around Venus, before it passes by Earth twice on its way to Jupiter. A diagram of a nominal interplanetary trajectory is shown in Figure C-4.

TABLE C-1. ASCENT-INJECTION ACTIVITIES FOR REFERENCE MISSION (GALILEO)

Sequence	Time
SRM Ignition	0.0
Lift off of Titan IV launch vehicle	0.2
Start of Titan 1st stage liquid engine	117
SRM jettison	126
PLF jettison	250
Start of Titan 2nd Stage liquid engine	303
Separation of IUS-Spacecraft from Titan (IUS-Spacecraft is in low Earth orbit)	543
IUS Stage 1 ignition	5,605
IUS Stage 1 burn out	5,757
IUS Stage 2 ignition	5,875
Escape velocity from Earth gravity field reached	5,965
IUS Stage 2 burn-out	6,005

JUNE 1991 VEEGA (EGA1 OUT, EGA2 IN)



b. Complete Trajectory

FIGURE C-4. NOMINAL INTERPLANETARY VEEGA-TYPE TRAJECTORY FOR A JUNE 1991 GALILEA MISSION

C.1.4 Range Safety

To ensure that the Titan IV/IUS launch vehicle and its payload will not pose a threat to people or property on the ground in the event of a launch accident or failure, the following range safety capabilities exist on the launch vehicle:

1) The liquid propellants of either stage of the core vehicle can be shut off.

2) The liquid propellants of the core vehicle can be disbursed by rupturing the tanks. This capability may also be incorporated for the spacecraft tanks by a shaped charge located on the second (upper) stage of the IUS.

3) The solid propellants (SRMs and IUS) can have their thrust terminated and/or the propellant broken up by rupturing the outer cases with an explosive-charge destruct system.

The rupturing can be accomplished by the inadvertent separation destruct system (ISDS) which is automatically initiated by on-board systems if either of the SRMs inadvertently becomes detached from the core vehicle. Although only the SRM which experiences an unscheduled separation is initially destroyed by ISDS action, the consequences of this action will cause further elements to become separated and subsequently destructed. The Range Safety Officer (RSO), based upon the interpretation of the launch vehicle's actual trajectory versus the acceptable one, can initiate the command shutdown and destruct system (CSDS) which will shut down the motors and/or activate the launch vehicle destruct system by radio command.

C.2 USE OF THE TITAN IV/IUS AS A LAUNCH VEHICLE

The activities associated with preparation of the spacecraft for launch on a Titan IV/IUS for launch in 1991 are minor. There are no expected environmental consequences associated with these activities, either in the existing buildings at the Jet Propulsion Laboratory (JPL) or at the KSC (NASA 1988a).

C.2.1 Expected Environmental Consequences from Normal Titan IV/IUS Launch

The anticipated environmental consequences associated with the normal launch of the Titan IV/IUS from Cape Canaveral Air Force Station (CCAFS) have been addressed by the U.S. Air Force in its Environmental Assessment of the Complementary Expendable Launch Vehicle (CELV), dated June 1986 (USAF 1986) (The CELV is now known as the Titan IV.) The CELV Environmental Assessment was supplemented in May of 1988 (USAF 1988b). These two documents form the bases for the following assessment of a Titan IV/IUS launch of the Galileo spacecraft.

Land Use

The launch of the Galileo mission on a Titan IV/IUS from Cape Canaveral Air Force Station should have no significant impacts on land uses at the launch site or in the local area or region.

Air Quality

Air emissions would be generated during all the launch phases of the Galileo mission. Pre-launch emissions would occur during fueling of the Titan IV, from associated industrial operations, and from the use of mobile backup diesel electric generators (USAF 1986, USAF 1988b). Emissions from fueling would be controlled by the use of a Fuel Vapor Incinerator System (FVIS) and an Oxidizer Vapor Scrubber System (OVSS). Oxidizer (nitrogen tetroxide) emissions of about 0.06 tons of NOx during the pre-launch phase will occur. Fueling emissions would occur over a 20-hour period during the 20-day launch cycle (USAF 1988b). Both the FVIS and the OVSS represent Best Available Control Technology (BACT) for the control of fuel and oxidizer emissions (USAF 1986), and the air emissions from both systems are not expected to exceed National Ambient Air Quality Standards (NAAQS).

The safety of propellant loading is increased by the requirement that specific conditions be met before and during this activity. Range Safety personnel monitor meteorological parameters from the on-site network of meteorological towers, and integrate the data into the Weather Information Network Display (WIND) (USAF 1986). The WIND system combines the meteorological data into a dispersion model to predict the downwind distance to a safe concentration assuming a "worst case" spill of propellant. (The worst case spill is a complete loss of N_2O_4 from the launch vehicle.) If the predicted critical distance includes an on- or off-site uncontrolled area, propellant loading is prohibited by range safety criteria.

Launch emissions are exempt from FDER permitting (USAF 1988b), largely due to the short-term intermittent nature of the emissions. At launch, the solid rocket motors (SRMs) ignite and continue to burn through the first 115 seconds of the flight, at which time the Titan IV would be at an altitude of about 160,000 feet and about 30 miles downrange. At this point, the main liquid propellant engines would ignite. The principal SRM exhaust emissions are aluminum oxide (Al_2O_3) particulates, gaseous hydrogen chloride (HCl) and carbon monoxide (CO) (USAF 1986). The exhaust emissions would be distributed along the trajectory of the Titan IV, with the greatest emissions occurring at ground level and remaining detectable through the first 2,500 feet of altitude. The resulting "ground cloud" would be concentrated in the pad area, and would disperse in a downwind direction from the launch site. Given the prevailing winds during the spring of the year, (see Section 3.1.2), at the time of year when a 1991 launch of the Galileo mission would probably occur, the ground cloud would tend to move to the west and northwest from the launch site. The Titan IV ground cloud would be about 60 percent smaller than for the STS, given the smaller amount of solid rocket fuel and faster acceleration of the Titan IV.

The Air Force concluded that SRM exhaust emissions would not affect uncontrolled areas in the vicinity of the launch site (the nearest uncontrolled areas are 16 km from the site) (USAF 1986, USAF 1988b). Workers at and near the launch site would be appropriately protected.

During the post-launch phase, small releases of fuel and oxidizer will probably occur when the filters in those delivery systems are changed. Estimated releases are 0.5 pound of fuel and 0.1 pound of oxidizer (USAF 1988a). These releases are unavoidable and are not expected to significantly affect air quality at the launch site or in the local area or region.

Sonic Boom

The ascent phase of a Titan IV launch results in sonic booms (USAF 1986). Overpressures from the ascent phase will be experienced over the open ocean. Shipping along the ocean track where sonic boom may occur is warned of impending launches as a matter of routine. No problems have been reported as a result of sonic booms.

Sonic booms will also occur during the descent of spent suborbital booster stages and with random re-entry of spent orbital stages. The sonic booms associated with these events will be relatively small compared with the ascent phase. As a matter of standard practice, the ascent phase of all Titan IV launches and planned re-entry of suborbital stages occur over open ocean areas, thus precluding sonic booms over land areas.

Hydrology and Water Use

The principal source of potential groundwater contamination associated with the launch of the Galileo mission aboard a Titan IV/IUS at CCAFS is the water used for deluge during launch and for post-launch washdown and fire suppression (USAF 1988b). Approximately 400,000 gallons of municipal water will be utilized for these purposes during a Titan IV launch (about 300,000 gallons deluge water, 100,000 gallons post-launch washdown and fire suppressant water). About 20 percent of this water is estimated to flow off the launch pad and percolate directly into the shallow unconfined aquifer described in Section 3.1.3. The remaining water would collect in the flame bucket beneath the launch vehicle. This water would be tested and if meeting State of Florida and Federal regulations, would be released to grade to percolate into the shallow unconfined aquifer. If the water fails to meet these regulations, it will be disposed of in accordance with applicable regulations. An industrial wastewater permit application has been filed with the FDER for the discharge of deluge, washdown, and fire suppressant water to grade. Given that the volume of water involved is relatively small, no significant impact to groundwater hydrology or water quality should occur.

Surface water hydrology in the vicinity of the launch site should not be affected by the launch of the Galileo mission. As noted above, the waterborne effluents from the launch will either be discharged to ground and will percolate through the sands into the shallow aquifer, or will be disposed separately as a contaminated industrial discharge in accordance with Florida and Federal regulations.

Surface water quality may be affected by the ground cloud of SRM exhaust emissions. The ground cloud would tend to move downwind of the launch complex, and would be resident at any given location for only a few minutes (USAF 1988b). Given the prevailing winds in the spring at CCAFS, the ground cloud would most likely move to the west or northwest of the launch site towards the Banana River and nearby marsh areas. Given the short-term nature of the launch event, significant impacts to surface waters from HCl deposition should not ensue (USAF 1988b).

Geology and Soils

Launch of the Galileo spacecraft aboard the Titan IV/IUS is not expected to impact the geology of the launch site, nor that of the local or regional areas.

Biological Systems

Launch of the Galileo mission aboard the Titan IV/IUS at CCAFS is not expected to result in long-term adverse effects on terrestrial flora and fauna (USAF 1986, USAF 1988b). Wildlife directly in the path of the ground cloud will experience short-term exposure to elevated but non-lethal aluminum oxide particulates and hydrogen chloride (principally gaseous, with some mist) with levels dependent upon distance from Launch Complex 41.

Vegetation near Launch Complex 41 is primarily scrub habitat. This vegetative community would be subject to impacts from HCl depositon. In the "near field" within about 700 feet of the launch complex, vegetation may experience acute damage similar to that associated with STS launches at KSC (USAF 1986). Vegetation in the "far field" (beyond about 700 feet from Launch Complex 41), may experience short-term impacts from launch of the Galileo mission such as leaf spotting. These effects should be less than those experienced with an STS launch, given that a Titan IV would yield much less HCl mist (about half, USAF 1988a) than experienced with the STS.

Aquatic biota may also be impacted by launch of the Galileo mission through interaction of the ground cloud with the aquatic environment. Nearby surface waters will probably experience short-term acidification depending upon the direction the ground cloud moves. Acidification would likely be short term due to rapid neutralization of the HCl fallout by the moderately high buffering capacity of Banana River water (Total Alkalinity 141 to 164 mg/l; Calcium about 54 mg/l). Aquatic organisms would likely experience short term stress from depression of pH, and if also subject to other seasonal stress (high temperature, low dissolved oxygen) some fish kill could also ensue. If fish kills occurred, they would probably be experienced in small nearby impoundments and not in the Banana River itself.

Should the ground cloud move over the nearby ocean (about 1/2 mile to the east) the HCl fallout would be rapidly neutralized by the ocean's high buffering capacity and aquatic biota should not experience any impact.

Endangered and Threatened Species

Launch of Galileo from Launch Complex 41 aboard the Titan IV/IUS is not expected to adversely affect any endangered or threatened plants or animals residing at CCAFS or in nearby surface waters, (USAF 1986, USAF 1988b).

Socioeconomic Factors

The CCAFS has been developed to provide launch, tracking, and other facilites in support of space programs. The normal launch of the Galileo mission program is compatible with current and projected future land uses on CCAFS. The program will have no significant impacts to the socioeconomics of CCAFS or Brevard County, Florida. No undisturbed lands will be affected by the proposed action. No new utility services, social services, or additional transportation access will be required. Emergency services are already in place, and no historical or cultural resources will be disrupted.

C.2.2 Implications of Balance of Mission

Post-launch impacts to surface waters under normal flight conditions will be confined to the oceans (USAF 1986). Vehicle stages that do not go into orbit will enter the ocean, while stages that reach initial orbit will re-enter the atmosphere and will also enter the open ocean due to pre-programmed flight trajectories. Small amounts of residual fuels may be released to the ocean waters as a consequence (USAF 1986). The Stage I residual propellant (Aerozine 50 and N_2O_4) for the Titan IV/IUS would amount to about 1,100 pounds. The SRMs may contain small amounts of ammonium perchlorate and binder. The initial concentrations of fuels entering the marine environment from the spent stages may be beyond the maximum acceptable limits for marine organisms in the immediate vicinity of the spent stage. The rapid dilution by the ocean waters combined with the small amounts of propellants, however, should preclude significant adverse impacts to marine biota.

Corrosion of the hardware on the spent stage will contribute metal ions to the immediate waters, but should not result in significant impacts due to the long period over which the corrosion process takes place and the large quantity of dilution water available (USAF 1986).

C.3 MISSION ACCIDENTS

C.3.1 Accident Scenario Definition Approach

The approach used to develop catastrophic accident scenarios was to divide the Titan IV mission launch profile into seven phases as listed below. Subsequently, credible single point failures and some multiple failures were identified, from a review of failure modes and effects analyses and safety analyses, that could cause catastrophic failures in the launch vehicle. Each scenario was developed to determine which environments could be created. In general, many failures could initiate responses which had the potential to create blast, fragmentation, fire/thermal, and impact environments. In addition, certain system failures are common in more than one phase. Many of the different initiating failures lead to a common vehicle response. Thus, two pre-flight accident scenarios and five in-flight accident scenarios are representative of the vehicle response to any of the known credible single-point of multiple failures which were identified.

Mission Phases for Accident Assessment

Phase 0:	Propellant loading to launch (maximum)	T-40 days to T-0
Phase 1:	Launch stack clears the launch tower	T-0 to T+5 sec
Phase 2:	Predicted instantaneous impact point still on land	T+5 to T+23 sec
Phase 3:	Predicted instantaneous impact point on water to time of jettison of PLF	T+23 to T+250 sec

Mission Phases for Accident Assessment (Continued)

Phase 4:	PLF jettison to separation of IUS from Titan IV launch vehicle	T+250 to T+543 sec
Phase 5:	Separation of IUS to Planetary Injection	T+543 sec to 5965s
Phase 6:	Interplanetary Injection to 2nd Earth Flyby	T+5965s to T+38 months

C.3.2 Accident Scenarios

Phase 0 pad fires and/or explosions can occur from a structural failure of the launch vehicle during or following tanking of the liquid stages of the core vehicle. Also, the same events can occur if the Flight Termination System (FTS) is inadvertently activated (Figure C-5).

In-flight accidents during phase 1 must consider interactions with the launch tower, and ground impact with pieces of the vehicle and or propellant/ground interaction environments apply during Phase 2. The basic vehicle response to various vehicle failures, however, can generally be broken into three specific scenarios during powered flight.

1) SRM case failure leading to instantaneous vehicle breakup, and production of SRM fragments toward the RTG if the failure occurs in the top end of the SRM.

2) Vehicle dispersement by actuation of the ISDS due to a SRM case failure or any other structural failure.

3) Vehicle dispersement by activation of the CSDS by ground command in event of vehicle loss of control.

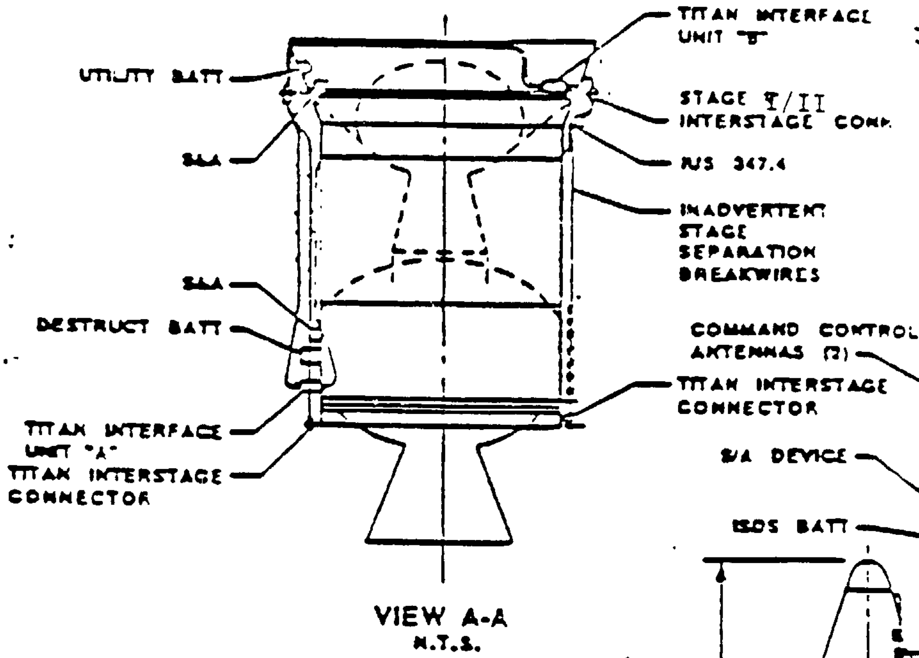
The specific environments associated with these scenarios depend on when the accident occurs, as summarized in Section C.4 and addressed in detail in Section C.5.

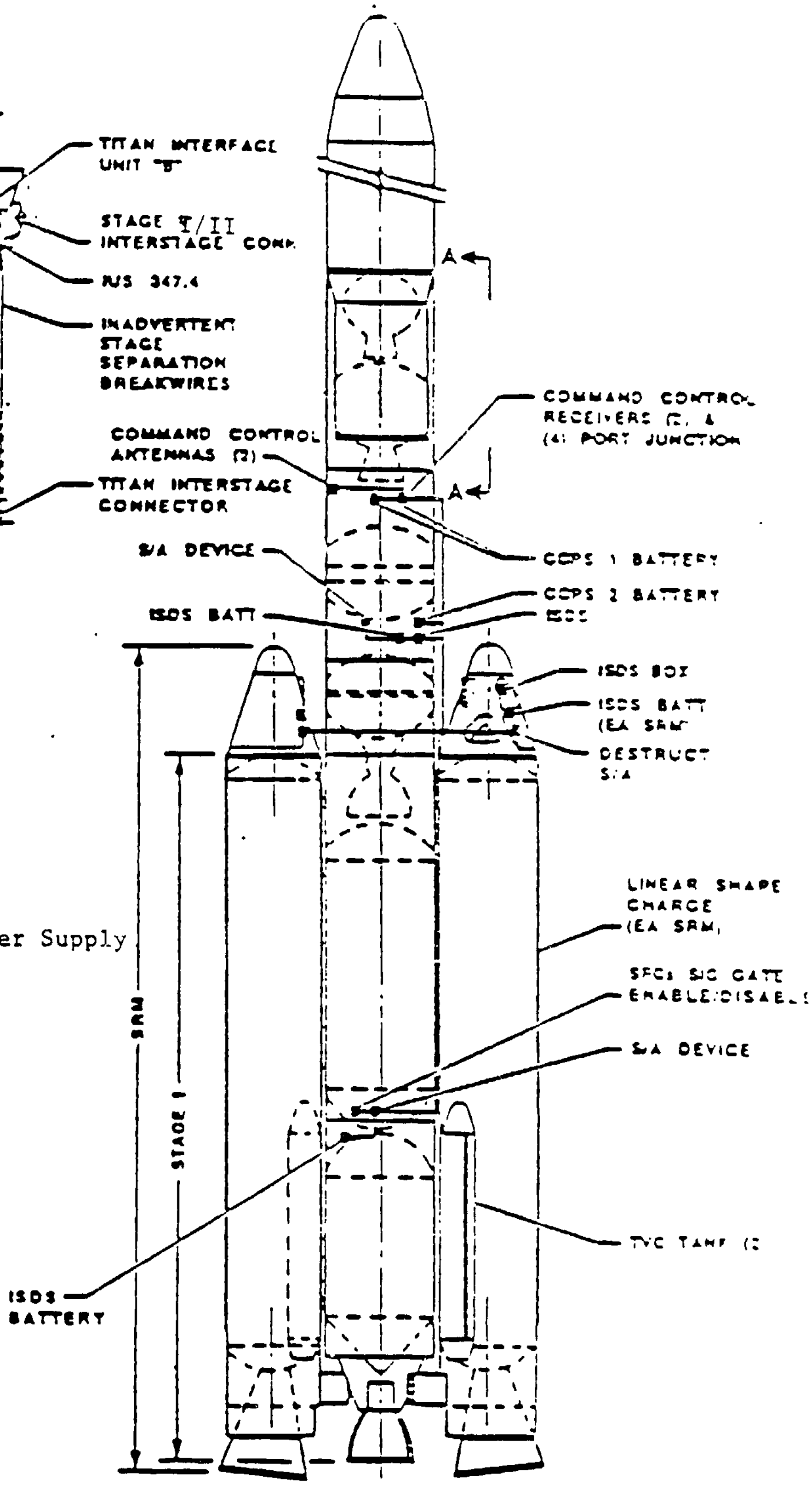
Accidents which occur after SRM Burnout through Phase 4 are similar to the Space Transportation System (STS) in that they would result in vehicle breakup at the time of the accident or on subsequent re-entry.

Similarly, IUS failures during phase 5 are identical to the treatment of these failures for the STS/IUS launch vehicle treated in Appendix B.

The Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory design approach for the 1991 mission is generally similar to the 1989 mission. However, while planetary alignments require two Earth flybys at minimum altitudes of approximately 900 and 300 kilometers (km) for a 1989 launch; the corresponding values are 9,000 and 3,200 km for a 1991 launch.

Although one might conclude that the greater flyby altitudes would reduce the probability of inadvertent re-entry, this is not true. Trajectory dispersions for a functioning spacecraft are very small compared to the minimum flyby altitudes as documented in JPL 1988. However,





SFC - Squib Firing Circuit
S/A - Sub-Assembly
S& A - Safe& Arm
CCPS - Command/Control Center Power Supply
TVC - Thurst Vector Control

FIGURE C-5. FLIGHT TERMINATION SYSTEM COMPONENT LOCATIONS FOR THE TITAN/IUS trajectory dispersions for a failure such as micrometeroid penetration of a propellant tank are large compared to the 13,300 km diameter of the Earth. Therefore, the expected probability of inadvertent re-entry would not change from the 1989 mission value of 5 X 10^{-7}. In the remote chance that re-entry did occur, the environments would be the same as for the 1989 mission.

C.4 ACCIDENT ENVIRONMENTS

C.4.1 SRM Fragment Environment

A Radioisotope Thermoelectric Generator (RTG) threat can only come from a catastrophic failure of the forward closure of a SRM by virtue of the substantially forward position of the RTG relative to the SRM. Intrinsic structural failure of the forward closure would certainly produce closure fragmentation. Sidewall failures of the upper cylindrical segments or destruct system action might also cause forward closure fragments. It is noted, however, that no damage was sustained by the upper stage/payload involved with the Titan 34D-9 launch accident. In this accident, one of the SRMs failed by case rupture of an aft positioned segment and the other was destroyed by ISDS actuation.

Experience with the modeling performed in determining the STS SRB fragmentation specifications (Appendix B) has shown that the Titan SRM forward closure fragmentation specification can be significantly simplified. For very early Mission Elapsed Time (MET), when most of the propellant remains, the fragment characteristics can be based on Titan 34D-9 findings. By design, forward section propellant is consumed in about 30 seconds, thus beyond this time fragment characteristic can be based on STS 51-L findings, appropriately scaled to account for the propellant remaining attached to the case wall on STS 51-L. Applying this approach results in the Titan SRM fragmentation characteristics as a function of MET shown in Table C-2. Velocity reduction due to the intervening PLF structure and its oblique aspect to the expected fragment trajectories is also shown in Table C-2 together with the estimated probability of a fragment hitting an RTG.

C.4.2 Core Propellant Explosion Environments

C.4.2.1 Blast Environments

The hazards imposed by explosions can be characterized for purposes of safety analysis by specifying estimated values for the blast wave parameters of peak overpressure, overpressure impulse, peak dynamic pressure, dynamic pressure impulse, and peak reflected pressure in probabilistic terms. These parameters are described in Appendix B.

Pre- and Early-Flight Ground-Pool Explosions

A significant explosion source for the Titan is from the possible massive spill of the hypergolic core propellants. Spills of these propellants result from core structure breakup; Titan impact with the launch tower or tip over to the ground, due either to one SRM failure to ignite or very early loss of thrust; early destruct action; or SRM case rupture which could lead to collection, mixing, and ignition of significant portions of the propellants on launch-pad surfaces while the Titan is still essentially at the pad.

TABLE C-2. SRM FRAGMENT ENVIRONMENT: TITAN/IUS

MET (s)	Fragment Velocity (fps)	Spin Rate (HZ)	Hit Probability	Intervening Structure Velocity Reduction (%)
0	130-380	0-18	~1/50	~30
0-30	Linear Interpolation Between 0 and 30s Values			
30-120	400-760	0-18	~1/50	~30

Along with a massive fire, a low-yield (10 percentile upper limit of 0.5 percent TNT equivalent) explosion would be expected even though the short ignition delay for hypergolic propellants assures little accumulation of mixed propellants compared to non-hypergols such as liquid oxygen and liquid hydrogen. The resulting explosion-driven blast wave subsequently sweeps past the PLF, acting on its exterior surfaces in a manner to implode or crush the structure into the RTGs within the PLF. It is also possible that, as the blast wave fails the structure, the RTGs will be directly exposed to the blast environment. Thus, not only PLF fragmentation but also blast loading (acceleration) hazards are presented to the RTGs.

Upper limit blast environments are estimated for the Titan IV core propellants spilling to the pad surface by using existing experimental data from 100 foot drop tests. These blast environments are applied to the PLF surface via a blast loading calculation model (same as mentioned in Appendix B). Typical blast and PLF fragmentation environments estimated to result from these ground-pool explosions at several distances above the pad surface are shown in Tables C-3 and C-4, respectively.

<u>In-Flight Explosions</u>

A second explosion source involving the Titan core propellants is possible for a short time after the Titan has cleared the tower. Aerodynamic conditions through the next 18 seconds (up to a MET of 23 seconds) are such that failures of the core structure or initiation of destruct action leads quickly to Titan breakup and the consequent airborne dump of the hypergolic propellants. The low-yield nature of any ensuing hypergolic propellant explosion and the unconfined collection and mixing situation in-flight leads to a low chance of significant explosion; however, two separate explosions associated with the two separate core stages are considered possible. The estimated blast environment from these explosions are shown in Table C-5 for the breakup starting within the MET period of 5-23 seconds. Beyond 23 seconds, changing atmospheric and aerodynamic conditions will preclude significant airborne explosions.

TABLE C-3. BLAST ENVIRONMENTS* DUE TO DESTRUCT OR GROUND-POOL EXPLOSIONS: TITAN IV/IUS

	Pressure (psi)			Impulse (psi-s)	
Height (ft)	Over-pressure	Dynamic	Reflected	Static	Dynamic
In-pool	900	400	2,300	0.50	0.050
Just Above Pool	300	610	2,010	1.7	0.28
20	15	15	56	0.45	0.23
100	7	7	32	0.19	0.10

*Upper 10 percentile estimates for on-pad explosions of respective liquid bipropellants (except for in-pool and just above pool).

TABLE C-4. FRAGMENT VELOCITIES* FROM DESTRUCT OR GROUND POOL EXPLOSIONS: TITAN/IUS

Height (ft)	Flyer Plate Velocity (fps)	Shrapnel Velocity (fps)
In-Pool	727 - 1,936	0 - 57
Just Above Pool	965 - 2,138	1 - 101
20	189 - 347	0 - 62
100	93 - 177	0 - 29

*Upper 10 percentile estimates for on-pad explosions of respective liquid bipropellants (except for in-pool and just above pool).

The potential PLF fragment velocities associated with the airborne blast environments in Table C-5 are shown in Table C-6. These fragment velocities were estimated by the same procedure used for ground-pool explosions.

C.4.3 Fireball Environment From Titan Core Propellants

The updrafts and high temperatures within the fireball produced by a large liquid propellant ground fire are hazards 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.

The fireball characteristics and thermal environment that would result from a massive spill of Titan Core propellants at the launch pad can be specified by: (1) maximum fireball diameter, (2) fireball lift-off time, (3) duration of the fireball, (4) temperature inside the fireball, and (5) total heat flux produced within the fireball.

Using available experimental and analytical information and assuming a full Titan load of propellant is involved (417,400 pounds), a maximum fireball diameter of 649 feet is predicted. The fireball is also predicted to have a total duration of 18 seconds and to lift completely off the ground after about 8 seconds.

The temperatures to which an RTG could be exposed range from approximately 4,000 degrees Fahrenheit at fireball inception down to 3,500 degrees Fahrenheit at fireball lift off. The total heat flux ranges from about 300 to 100 Btu/second/100 feet over the same time span.

C.4.4 Environments For Re-entry From Orbit

The results of analysis of the uncontrolled, accidental re-entry of the Shuttle/IUS prior to the deployment of the upper stage and payload is deemed applicable to the Titan/IUS mission. This analysis 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 SRM separation (MET = 126 seconds) and the achievement of the parking orbit (MET = 543 seconds), the breakup predictions are:

1) The Titan and IUS will always break up during re-entry and will not reach the surface intact.

2) For MET less than 495 seconds, the RTGs or General Purpose Heat Source (GPHS) modules reach the surface over the Atlantic Ocean.

3) For MET between 126 and 155 seconds, the RTGs reach the surface intact and without case melting.

4) For MET between 155 and 210 seconds, the RTGs may reach the surface without case melting, or the GPHS modules may be released prior to reaching the surface.

5) For MET greater than 210 seconds, the GPHS modules are released prior to surface impact.

TABLE C-5. BLAST ENVIRONMENTS DUE TO IN-FLIGHT EXPLOSIONS FROM DESTRUCT OR MASSIVE STRUCTURAL FAILURES: TITAN/IUS

	Pressure (psi)			Impulse (psi-s)	
MET(s)	Over-pressure	Dynamic	Reflected	Static	Dynamic
5 - 23*					
Stage 1	7	7	32	0.12	0.06
Stage 2	10	10	40	0.16	0.08

*Over-water threshold.

TABLE C-6. FRAGMENT VELOCITIES FROM IN-FLIGHT EXPLOSIONS FROM DESTRUCT OR MASSIVE STRUCTURAL FAILURES: TITAN/IUS

MET(s)	Flyer Plate Velocity (fps)	Shrapnel Veolocity (fps)
5 - 23*		
Stage 1	69 - 127	0 - 22
Stage 2	83 - 157	0 - 23

*Over-water threshold.

C.4.5 IUS Payload Environments

The IUS vehicle itself does not significantly add to any of the accident environments produced by the main launch vehicle. The solid propellant is not detonable under credible accident conditions for the Galileo mission. Although IUS 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 Galileo/IUS from the Orbiter result in errant re-entry within the design capability of the RTGs. Earth impact conditions are similar to those for re-entry from orbit.

The only IUS failure that can cause a direct threat to the RTGs 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.

The Galileo spacecraft also does not significantly add to any of the accident environments produced by the main launch vehicle.

C.5 NON-RADIOLOGICAL ACCIDENT CONSEQUENCES

Accidents of concern range from propellant loading emergencies prior to launch, to an on-pad destruct of the Titan IV/IUS to an explosion during ascent of the vehicle (USAF 1986, USAF 1988a, USAF 1988b). During a fueling emergency, both fuel and oxidizer may be vented directly to the atmosphere with rupture of a part of the fueling system. The fueling system utilizes redundant flow meters and redundant automatic shutoff devices to minimize the consequences of such an event. Only one emergency release of nitrogen tetroxide (1,000 gallons) has occurred since operational start-up of the Titan program at CCAFS in 1963. That release was controlled and occurred slowly into the flame bucket where it was neutralized. As noted in Section 4.2.2.2, propellant loading operations are prohibited when meteorological conditions would be such that a total release of nitrogen tetroxide from the Titan IV would result in an unsafe concentration in downwind uncontrolled areas. All propellant spills at the launch site would be retained in either the impervious lined holding areas surrounding the fuel tanks, or in the flame bucket beneath the launch vehicle. Spills would be removed and disposed at an appropriate off-site hazardous waste facility (USAF 1986), thus surface water resources and associated biota should not be impacted.

In the event of a destruct on the pad, a failure in flight, or a commanded vehicle destruct, the liquid propellant tanks and solid rocket motors would be ruptured (USAF 1986). Most of the liquid propellants would ignite and burn due to their hypergolic nature. The solid rocket motors are designed such that most of the solid propellant would be extinguished due to the sudden reduction in chamber pressure.

The air emissions from such an event would be similar to those produced during launch, with resulting nitrogen oxide concentrations dependent upon the type of accident (USAF 1988a). For all but a launch pad accident, nitrogen oxide would be generated at a vertical distance from the pad. The amount of dilution at ground level would depend upon that distance and existing meteorological conditions.

In the case of a launch pad accident, ground-level increases in nitrogen oxide emissions would occur, (USAF 1988a). Again, the levels reaching uncontrolled areas would depend upon the amount of atmospheric mixing and existing meteorological conditions. Adherence to launch meteorological requirements would minimize the transport of high concentrations to uncontrolled areas.

Some liquid propellant may enter nearby surface waters. In the event of a worst case scenario (USAF 1986), the vehicle would fail on or near the pad, and the commanded destruct system would fail (an event which has never occurred. Depending upon the amount of fuel reaching the surface waters (e.g., Banana River or Atlantic Ocean), aquatic biota in the receiving area could be subject to short-term impacts. The U.S. Air Force has estimated the probability of such a "worst case" scenario to be extremely small. In the case of a release to the ocean, the resulting plume could extend to a radius of 800 to 8,000 feet depending upon the amount of fuel entering the ocean. Subsequent mortality of aquatic biota could occur in at least the near field plum due to exposure to hydrazine (from the Aerogine 50 fuel) or from the nitrogen tetroxide. Given the volume of the receiving waters offshore CCAFS, the impacts would be localized and short-term in nature. Entry of the propellant into nearby surface waters such as the Banana River could result in a relatively higher amount of impact, given the smaller receiving water volume. Fish kills and mortality of other aquatic biota could be greater in the near-field plume, but again such effects would be short-term in nature.

With a vehicular breakup or destruct further into the mission, the ocean would receive the impact. Some amount of liquid propellant could enter the ocean, depending upon the length of time after lift off the accident occurs. Between lift off and separation of the solid rocket motors (about 126 seconds into the flight) the potential for liquid propellant entering the ocean diminishes with increasing altitude. The liquid propellant that can reach the ocean in concentrated quantities decreases because of the dispersing effects from the released propellant falling through the air. Beyond about 1?6 seconds, the amount of liquid propellant that is available to contaminate ocean waters decreases rapidly with ignition of the main liquid fueled rocket engines. Solid rocket fuel that could enter the ocean decreases rapidly from ignition until about 126 seconds into the mission.

Until such time as the Titan IV clears land and is out over the ocean, a vehicle destruct could also impact the terrestrial environment through fragment impacts and fire. Fire would affect the environment near the launch pad. It can be assumed that plants and animals near the launch pad would probably expire in the fire. Some biota would also expire from fragment impacts. The work force in the launch exclusion area would also be impacted, although impacts should be relatively minor given the protective measures employed by the workforce during a launch (shelters, protective clothing, etc.).

C.6 TITAN IV/IUS RADIOLOGICAL RISK ANALYSIS

The Titan IV/IUS is a potential alternative launch vehicle for the Galileo mission in 1991. Because the configuration and propellants of the Titan IV are different from the Shuttle, the potential accident scenarios, accident environments, and accident probabilities will also be different. As a consequence, the risk quantification and environmental impacts of potential accidents must be evaluated to evaluate Titan IV/IUS as an alternative to the Shuttle/IUS.

C.6.1 Risk Analysis Methodology

It is desirable to put the Titan IV/IUS risk assessment on the same analytical basis as for the Shuttle/IUS. Differences due to the preliminary information available for the Titan IV are described. The resources used for the Titan IV/IUS risk analysis were:

- Titan IV Data Book (Martin Marietta 1988),
- Shuttle/IUS Final Safety Analysis Report Vol III, Books 1 and 2 (USDOE 1988c),
- The same radiological consequence and risk quantification models and methodology as used for the Shuttle/IUS Final Safety Analysis Report Vol III.
- Hydrocode analyses for the Titan IV/IUS - Radioisotope Thermoelectric Generators (RTG) geometry, to determine the response of the RTGs to fragment impacts.

In summary, the Titan IV/IUS risk assessment was performed as follows:

1. Titan Data Book information was used to construct Failure/Abort Sequence Trees (FASTS) for each mission phase. FASTs are also known as Event Trees.
2. The accident scenario end points were examined to identify accident environments of the RTGs, as described in the Titan Data Book. These environments are described in Section C.5.2.1 and can broadly be characterized as:
    - Pool explosion (a massive spill of Titan hypergolic propellants onto the launch pad forming a "pool", and exploding)
    - Flight destruct
    - Forward closure Solid Rocket Motor (SRM) failure (a SRM case failure resulting in fragmentation of the forward dome of the case)
    - Reentry.
3. RTG behavior in each accident environment and subsequent events was analyzed for upper-limit and average accident parameters.

4. Accident RTG fuel release estimates were made based on the following steps:

   - Use of Shuttle/IUS Final Safety Analysis Report analyses and specific Titan IV hydrocode analyses toestimate Fueled Clad distortions,

   - Use of Shuttle/IUS Final Safety Analysis Report correlations between clad distortions and failure thresholds and release quantification,

   - Use of Shuttle/IUS Final Safety Analysis Report judgments and assumptions regarding fuel release, given Fueled Clad failure.

5. For each mission phase, three release cases are defined, identical to those defined in the Shuttle Final Safety Analysis Report and described in AppendixB.

The most probable case is the average release for the Failure/Abort Sequence Tree subbranch having the highest probability of a release. This case can be used to estimate the likely consequences of an accident that results in a release.

The maximum case is that Failure/Abort Sequence Tree subbranch that on upper limit accident parameters, will result in the greatest consequences. This case can be used by planners to identify the upper magnitude of accidents which may have to be dealt with.

The expectation case is a probability weighted release considering all accident scenarios in the phase and their release probabilities. This case is used for overall risk quantification. It does not represent a particular accident, but is a way of representing all potential accidents according to their probabilities.

The Titan IV Data Book is the analog of the Shuttle Data Book (NASA 1988c), which was the basis of the accident scenarios and parameters used for the Shuttle/IUS risk assessment. The Titan Data Book however, is preliminary in nature and has not received the same level of peer review as the Shuttle Data Book. Further, the scenario descriptions and accident environments tend toward upper limit or worst case situations. The Shuttle Data Book provides probability distributions of accident environments. Equivalent data are not yet available for the Titan IV.

The Shuttle/IUS Final Safety Analysis Report II Volume II (USDOE 1988b) contains descriptions of the technical bases for the Shuttle accident analyses. These bases include RTG test program data; hydrocode analyses of explosion, fragment and impact events that are calibrated using the test data; and correlations of test and analyses information to describe criteria for RTG fuel containment failure and quantification of release amounts. This work is used as the starting point for the analyses of Titan IV/IUS accidents. The Titan Safety analysis makes use ofpoint values (as opposed to probability distributions) of upper limit and average or mid range accident parameters to quantify maximum and average releases. In contrast, the

Shuttle/IUS Final Safety Analysis Report II makes use of Monte Carlo analyses, running 10,000 trial accident analyses for each scenario with independent accident parameters selected from their respective probability distributions.

A number of hydrocode analyses specific to the Titan IV/IUS configuration were performed in order to calculate RTG response to accident environments.

Where release of fuel material is identified using the same failure criteria and fuel release models as for the Shuttle/IUS, identical models and methodologies for consequence assessment were used for both the Shuttle/IUS Final Safety Analysis Report II and Titan IV/IUS.

C.6.2 Accident Scenarios and Source Terms

C.6.2.1 Failure/Abort Sequence Trees (FASTs)

The Failure/Abort Sequence Trees generated for each mission phase are representations of potential accident sequences that could impose environments on the RTGs which might led to a fuel release. Each FAST begins with mission phase identification and divides into decision branches representing mission phase success and failure. The success branch indicates that the mission phase objective is achieved and it leads directly to the next mission phase. The failure branch is subdivided into various accident scenario initiating events, as defined in the Titan IV Data Book (Martin Marietta 1988). Each of the initiating events has been associated with an RTG environment such as a pool explosion, destruct, reentry, and so on. Probability estimates for the various FAST branches and events are included. The mission phases are defined in Section C.3.1.

Mission phases 5 and 6 are essentially the same for the Shuttle/IUS and the Titan IV/IUS. Some probabilities will be different due to likely differences in the duration the spacecraft-IUS combination remains in Earth orbit depending on the launch vehicle and because of the capability of the Shuttle to return with its payload from orbit. However, these differences are judged not to be of sufficient magnitude as to require specific analysis.

The initiating accidents shown on the Failure/Abort Sequence Trees result in accident environments for the RTGs which must be evaluated for the risk assessment. Figure C-6 shows the mission summary level FAST. In phases 0 and 1 of the mission, pool explosion environments are involved. Many in-flight failures in Phases 1, 2, and 3 involve vehicle destruct environments. Some Solid Rocket Motor failures (loss of thrust) pose a unique fragment threat to the RTGs during Phases 1, 2, and 3. Phase 4 and 5 failures can involve reentry and impact of the RTG. Phase 4 and 5 failures are like the Shuttle/IUS Phase 4 failures.

IUS initiated failures in mission phases 1 through 4 are Reaction Control System tank failures, inadvertent IUS destruct, and structural failures. The Reaction Control System tank failure is dismissed from consideration since the resulting tank fragments would not be a threat to the RTGs. It would lead to a mission failure like a vehicle break-up,

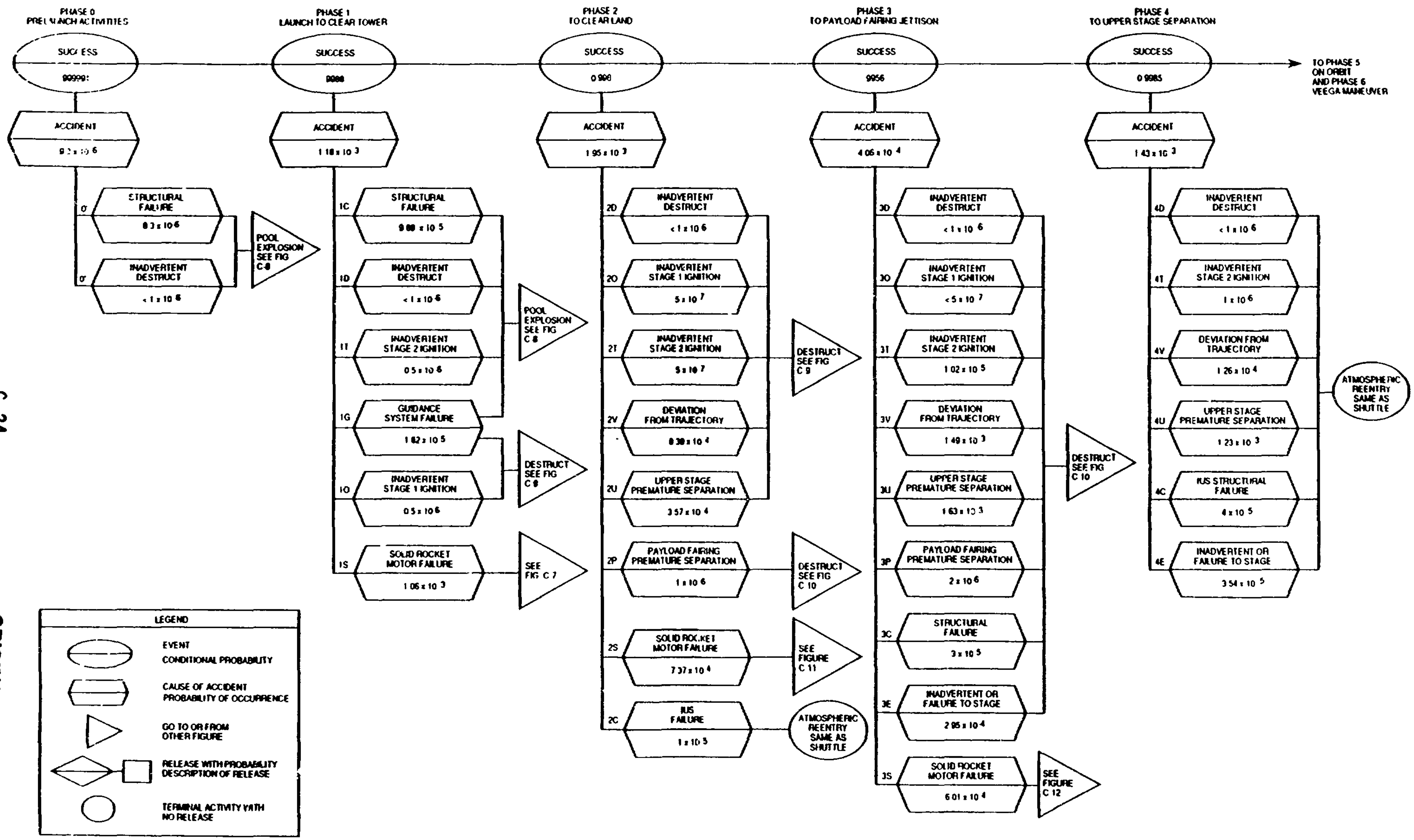


FIGURE C-6
MISSION SUCCESS AND ACCIDENT SUMMARY

destruct, or reentry depending on the mission phase, but the probabilities are judged "rather remote" in the Titan IV Data Book (Martin Marietta 1988). This was interpreted to mean that their probabilities were small when compared to other initiating failures leading to the same consequences. The IUS destruct scenarios are included with the Titan IV/IUS destruct failure Failure/Abort Sequence Tree branches.

Failures Leading to Pool Explosion Scenarios

Several accident types in mission phases 0 and 1 are projected by the Titan Data Book to lead to massive spills of the Titan IV core vehicle liquid propellants onto the launch pad such that they would pool and explode. The RTGs response was evaluated for varying distances above or away from the pool explosion. These scenarios are discussed under their scenario descriptors in the following paragraphs.

Prelaunch Structural Failure (FAST Branch 0′). Titan IV or IUS structural failure during the period of fuel loading and preparations for launch is projected to result in a collapse of the vehicle and the upper-stage/spacecraft onto the launch pad. During the process of collapse, the core vehicle hypergolic propellants are postulated to pool on the pad such that a low yield explosion and fireball results. The RTGs are within the payload fairing, which is above the pooled propellants. Pooled propellant explosion parameters are provided in the Titan IV Data Book, based on Project PYRO test data (Welloughby et. al. 1968). An upper limit of 0.5 percent TNT equivalent yield and an average (50 percentile) TNT equivalent yield of 0.3 is estimated.

The probability of this failure occurring has been estimated as 8.3×10^{-6} for the Titan IV and less than 1×10^{-6} for the IUS. The IUS probability is assumed to be much less than 1×10^{-6} and does not contribute significantly to the overall probability. Further, the IUS would not contribute to the threat environment of the RTG except through fire, according to the Titan IV Data Book.

Inadvertent Command Shutdown and Destruct System (CSDS) Activation in Phase 0 (FAST Branch 0"). Inadvertent Command Shutdown and Destruct System activation on the launch pad would cut the cases of the Solid Rocket Motors, core, and upper stages. Solid Rocket Motor case cutting before ignition is benign since there is no internal pressurization to propel fragments. Cutting core propellant tanks will cause a massive dump of propellants. The Titan Data Book projects that a propellant pool is created resulting in low yield local explosions. The payload fairing, containing the RTGs, is above the pool at the time of the explosions. The probability of this scenario has been given as less than 1×10^{-6}. For analysis purposes, it has been taken to be equal to 1×10^{-6}. The RTG environment has been specified to be like the structural failure case.

It should be noted that the PYRO command destruct tests, on which the explosion environment is based, involved cutting the propellant tanks on opposite sides of the tanks so that the propellants would not contact each other until hitting the ground surface. The Titan destruct charges are between tanks. This placement would result in immediate contact of the propellant. Since hypergolic propellants ignite on contact with essentially no delay, a more likely scenario than the pooling of propellants on the pad and explosions would be a deflagration and fireball with extremely low pressure waves.

Phase I (0-5 seconds) Structural Failure (FAST Branch 1C). During this lift-off period structural load margins of the vehicle are at their minimum. Catastrophic structural failure would result in activation of the Inadvertent Separation Detection System, which would cause the destruct charges on separated elements of the Titan IV/IUS stack to explode. The Titan Data Book projects that this would result in the spillage of Titan core liquid propellants on the launch pad which would collect, pool, and explode.

At the time of explosion, the RTGs would be falling either laterally away from the pooled propellants or downward toward the pool. The parameters specified in the Titan Data Book are that each possibility is equally probable, with the RTGs being between 20 to 140 feet above the pool in the case of a downward fall.

Phase I Solid Rocket Motor Failures (FAST Branch 1S). There are four types of solid rocket motor failures that have been defined (see Figure C-7).

a. Uneven thrust, wherein one of the two Titan IV Solid Rocket Motors has an off-nominal thrust resulting in either an impact with pad structures causing a structural failure scenario as described above or a deviation from the prescribed trajectory and destruct action in Phase 2 (FAST Branch 1S1)

b. One (only) Solid Rocket Motor ignition leading to vehicle tipover on the pad with the RTGs being 40 to 140 feet above a pool explosion or leading to tower impact of the vehicle, wherein the RTGs could be from 20 to 140 feet above a pool explosion (FAST Branch 1S2)

c. Solid Rocket Motor thrust vector control failure leading to an errant trajectory and Phase 2 destruct action (FAST Branch 1S3)

d. Solid Rocket Motor loss of thrust caused by failure of a motor insulation liner and local case burn-through or a fracture of the motor casing (FAST Branch 1S4)

As discussed above, the first two failure types can lead to variations on a pool explosion scenario with the RTGs at varying distances above or away from the pool at the time of explosion.

Phase 1 Inadvertent Destruct (FAST Branch 1D). The Titan IV Data Book defines this scenario as equivalent to a Phase 1 structural failure. However, for the same reasons discussed for the prelaunch inadvertent Command Shutdown and Destruct System activation, a more likely scenario is a deflagration and fireball. This would be no threat to the RTGs since testing has shown them to withstand launchpad fires.

Phase 1 Inertial Guidance System (IGS) Failure (FAST Branch 1G). A failure of an electronic component of the IGS Flight Control Computer could

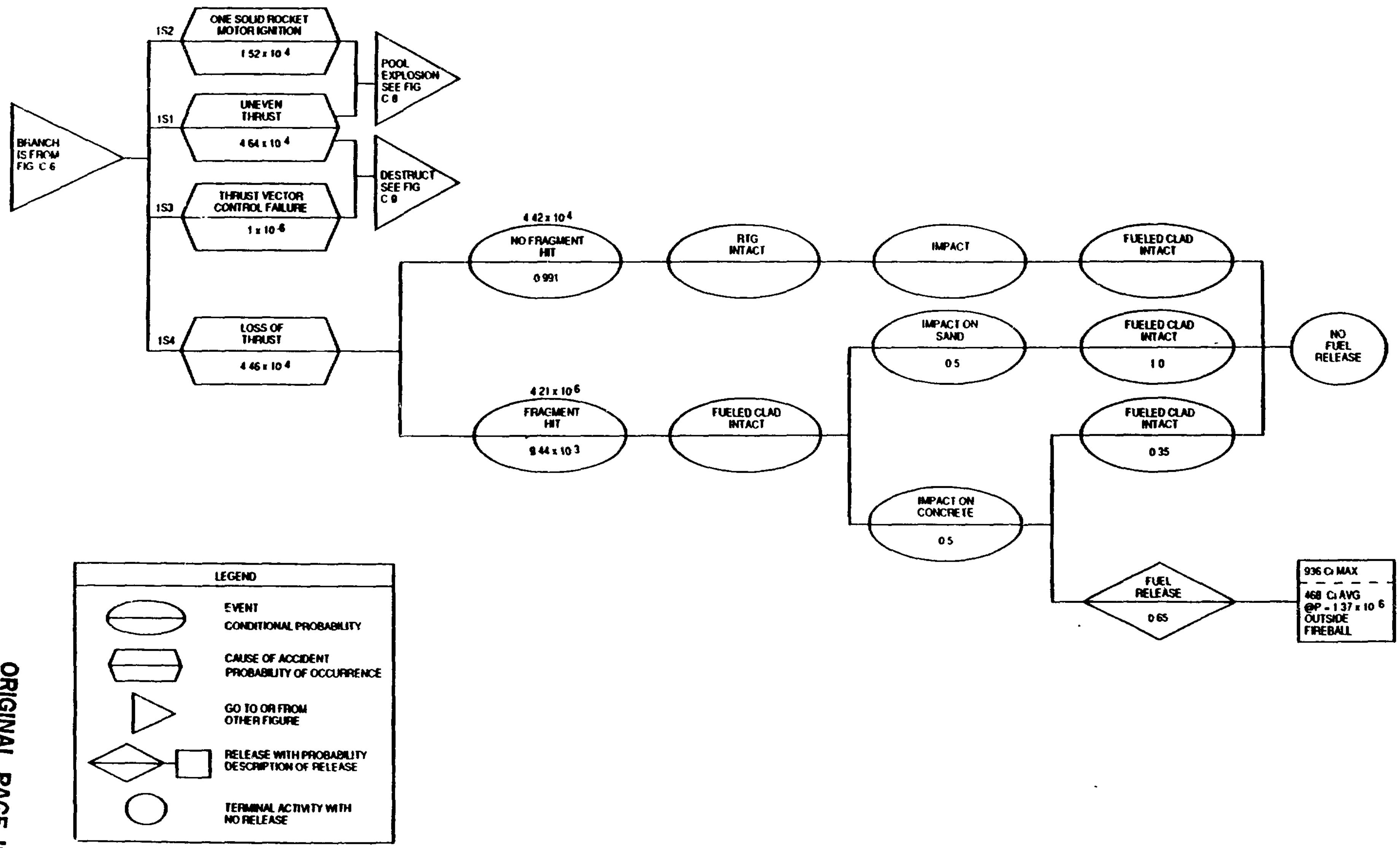


FIGURE C-7
SOLID ROCKET MOTOR FAILURE, PHASE 1

result in loss of attitude control or premature initiation of a roll program. The Titan IV Data Book estimates that one half of the time this could lead to impact with the launch tower and a pool explosion type of scenario with the RTGs above or to the side of the pool, like the Solid Rocket Motor tipover scenario. The other 50 percent of the time, this failure is projected to lead to a Command Shutdown and Destruct System action in Phase 2.

Inadvertent (Titan) Stage 2 Ignition (FAST Branch 1T). In the case of premature Stage 2 ignition, that is ignition before Stage 1 has separated, the burning propellants and thrusting would cause a structural breakup of the Titan IV vehicle and the initiation of the Inadvertent Separation Destruct System due to the breakage of the continuity wires.

In Phase 1, this scenario is identical to the Phase 1 Structural Failure, that is, it would result in a pool explosion on the launch pad, with the RTGs above or away to the side of the pool.

Failures Leading to In-Flight Destruct Scenarios

Most in-flight failures will lead to vehicle destruct, either by deliberate or accidental activation of the Command Shutdown and Destruct System, or by activation of the Inadvertent Separation Destruct System as the vehicle breaks up because of aerodynamic loading. Since the destruct systems are designed to induce structural breakup with mild explosions of destruct charges, these are not a threat to the RTGs. The IUS destruct, because of its location near the RTGs, appeared to represent some potential threat, but this was analyzed and found not to be the case. A vehicle in-flight destruct would result in a deflagration of liquid propellants. Even in the case of an explosion, rather than deflagration, the distances of the RTGs from the destruct charge locations are such that the explosion environment would leave the RTGs intact. Fragments from the Solid Rocket Motor case would not be directed toward the RTGs and thus are not a threat. Therefore, the only difference between destruct scenarios are the altitude of the destruct and the location of impact of the RTGs (ocean or land).

Consistent with the treatment of RTG impact in the Shuttle/IUS Final Safety Analysis Report II (USDOE 1988b), there will be no RTG fuel release in the cases of impact in the Cape Canaveral area (Phase 2) or for water impacts. In Phase 4, there may be impacts of General Purpose Heat Source modules on hard rock, which can involve a release of fuel. Phase 4 destruct scenarios are treated as atmospheric reentry cases.

Solid Rocket Motor Loss of Thrust Scenarios (FAST branches 1S2, 2S, and 3S)

Solid Rocket Motor failures that lead to loss of thrust include failure of the Solid Rocket Motor insulation liner leading to motor case burn through and failure of the motor case by fracture. This fracture might be caused by an undetected case flaw or by a pressure pulse induced by a propellant flaw. In most failures, Solid Rocket Motor case fragments would not be directed toward the RTGs, and a simple destruct type of environment would be involved. However, if the case failure were to occur in the motor forward closure, fragments may be directed toward the RTGs. Only one RTG might be impacted by these fragments since the IUS would shield the one opposite the failed Solid Rocket Motor.

Atmospheric Reentry Scenarios

The scenario consequences for reentries during ascent in Phase 4 (to impact in Africa) or in Phase 5 are the same for the Titan IV/IUS as for the Shuttle/IUS. Only the probabilities are affected because of the different vehicles and the fly-back capability of the Shuttle in the case of some failures. The Phase 2 IUS failure is deferred to Phase 5 and would be a reentry case.

Mission Phase 5, on orbit, involves only the IUS and spacecraft and Mission Phase 6, VEEGA trajectory, involves only the spacecraft. The Titan vehicle is not involved except as how it might affect the time on orbit before insertion into the VEEGA trajectory. Therefore, the risks associated with accidental reentry during these mission phases are the same as for the Shuttle/IUS launch option.

C.6.2.2 Source Term Evaluations

Accidents that have been identified can be grouped into 1) those that result in a massive spill of liquid propellants that may pool on the launch pad and explode, 2) those that result in in-flight destruct action, 3) those which involve a solid rocket motor failure with the potential for a fragment field being directed toward an RTG, and 4) those that result in a reentry into the Earth's atmosphere. The following sections describe the source term evaluations performed for these types of RTG environments, as related to specific FAST branches.

Pool Explosion Scenarios

Figure C-8 shows the pool explosion FAST subbranch. These accidents occur in the prelaunch phase and in early (0-5 seconds) ascent, while the launch vehicle is just above the launch pad. The Titan liquid propellants are hypergolic bipropellants which ignite with essentially no delay upon contact with each other. Therefore, the concept of these propellants forming a pool and exploding, rather than resulting in a large deflagration and fire is essentially a conservative one in the context of a threat to the RTGs. In the absence of an explosion there would be only RTG fall-back and a fire environment. Tests have shown that a fire alone cannot cause an RTG fuel release. The fall-back is at sufficiently low speeds as to not be a threat to the RTGs.

Nevertheless, a pool explosion environment has been specified in the Titan Data Book, as well as a specification for the height above the pool of the RTGs for the various scenarios. Tables C-7 and C-8 show these specifications. It can be seen that the RTGs are not expected to be any closer than 20 feet above the postulated pool explosion. At this closest distance, the speed of impact of the collapsing Payload Fairing driven by the explosion is calculated to be no greater than 277 feet per second. Calculations performed for the Shuttle Solid Rocket Motor sidewall fragments impacting side-on to the RTG show a Fueled Clad distortion of ten percent or less as a result of an impact of a one-half inch thick steel plate at this

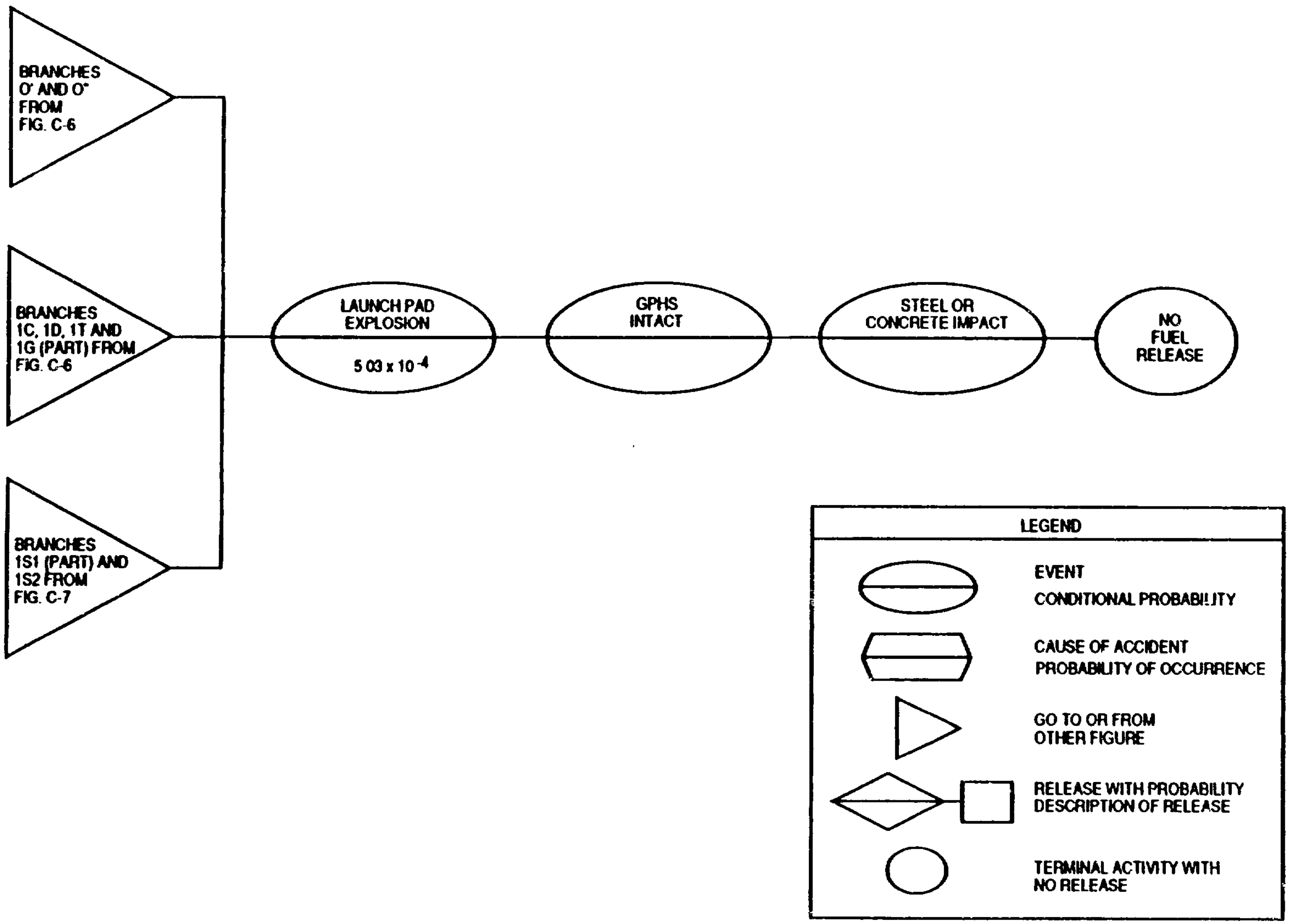


FIGURE C-8
POOL EXPLOSIONS

TABLE C-7. POOL EXPLOSION SCENARIO DISTANCE SPECIFICATIONS

FAST Branch	Scenario	Probability	Distance*
0′	Structural Failure	50% 50%	Out-of-range 40-140 ft.
0"	Inadvertent Command Shutdown Destruct System Activation	50% 50%	Out-of-range 20-140 ft.
1C	Structural Failure	50% 50%	Out-of-range 40-140 ft.
1S1	Uneven Thrust/Tower Impact	25% 75%	Out-of-range 20-140 ft.
1S2	1 Solid Rocket Motor Ignition/ Tipover to Ground	100%	40-140 ft.
1D	Inadvertent Command Shutdown Destruct System Activation	50% 50%	Out-of-range 20-140 ft.
1T	Inadvertent Stage 2 Ignition/Structural Break-up	50% 50%	Out-of-range 20-140 ft.
1G	Inertial Guidance System Failure/Tower Impact	25% 75%	Out-of-range 20-140 ft.

*Out-of-Range means distance is greater than 140 feet.
Distances in range given are uniformly distributed.

TABLE C-8. POOLS EXPLOSION SCENARIO PRESSURE AND VELOCITY PARAMETERS.

	20 Feet Above Pool
Static Overpressure (psi)	15
Peak Reflected Pressure (psi)	56
Peak Dynamic Pressure Impulse (psi-s)	15
Static Overpressure Impulse (psi-s)	0.45
Dynamic Pressure Impulse (psi-s)	0.23
Flyer Plate Velocity (fps)	157-277
Shrapnel Velocity (fps)	0-64

NOTE: In 1991, the VEEGA fly-by altitudes would be greater than in 1989, but the probability of inadvertent re-entry still remains at 5 x 10^{-7}.

APPENDIX C

ANALYSIS/CONSEQUENCES ASSESSMENT FOR THE TITAN IV LAUNCH VEHICLE

speed. The Payload Fairing is aluminum of about 0.154 inches thick, average. Thus, the Payload Fairing impact on the RTGs would be much milder than that calculated for the Shuttle Solid Rocket Motor fragment. Based on this information, none of the pool explosion scenarios are expected to cause a release of fuel from the RTGs, since the failure threshold of a Fueled Clad has been estimated to correspond to a distortion of thirty percent. It should be noted that the General Purpose Heat Source modules have not released fuel in tests of alumirum and titanium bullets being shot at them at speed of 319 m/s. Therefore, the shrapnel postulated for this scenario is also not a threat. Subsequent impacts of modules on concrete or steel also would not be expected to release fuel since no significant velocity would be imparted to the RTG or its components from the explosion.

In-Flight Destruct Scenarios

Figures C-9 and C-10 show the accident scenarios that result in a destruct environment while the Titan IV/IUS vehicle is in flight during ascent. The purpose of the destruct mechanism is to disrupt the flight in case of a failure so that the failure cannot result in danger to persons or property in a subsequent fall-back and impact. The Titan Data Book contains estimates of the static overpressure and impulse at the RTG locations in the case of a destruct of 7 to 10 psi and 0.12 to 0.16 psi respectively. These are very mild, and the result of a destruct would only be the fall-back of the intact RTG on land or water depending on the position of the vehicle at the time of destruct action. Based on analyses in the Final Safety Analysis Report for the Shuttle/IUS, such impacts would not be expected to release RTG fuel.

The IUS destruct charge is in a position to potentially affect the RTG. However, the fragments specified are so thin (0.068 in) that the impact of a fragment at the estimated speed of 5250 fps would not be a threat to the General Purpose Heat Source fuel containment. Any disruption of the RTG case freeing the General Purpose Heat Source modules would actually increase the margin of safety. The modules are designed to withstand reentry impacts individually; however impact of an intact RTG would be more severe than individual module impacts.

Solid Rocket Motor Loss of Thrust Scenarios

The Failure/Abort Sequence Trees for the Solid Rocket Motor loss of thrust scenarios in Mission Phases 1, 2, and 3 are shown in Figures C-7, C-11, and C-12:

- These failures can be a threat to RTG fuel containment if the loss of thrust results from or involves a failure and fragmentation ofthe forward closure of a Solid Rocket Motor case. If this were the situation, then the resulting fragments, propelled by the combustion products of the burning Solid Rocket Motor propellant, could be in the direction encompassing the location of the RTG above the failed Solid Rocket Motor.

The FASTs show a branching, differentiating between a fragment end-on hit of the involved RTG and no-hit. The no-hit branch includes Solid Rocket Motor sidewall failures and forward closure failures when the fragments miss

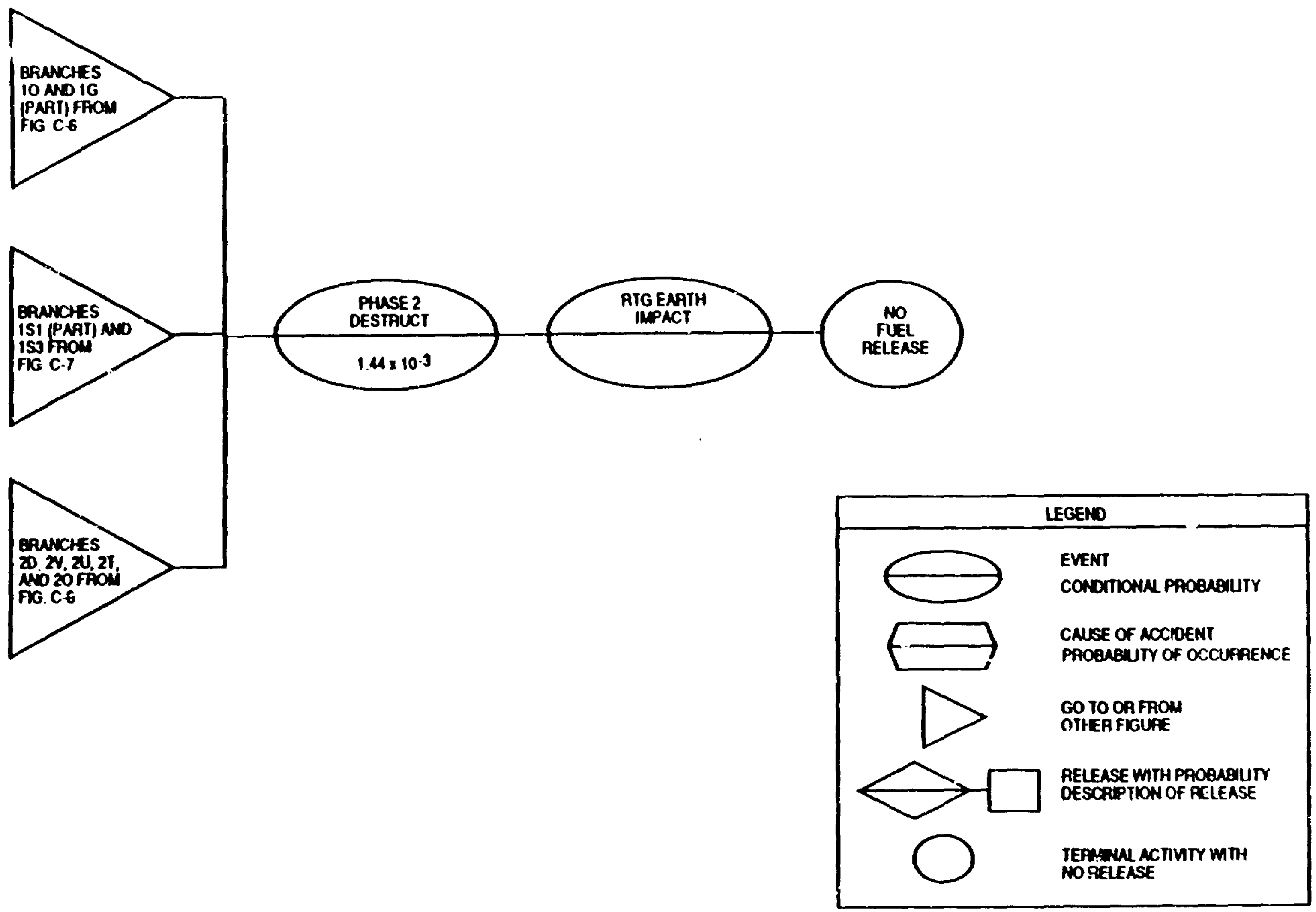


FIGURE C-9
DESTRUCT , PHASE 2

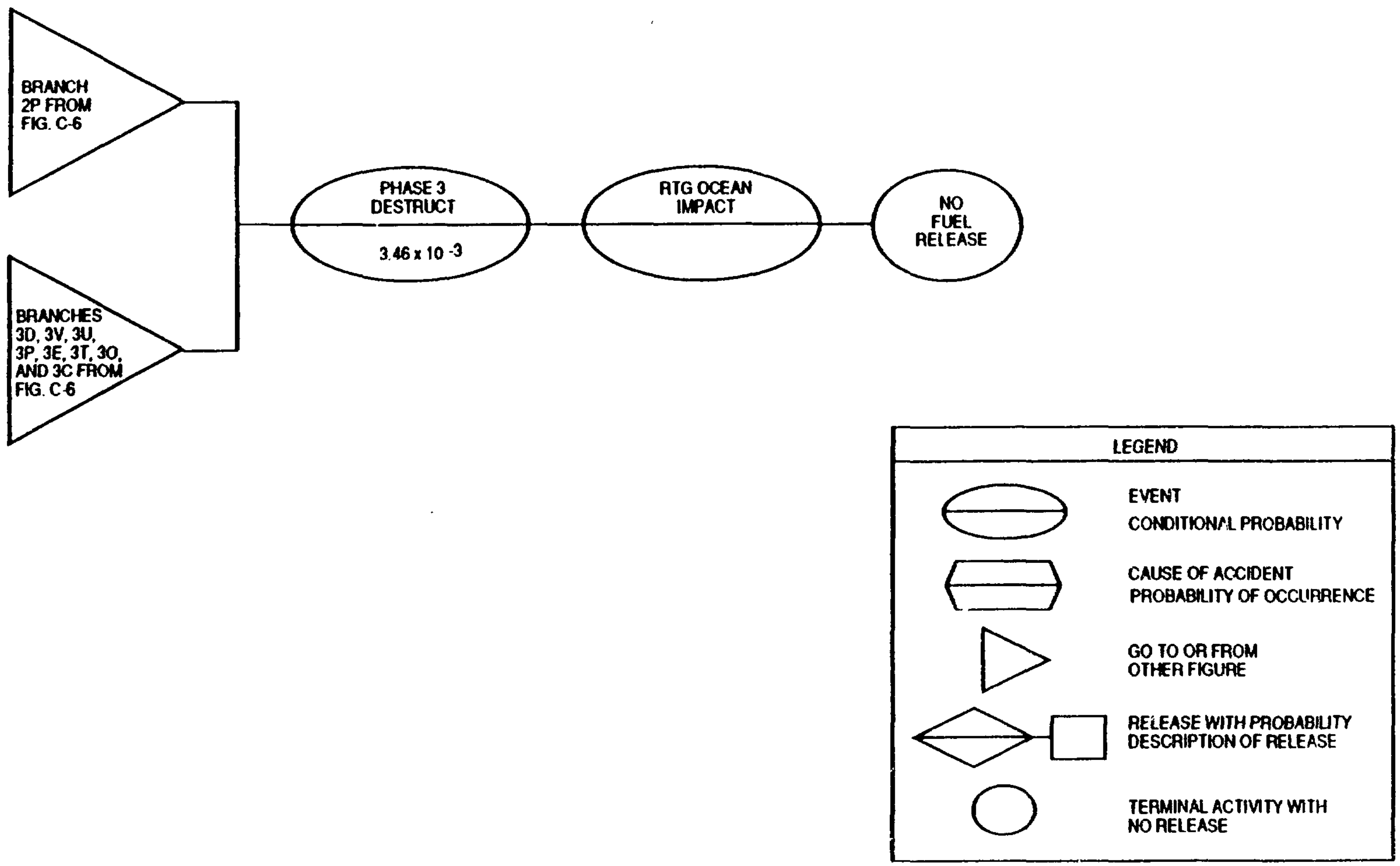


FIGURE C-10
DESTRUCT , PHASE 3

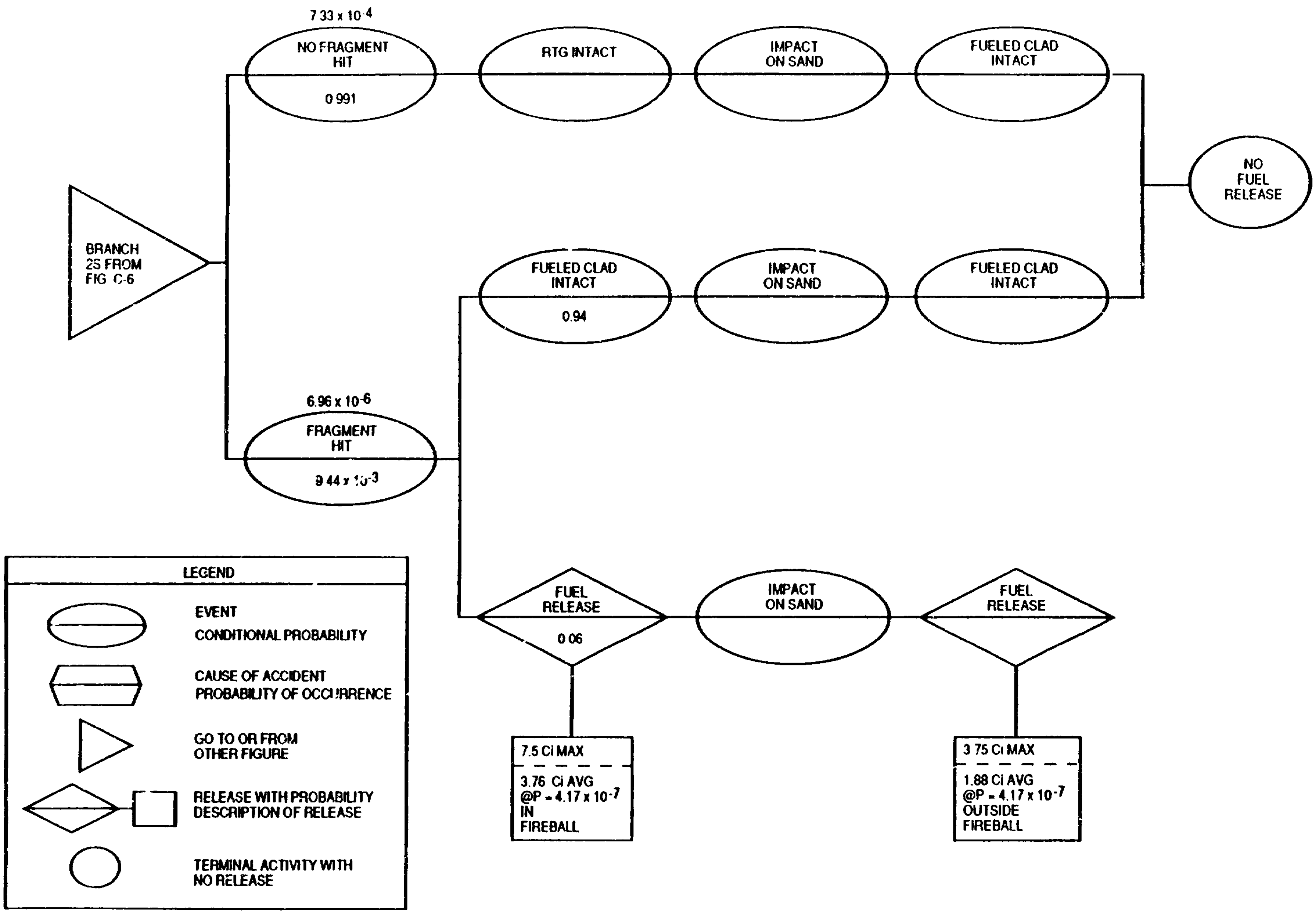


FIGURE C-11
SOLID ROCKET MOTOR LOSS OF THRUST, PHASE 2

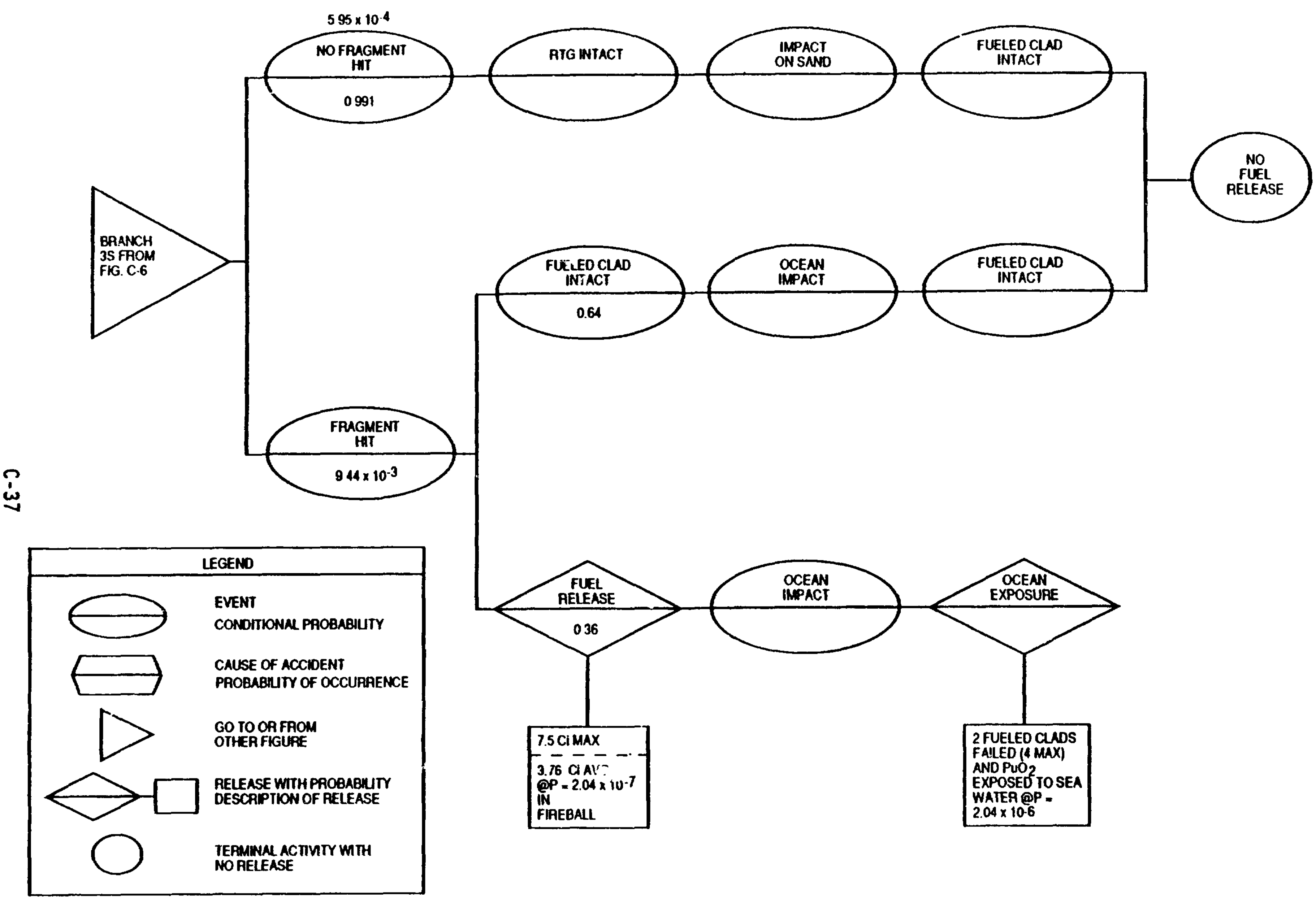


FIGURE C-12
SOLID ROCKET MOTOR LOSS OF THRUST, PHASE 3

the RTG. In this case, the consequences are much like the in-flight destruct scenarios. That is, the RTGs would be freed and fall-back intact on land or water depending on the position of the vehicle at the time of failure. Analyses documented in the Shuttle/IUS Final Safety Analysis Report II (USDOE 1988b) show no fuel release for these events.

In Phase 1, a fragment end-on hit on the RTG would release Fueled Clads from two General Purpose Heat Source modules. The momentum of the fragment would be shared with the freed General Purpose Heat Source modules and Fueled Clads, such that they would impact up to terminal velocity on the fall-back. There would be no fuel release from the modules. However, an end-on fragment hit in Phase 1 can release fuel if the freed Fueled Clads impact on concrete and the impacting fragment is sufficiently energetic. Because Phase 1 is from 0-5 seconds, it is estimated that one-half of the time such impacts are on concrete, but outside the influence of any associated fireball. The maximum release is calculated on the basis of an impact of the most energetic fragment and impact of all eight freed Fueled Clads on concrete. The average release is based on the assumption that during the interval to 5 seconds when the vehicle is clearing the tower that on average two of the four Fueled Clads will impact concrete. No detailed trajectory analyses were performed to support this. However, at the time of clearing the tower, the RTGs are at about 300 feet above the launch pad and the impacting fragment gives the Fueled Clads an additional upward velocity of more than 230 feet per second. Considering the non-vertical trajectory and the layout of the launch area, it is unlikely that any of these Fueled Clads would impact concrete.

In Phase 2 the fragments are more energetic, and would cause fuel releases from Fueled Clads in the first two GPHS modules near the end of the phase. Because this is away from the launch pad, subsequent impacts of the GPHS modules and Fueled Clads would be on sand. Those that failed in the initial fragment hit would have an additional release upon impact on sand, as shown in Figure C-11.

During Phase 3, the fragment energetics are similar to that at the end of Phase 1. It is estimated that about 36 percent of the fragments that hit will result in a fuel release at altitude. The failed Fueled Clads will expose fuel to seawater when they fall-back in the ocean.

The source term estimates shown in the Failure/Abort Sequence Trees are based on a fragment model specification in the Titan Data Book and hydrocode calculations performed in support of this work. The probability splits for fragment energetics are based on an assumption that within specified fragment speed ranges, the probability distribution of those speeds is uniform. The estimated fuel release quantities use the same distortion failure threshold and distortion-quantity correlation for the Fueled Clads as used in the Shuttle/IUS Final Safety Analysis Report (USDOE 1988b).

Failures Leading to African Impact

There is a one second period at the end of Mission Phase 4, during which a failure leading to Titan vehicle breakup could result in impact of modules on the African continent. The total probability of Phase 4 breakup scenarios is 1.27×10^{-3}. The probability that the failure will result in

African impact is 4.32 x 10^{-6}. The consequences are the same as if the failure were a Shuttle vehicle breakup.

Source Term Summary

The most probable, maximum, and expectation case source terms for the RTG using Titan IV as the launch vehicle are summarized in Tables C-9 through C-11, respectively. It should be noted that the source terms for Titan IV phases 4, 5 and 6 are identical for those corresponding to Shuttle/IUS phases 2, 4, and 5, respectively, although the probabilities may differ. (The description of information on the tables can be found in Appendix B).

The source terms and probabilities for the LWRHUs will be identical to those for Shuttle/IUS. The particle size distributions for the source terms presented are derived in the same manner as described for the Shuttle/IUS.

C.6.4 Radiological Accident Analysis

The Titan IV risk assessment is completed on the same analytical basis as the Shuttle. Where analytical techniques differ, the approach taken for the Titan IV was designed to be conservative relative to the Shuttle. Thus, Titan IV risks may be somewhat overstated. The methodology used and a detailed description of the following analysis is presented in Appendix C.4.4.

Each mission phase is defined by three release cases, most probable, maximum and expectation. These are identical to those defined for the Shuttle in Section 4.1.4.3. The mission phases definitions follow.

Phase 0 is from T-4C days to T-0 sec. Accidents involved here are launch pad accidents due to vehicle structural failures following tanking of the core vehicle liquid stages, or inadvertent activation of the Flight termination system. Phase 1 occurs from T-0 to T+5 sec and involves the lift off period. Accidentalinteraction with the launch tower and catastrophic structural failure can resultr in ground impact of the vehicle and pooling/explosion of the liquid propellants. Phase 2 (T+23 to T+250 sec) involves accidents with predicted impact points on water. Phase 4 occurs from T+250 to T+543 sec and involves atmospheric re-entry consequences with impacts in Africa.

Mission phases 5 and 6 are on-orbit and the VEEGA maneuver, which are essentially the same for the Shuttle and the Titan IV. Some probabilities may change relating to mission time-lines. Also, the Titan has no capability of mission abort to landing from orbit.

The most probable, maximum and expectation case source terms are presented in detail in Tables C-9, C-10 and C-11. The source terms and probabilities for the RHUs will be identical to those for the Shuttle, because the source terms occur during VEEGA re-entry only. The results of the radiological consequence analysis for the most probable and maximum cases are summarized in Tables C-12 and C-13. The results for the RHUs are identical to those for the Shuttle.

TABLE C-9. DESCRIPTIONS OF RELEASES FOR THE MOST PROBABLE CASES

Phase	Accident Type	Source Term (Curies)	Probability	Release Category	Description
0	No accident resulting in a release				-
1	Solid Rocket Motor Loss of Thrust	468	1.37×10^{-6}	Ground level	• Occurs on the Launch Pad • Fueled Clads breached by impact on concrete outside the fireball
2	Solid Rocket Motor Loss of Thrust	4 2	4.17×10^{-7} 4.17×10^{-7}	Fireball Ground level	• Occurs on the Launch Pad • Fueled Clads breached when hit by a fragment inside fireball, and a release when Fueled Clad impacts on sand outside fireball
3	Solid Rocket Motor Loss of Thrust	4	2.04×10^{-6}	Fireball	• Occurs at altitude • Fueled Clads breached when hit by a fragment
4	Vehicle Breakup	0.9	4.32×10^{-6}	Ground level	• On African Continent • One module breached by impact on rock
5	IUS Failure	4	3.50×10^{-4}	Ground level	• Occurs at 0° Latitude • One module breached by impact on rock
6	Inadvertent Re-entry	11,568[a]	1.12×10^{-7}	Ground level	• Occurs at 0° Latitude • Three Graphite Impact Shells breached by impact on rock

a. 3856 Curies per Graphite Impact Shell.

TABLE C-10. DESCRIPTIONS OF RELEASES FOR THE MAXIMUM CASES

Phase	Accident Type	Source Term (Curies)	Release Category	Description
0	No accident resulting in a release			
1	Solid Rocket Motor Loss of Thrust	936	Ground level	• Occurs on the Launch Pad • Fueled Clads breached by impact on concrete outside the fireball
2	Solid Rocket Motor Loss of Thrust	8 4	Fireball Ground level	• Occurs on the Launch Pad • Fueled Clads breached when hit by a fragment inside fireball, and a release when Fueled Clad impacts on sand outside fireball
3	Solid Rocket Motor Loss of Thrust	8	Fireball	• Occurs at altitude • Fueled Clads breached when hit by a fragment
4	Vehicle Breakup	3	Ground level	• On the African Continent • Fueled Clads breached following impact of 3 modules on rock
5	IUS Failure	20	Ground level	• Occurs at 33°N Latitude • Fueled Clads breached following impact of 5 modules on rock
6	Inadvertent Re-entry	11,568[a]	Ground level	• Occurs at 33°N Latitude • Fueled Clads breached following impact on rock of 3 Graphite Impact Shells

a 3856 Curies per Graphite Impact Shell impact and 3 impacts

TABLE C-11. DESCRIPTIONS OF RELEASES FOR THE EXPECTATION CASES[a]

Phase	Accident Type	Source Term (Curies)	Release Probability	Release Category	Description
0	No accidents that result in a release				
1	Solid Rocket Motor Loss of Thrust	468	$1.37E\times10^{-6}$	Ground level	• Occurs on the Launch Pad • Fueled Clads breached by impact on concrete outside the fireball
2	Solid Rocket Motor Loss of Thrust	4 2	4.17×10^{-7} 4.17×10^{-7}	Fireball Ground level	• Occurs on the Launch Pad • Fueled Clads breached when hit by a fragment inside the fireball, and a release when Fueled Clad impacts on sand outside the fireball
3	Solid Rocket Motor Loss of Thrust	4	2.04×10^{-6}	Fireball	• Occurs at altitude • Fueled Clads breached when hit by a fragment
4	Vehicle Breakup	0.9	4.32×10^{-6}[b]	Ground level	• On African Continent • One module breached following impact on rock
5	IUS Failure	4	3.57×10^{-4}[b]	Ground level	• Occurs at 0° Latitude • One module breached by impact on rock
6	Inadvertent Re-entry	12,400	5.00×10^{-7}	Ground level	• Occurs at 0° Latitude • 3.34 Graphite Impact Shells breached by impact on rock

[a] Because there is only one accident scenario per phase resulting in a fuel release for mission phases 1-4, the expectation source terms and probabilities are the same as the average. Mission phases 5 and 6 are the same as for the Shuttle, since these involve IUS solo and spacecarft only scenarios.

[b] Probability of one or more impacts

TABLE C-12. SUMMARY OF RADIOLOGICAL CONSEQUENCES MOST PROBABLE CASES

		Population Dose, Person-rem[a]		Square Kilometers of Area With Deposition Above 0.2 $\mu Ci/m^2$[b]			
Mission Phase	Release Probability	Total	Above De Minimis	Dry Land	Swamp	Inland Water	Ocean
0	-	-	-	-	-	-	-
1	1.37×10^{-6}	278	.05	.6	-	.1	-
2	4.17×10^{-7}	-	-	-	-	-	-
3	2.04×10^{-6}	-	-	-	-	-	-
4	4.32×10^{-6}	.23	.07	-	-	-	-
5	3.50×10^{-4}	5.99	2.45	.06	-	.001	-
6	1.12×10^{-7}	1,280	833	13.2	-	.3	-

a. Person-rem is the cumulation of dose to the affected population.
b. 0.2 $\mu Ci/m^2$ is microcuries per square meter.

TABLE C-13. SUMMARY OF RADIOLOGICAL CONSEQUENCES MAXIMUM CASES

Mission Phase	Population Dose, Person-rem[a]		Square Kilometers of Area With Deposition Above 0.2 μCi/m²[b]			
	Total	Above De Minimis	Dry Land	Swamp	Inland Water	Ocean
0	-	-	-	-	-	-
1	247C	873	1.26	0	1.73	.045
2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	.227	.068	-	-	-	-
5	217	59	.01	-	.003	-
6	54,000	52,900	8.9	-	.2	-

a. Person-rem is the cumulation of dose to the affected population.
b. $\mu Ci/m^2$ is microcuries per square meter.

The mission risks associated with a Titan IV launch vehicle have been assessed based on the source terms for the expectation release cases. The radiological consequences calculated for the expectation case are summarized in Table C-14.

C.6.4.1 Impacts of Radiological Accidents to Individuals

Individual impacts are expressed in terms of individual dose and the number of persons exceeding the dose level. These are presented for the most probable and maximum cases in Figures C-13 and C-14. Table C-14 also presents the average individual risk for each mission phase. This quantification of average individual risks can be compared with other risks due to natural and man-made hazards as summarized previously in Appendix B, Table B-17.

C.6.4.2 Surface Areas Contaminated by Representative Accidents

The plutonium dioxide (PuO_2) releases for the most probable, maximum and expectation case accidents are described in Section C.6.2. The most probable and maximum case accidents are developed to identify population dose impacts and do not necessarily represent maximum environmental consequences. The expectation case is included in the impact analysis because it more accurately reflects potential environmental impacts through the use of average meteorological conditions, as described in Section B.4.

Areas of radioactive deposition resulting from the most probable, maximum, and expectation case accidents are presented in Section C.2, Tables C-12 through C-14. The deposition is reported for areas of dry land, swamp, inland water, and ocean.

Accidental releases can occur in the Kennedy Space Center and vicinity during Phase 0, 1 and 2 and at unspecified areas worldwide during Phase 3 - 6. Chapter 3 of the EIS presents a description of the environments that could be affected by the accidents. Two different impact assessment methodologies were developed to analyze these accidents. Both methodologies use the most probable, maximum, and expectation cases. One is for the Kennedy Space Center and vicinity during Phases 0, 1, and 2. The other is global for Phases 3 - 6. The methodology for estimating potential economic costs resulting from the accidents is also provided. These methodologies are described in Section B.5 of Appendix B.

No specific locations are defined for the most probable and maximum case accidents for Phases 3 through 6. The amount of surface area of deposition and the concentrations of contamination from an accident during these phases could change if accident characteristics and meteorologic conditions are different than those assumed. Because the latter phases of the mission deal with impacts on a global scale, the environmental impacts are discussed in general terms.

Due to the difficulty in defining the exact magnitude of economic costs associated with the impacts, minimum and maximum mitigation costs were estimated in order to bound the range of costs which could result from an accident. The methodology and basis for the economic cost analysis is presented in Appendix B.5.3.

TABLE C-14. SUMMARY OF RADIOLOGICAL CONSEQUENCES EXPECTATION CASES

		Population Dose, Person-rem[a]		Square Kilometers of Area With Deposition Above 0.2 µCi/m2[b]			
Mission Phase	Release Probability	Total	Above De Minimis	Dry Land	Swamp	Inland Water	Ocean
0	-	-	-	-	-	-	-
1	1.37×10^{-6}	278	.045	.564	-	.09	-
2	4.17×10^{-7}	-	-	-	-	-	-
3	2.04×10^{-6}	-	-	-	-	-	-
4	4.32×10^{-6}	.227	.068	-	-	-	-
5	3.57×10^{-4}	5.99	2.45	.058	-	.001	-
6	5.00×10^{-7}	1430	927	14.7	-	.3	-

a. Person-rem is the cumulation of dose to the affected population.
b. 0.2 µCi/m2 is microcuries per square meter.

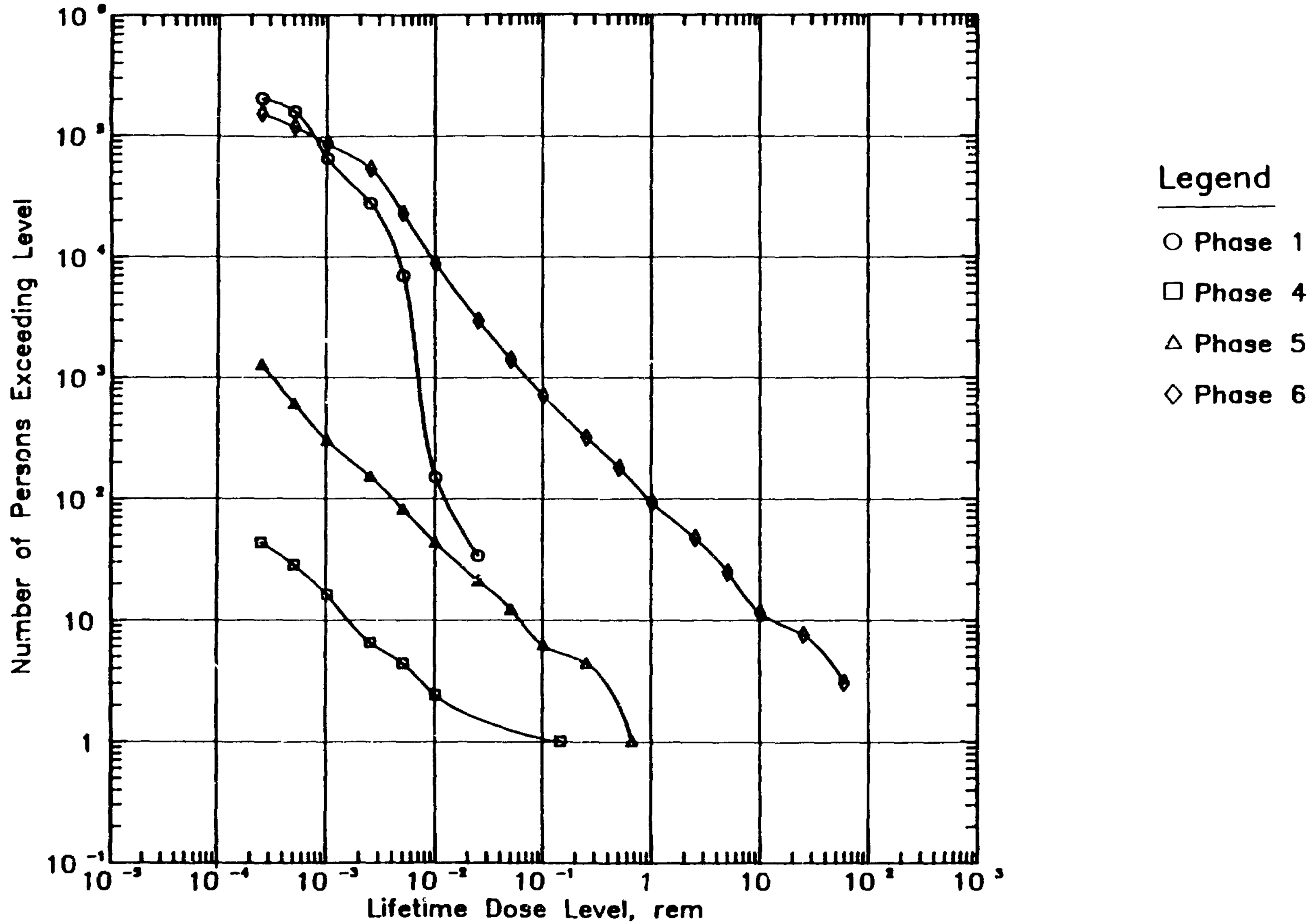


Figure C–13. RADIOLOGICAL CONSEQUENCE SUMMARY MOST PROBABLE CASE, TITAN IV

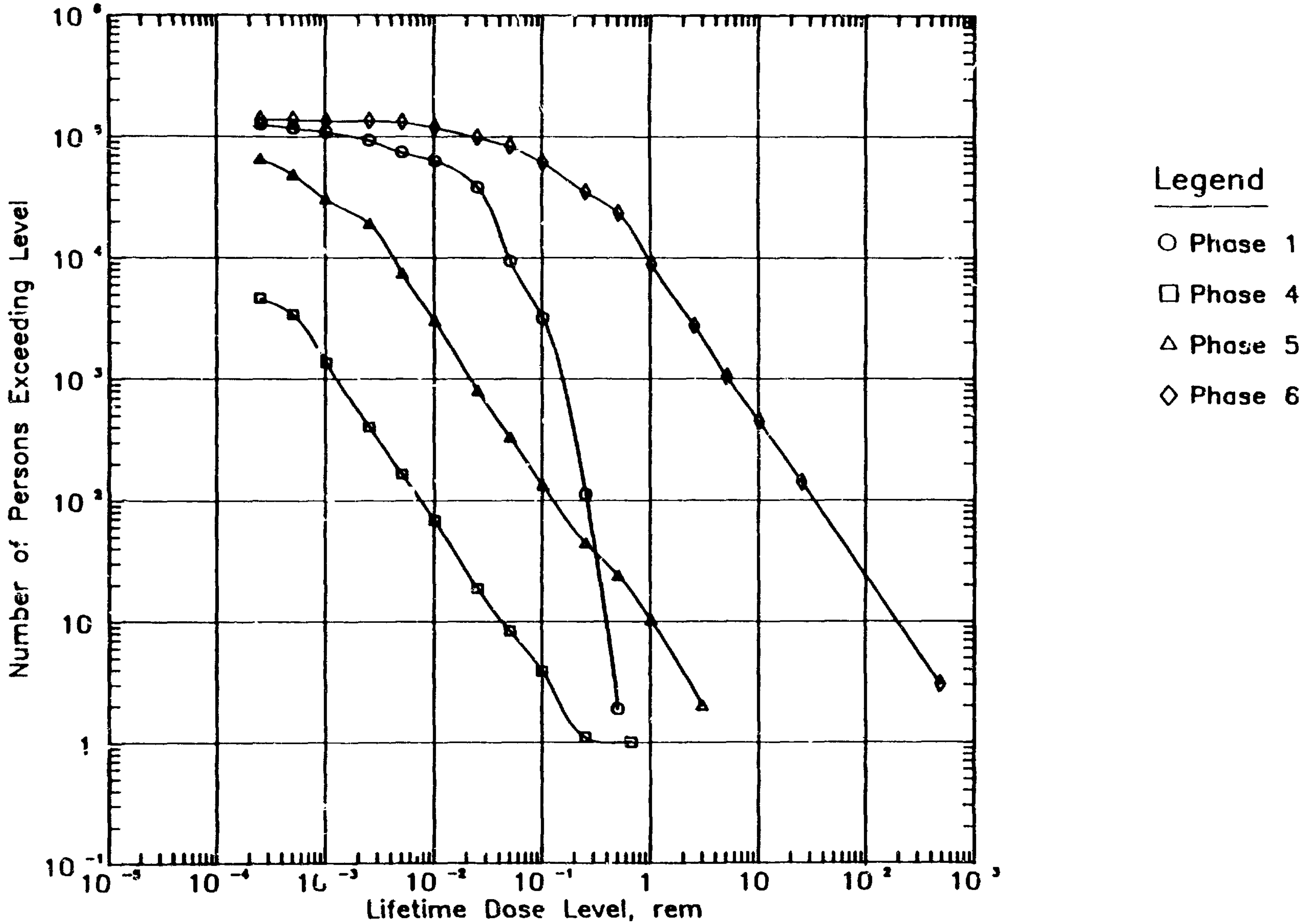


Figure C–14. RADIOLOGICAL CONSEQUENCE SUMMARY MAXIMUM CASE, TITAN IV

C.6.4.3 Effects and Mitigation of Land Deposition

This section presents the environmental consequences of an accident in which PuO_2 is exposed to the environment. The analysis is divided into two major categories: 1) the potential effects of the most probable and maximum case accidents during Phases 0, 1 and 2; and 2) the potential effects of the most probable and maximum case accidents during Phases 3, 4, 5, and 6. The first category are those accidents which could affect KSC and vicinity and can be represented by a specific mathematical model. The second category of accidents are those which could affect unspecified areas of the world and cannot be precisely represented.

Results are presented for exposure effects and long-term and mitigation effects. Exposure effects are those that result from the deposition of PuO_2 on various environmental media. Long-term and mitigation effects are those that result from leaving PuO_2 in the environment. They include impacts to natural environments, agricultural resources, man-used resources, and water bodies, along with possible mitigation measures and the effects of mitigation. The economic cost estimates associated with the analyses are also presented. The methods used are the same as used for the STS alternative.

<u>Assessment of Impacts to Kennedy Space Center and Vicinity</u>

This section presents the environmental consequences of Phases 0, 1, and 2 accidents. There are no radiological releases from Phase 0 accidents and no areas contaminated above the 0.2 uCi/m^2 EPA screening level recommendation from Phase 2 accidents. Therefore, Phase 0 and Phase 2 accidents are not discussed further.

<u>Exposure Consequences</u>

The deposition of plutonium dioxide from the representative accidents does not physically alter land covers unless a particle provides enough heat to start a fire. However, the PuO_2 can affect the human use of these land covers and could result in a change in land cover.

Contaminated areas were analyzed to determine current land cover use and how PuO_2 would react to various environmental conditions. This analysis was used to draw the following conclusions on immediate consequences:

There is no initial impact on soil chemistry. Most PuO_2 deposited on water bodies is not expected to react chemically with the water column, therefore no immediate consequences are expected in these waters. No significant consequences to flora and fauna are expected from surface contamination and skin contact with PuO_2.

The contaminated areas on the Kennedy Space Center have characteristics similar to the area contaminated for Phase 0 of the Shuttle accident. The impacts and mitigation techniques for the Shuttle accident as described in Section 4.1.4.5 and Appendix B (Section B.6.2.3.) are applicable to the Titan IV Phase I accident.

The bounding economic cost of each release case accident for Phases 0, 1, and 2 are presented using the methods described in Section B.5.3. In all cases the minimum cost will be the cost of the monitoring program. This program is estimated to cost $1 million in the first year, $500,000 in the second year, $250,000 in the third year, and $100,000 per year after the third.

All deposition resulting from Phase 1 most probable, maximum, and expectation cases is confined to the Kennedy Space Center and Cape Canaveral Air Force Station property. The economic impacts from these accidents will therefore be confined to these areas. Table C-17, provides a breakdown of economic costs associated with the Phase 1 case. The total cleanup cost represents only the costs of cleanup and decontamination activities. The overall total cost is determined by multiplying the urban agricultural cleanup costs by a factor of five to include secondary costs related to temporary relocation, agricultural product losses, public health effects, etc. Actual costs will fall within this range. The discussion of economic costs and the influence of mitigation presented in Appendix B (Section B.6.2.3) is also applicable to a Phase 1 accident involving the Titan IV.

<u>Assessment of Global Impacts</u>

This section presents the environmental consequences of accidents during Phases 3, 4, 5, and 6. A general discussion of the impacts and possible mitigation measures are presented.

No contamination is expected from a Phase 3 accident since the release of PuO_2 occurs in the fireball during an explosion and no particles are expected to reach ground.

Impacts result from one module impacting land for the most probable accidents and 3 or 5 modules impacting land in the maximum case for Phases 4 and 5 respectively. For Phase 6, three Graphite Impact Shells could impact for the most probable and the maximum cases (Section C.6.4, Appendix C).

A reentry accident during Phases 4 and 5 would involve orbiter failure and breakup. Atmospheric reentry speed and orbiter breakup rate will likely result in PuO_2 modules or Graphite Impact Shells being released at different locations. These independent release points will result in impact areas that may be separated by many thousands of kilometers. Except for Phase 6, the areas involved are less than 1 km^2 (0.6 m^2). For Phase 6, the deposition that exceeds the 0.2 uCi/m^2 screening level occurs on dry land and inland water. The area of impact is estimated at 0.197 km^2 for the expectation case. Cleanup costs for the expectation case vary from $0.5 million to $240 million. Mitigation would include recovery and cleanup.

<u>Additional Mitigating Measures</u>

The principal mitigating measures for the launch configurations available under the delay alternative are the protective shields or barriers for the RTGs and emergency planning. The radiological contingency planning measures would be similar for all of the alternatives and were discussed in Section 4.1.4.6.

For an expendable launch vehicle such as the Titan IV/IUS, the most reasonable additional RTG protection design probably would be a fragment barrier. The design concept would be an energy-absorbing structure mounted between the RTGs and the IUS. Because the fragment barrier design would not fully enclose the RTGs, protection from a near-pad ground impact would be limited. Mission performance considerations would require that the fragment barrier be jettisoned prior to the Earth-Orbit-Escape Phase, thereby providing no additional protection from an Earth-orbit explosion followed by reentry.

Limitations and Uncertainties of the Accident Analyses

The uncertainties in the accident analyses in the Titan IV/IUS are expected to be the same order of magnitude as for the STS, discussed in Section 4.1.4.7.

C.4.4 Radiological Consequences

C.4.4.1 Failure Abort Sequence Trees (FASTs)

The results of the radiological consequence analysis for the most probable and maximum cases identified in Tables C-9 and C-10, are summarized in Tables C-12 and C-13, respectively for the RTGs. Reference should be made to Tables C-9 and C-10 in relating accidential fuel release scenarios and the radiological consequences. (A discussion of the type of information presented on the tables is presented in Appendix B).

The results for this most probable case show population dose in Phase 1, 4, 5 and 6. These vary from a total person-rem of 0.23 in Phase 4 to 1,280 in Phase 6. The population dose above the de minimus ranges from .05 person-rem in Phase 1 to 833 person-rem in Phase 5.

Individual impacts are expressed in terms of individual dose and the number of persons exceeding the lifetime dose level. These are presented for the most probable and maximum cases in Figure C-13 and C-14.

C.4.5 Integrated Mission Risk

The risks associated with the use of the RTGs on the Galileo mission with a Titan IV launch vehicle have been assessed based on the source terms for the expectation release cases presented previously in Table C-11. The radiological consequences calculated for the release expectation case are summarized in Table C-14. The overall mission risks associated with the RTGs using Titan IV are presented in Table C-15.

C.6 ENVIRONMENTAL CONSEQUENCES

This section presents the environmental consequences of an accident in which plutonium dioxide (PuO_2) is exposed to the environment. A brief discussion of how plutonium dioxide reacts in the environment presented in Appendix B is also utilized. The impact analysis is divided into two major categories, 1) the potential impacts of the representative most probable, maximum and expectation cases during Phases 0, 1 and 2; and 2) the potential

TABLE C-15. MISSION RISK SUMMARY

Mission Phase	Release Probability	Population Dose, Person-rem Above De Minimis	Excess Health Effects[a]	Population Affected[b]	Average Individual Risk[c]
0		-	-	-	
1	1.37×10^{-6}	.045	8.259×10^{-6}	33.4	1.13×10^{-12}
2	4.17×10^{-7}	-	-	-	-
3	2.04×10^{-6}	-	-	-	-
4	4.32×10^{-6}	.086	1.26×10^{-5}	.75	3.81×10^{-11}
5	3.57×10^{-4}	2.45	4.53×10^{-4}	.122	1.33×10^{-8}
6	5.00×10^{-7}	927	1.71×10^{-1}	1,550	5.52×10^{-11}

a. Based on 1.85×10^{-04} excess health effects per person-rem
b. Applicable to persons receiving dose above de minimis
c. Average individual risk equals probability times health effects, divided by population affected.

impacts of the representative most probable, maximum and expectation cases during Phases 3, 4, 5, and 6. These cases are described in Section C.4. The description of the affected environment in Chapter 3 of this EIS is also used.

Results are presented for immediate impacts and long term impacts. Immediate impacts are those that result from the deposition of PuO_2 on various environmental media. Long term impacts are those that result from leaving PuO_2 in the environment. They include impacts to natural environments, (natural vegetation and wetlands), agricultural resources, urban areas, and water bodies (inland waters and ocean), along with possible mitigation measures and the impacts of mitigation. The economic cost estimates associated with the impact analyses are also presented. The methods described in Section C.5 are used in this assessment.

C.6.1 Assessment of Impacts to Kennedy Space Center and Vicinity

This section presents the environmental consequences of Phases 0, 1, and 2 accidents. Phase 0 includes the time period of RTG installation until launch. Phase 1 is the period from launch to 5 seconds of mission elapsed time. Included in this phase are lift off and clearing of the tower. Phase 2, from 5 seconds to 23 seconds of mission elapsed time, includes clearing of land.

C.6.1.1 Surface Areas Contaminated by Representative Accidents

The land area where PuO_2 is deposited from a Phase 1 accident is presented in Table C-16. All contamination is confined to Kennedy Space Center and Cape Canaveral Air Force Station property.

As discussed in Section C.4.2.1, there are no radiological releases from Phase 0 accidents and no areas contaminated above the 0.2 Ci/m^2 level from Phase 2 accidents. Therefore, Phase 0 and Phase 2 accidents are not discussed further.

C.6.1.2 Exposure Effects

Deposition of plutonium dioxide from Phase 1 most probable, maximum and expectation cases will have little direct effect on land use. The PuO_2 will not physically alter land covers 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 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 deposition and skin contact with PuO_2, except where particle concentration and/or size are great enough to overheat the surface upon which it is deposited.

Plutonium dioxide deposition from the most probable, maximum and expectation cases do not have any direct effects on historical or archaeological resources. The PuO_2 will not physically alter nor chemically degrade historical or archaeological resources.

TABLE C-16. PHASE 1 AREAS OF DEPOSITION IN SQUARE KILOMETERS

Land Cover Category	Most Probable Case	Maximum Case	Expectation Case
Natural Vegetation	.42	.93	.42
Urban	.1	.26	.1
Agriculture	.04	.07	.04
Wetlands	0	<.001	0
Inland Water	.095	1.73	.001
Ocean	0	.045	0

C.6.1.3 Long Term Consequences and Mitigation

Long term impacts from the deposition of PuO_2 on the Kennedy Space Center and vicinity are divided into six categories, natural vegetation, urban, agriculture, wetlands, inland waters, and ocean. The areas of deposition have characteristics similar to the area of deposition for Phase 0 and 1 of the Shuttle/IUS accidents. The impacts and mitigation techniques for the Shuttle/IUS accidents as described in Appendix B (Section B.6.2.3) are applicable to the Titan/IUS Phase 1 accident. It is assumed that any area with surface deposition will be monitored to determine the specific degree of impact.

C.6.1.4 Economic Impacts

The bounding economic cost of each release case accident for Phases 0, 1,and 2 are presented using the methods described in Section B.5.3. In all cases the minimum cost will be the cost of the monitoring program. This program is estimated to cost $1 million in the first year, $500,000 in the second year, $250,000 in the third year and $100,000 per year after the third.

All deposition resulting from Phase 1 most probable, maximum and expectation cases is confined to the Kennedy Space Center and Cape Canaveral Air Force Station property. The economic impacts from these accidents will therefore be confined to these areas. Table C-17 provides a breakdown of economic costs associated with cleanup activities for the Phase 1 case. The total cleanup cost represents only the costs of cleanup and decontamination activities. The overall total cost is determined by multiplying the urban and agricultural cleanup costs by a factor of five to include secondary costs related to temporary relocation, agricultural product losses, public health effects, etc. Actual costs will fall within this range. The discussion of economic costs and the influence of mitigation presented in Appendix B (Section B.6.2.3) is also applicable to a Phase 1 accident involving the Titan IV.

C.6.2 <u>Assessment of Global Impacts</u>

The methodology for impact assessment presented in Section B.5.2 is used to determine and describe impacts. Mitigation techniques that may be used are described along with the impacts that may result from mitigation.

No deposition is expected from a Phase 3 accident since the release of PuO_2 occurs in the fireball during an explosion and no particles are expected to reach ground. The deposition from Phases 4, 5 and 6 is similar to Phases 3, 4, and 5 of the Shuttle/IUS. The impacts and economic costs presented in Appendix B (Section B.6.3) are also representative of the Titan IV cases.

TABLE C-17. ESTIMATED ECONOMIC COSTS OF PHASE 1 ACCIDENTS

	Most Probable Case			Maximum Case			Expectation Case		
Land Cover Type	Area[a]	Minimum Cost[b]	Maximum Cost[b]	Area[a]	Minimum Cost[b]	Maximum Cost[b]	Area[a]	Minimum Cost[b]	Maximum Cost[b]
Natural Vegetation	0.42	0.11	52.50	0.93	0.23	116.25	0.42	0.11	52.50
Urban	0.10	0.13	62.50	0.26	0.33	162.50	0.10	0.13	62.50
Agriculture	0.04	0.05	25.00	0.07	0.09	43.75	0.04	0.05	25.00
Wetland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Inland Water	0.10	0.03	12.50	1.73	0.43	216.25	0.00	0.00	0.00
Ocean	0.00	0.00	0.00	0.05	0.01	6.25	0.00	0.00	0.00
Total	0.66	0.31	152.50	3.04	1.09	545.00	0.56	0.28	140.00

[a]In square kilometers
[b]In millions of 1977 dollars

C.7 REFERENCES

Martin Marietta, 1988. Titan IV Data for Planetary Mission Radioisotope Thermoelectric Generator (RTG) Safety Analysis - Galileo/IUS Portions Only. Denver CO. Draft Review Copy. September, 1988.

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APPENDIX D

ADDITIONAL INFORMATION TO SUPPORT THE CHARACTERIZATION OF THE AFFECTED ENVIRONMENT

APPENDIX D-1

HISTORICAL CLIMATOLOGICAL DATA
AND
LAUNCH WINDOW-SPECIFIC METEOROLOGICAL DATA*
FOR KSC

*Meteorological data from DOE 1988b.

LAUNCH WINDOW-SPECIFIC METEOROLOGICAL DATA

SURFACE DATA

Surface data utilized to represent near ground-level radiological releases from an accident involving the National Space Transportation System/Inertial Upper Stage (STS/IUS) launch vehicle were taken from the 1980-1984 records for the October 7-November 25 "launch window." Data were obtained from meteorological Tower 313 of the Weather Information Network Display System (WINDS) at Cape Canaveral (Figure D-1). This 500 foot high tower is located about 3 miles west of Launch Complex 39 and the Atlantic Ocean. While the tower is instrumented at six different heights, data from the 54-, 204-, and 492-foot levels were utilized for the radiological assessments in the Tier 2 Galileo mission draft Environmental Impact Statement (DEIS).

Figures D-2, D-3 and D-4 illustrate the distributions of wind speed and direction for the three tower levels noted above. The figures utilize standard meteorological convention in that each set of bars illustrates the wind speed and frequency from the indicated direction. The figures show that winds from the north through east sectors typically dominate the surface winds at all three tower levels during the 1989 launch window. Peak winds are from the north at the 54-foot level, and from the east at the 204- and 492-foot levels. At all levels the dominant winds represent onshore flow in the vicinity of the launch pads.

The average wind speeds for the 5-year period examined were 10.0, 14.3, and 17.2 mph for the 54-, 204-, and 492-foot levels respectively. Calm periods (i.e., zero wind speeds) in the Tower 313 data were treated as missing. Previous analyses of data collected at the Cape Canaveral Air Force Weather Station showed an average 4.4 percent calms during the fall season (September-November) based on 8 years of data (1961-1968).

Figure D-5 presents the maximum wind direction persistence periods by direction sector for each of the three tower levels as determined from the 5-year WINDS data set. It can be seen that the longer persistence periods at all levels are generally associated with onshore flows. The maximum persistence period for each level and its year/month of occurrence are listed in Table D-1.

The probability of onshore winds persisting for periods of 1 through 44 hours were calculated for the launch window using 492-foot wind data. These probabilities are presented in Figure D-6 which illustrates that persistence periods greater than 3 hours have less than a 50 percent probability of occurrence. Furthermore, it is seen that the maximum persistence period (44 hours) has only a 0.03 percent probability of occurrence.

Few detailed studies have been accomplished to determine the specific characteristics of the sea breeze at Cape Canaveral. A true sea breeze condition is characterized by the following:

1. Very light synoptic (e.g., gradient) winds usually associated with a high-pressure system over the region

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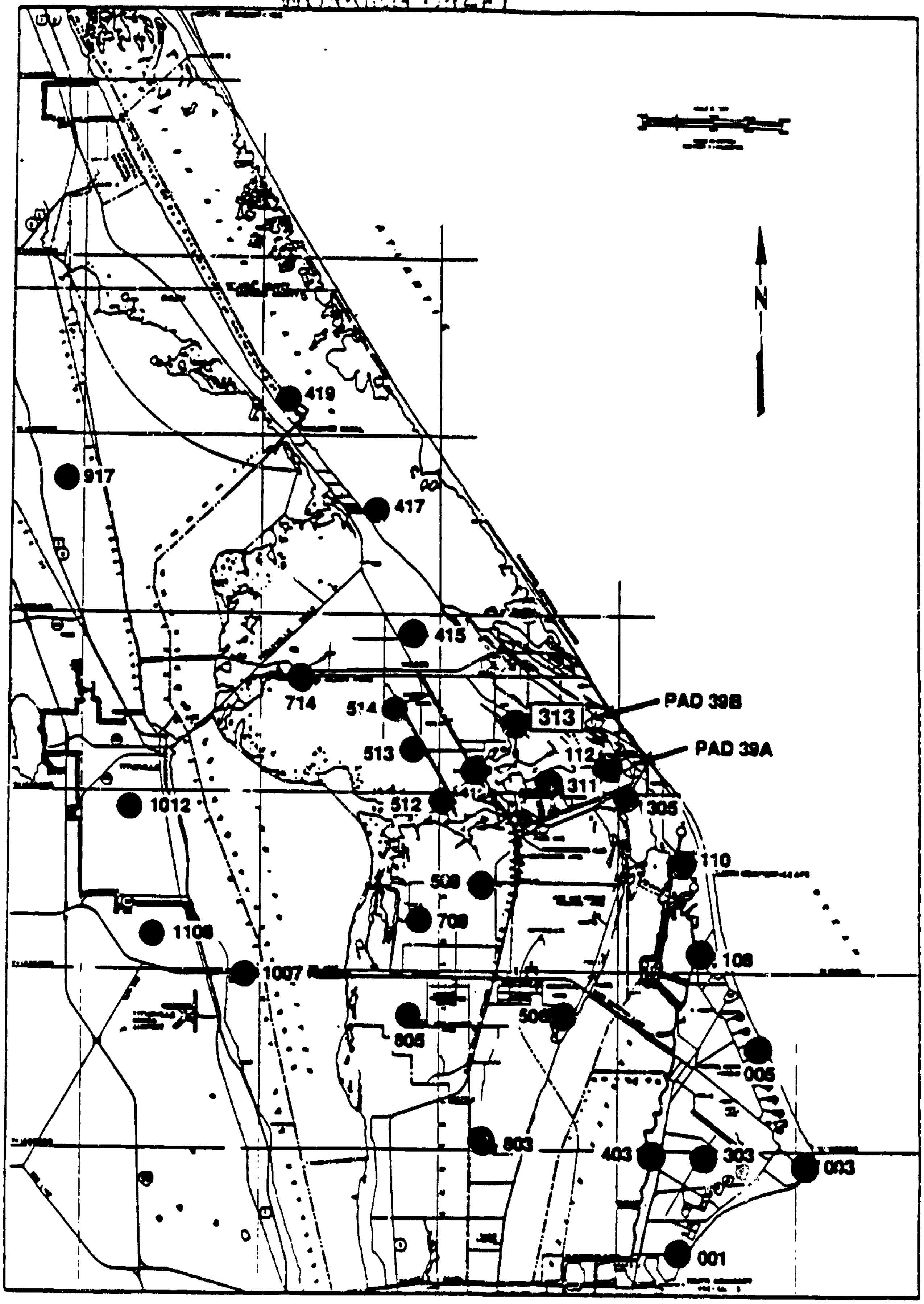

FIGURE D-1.
METEOROLOGICAL TOWER LOCATIONS

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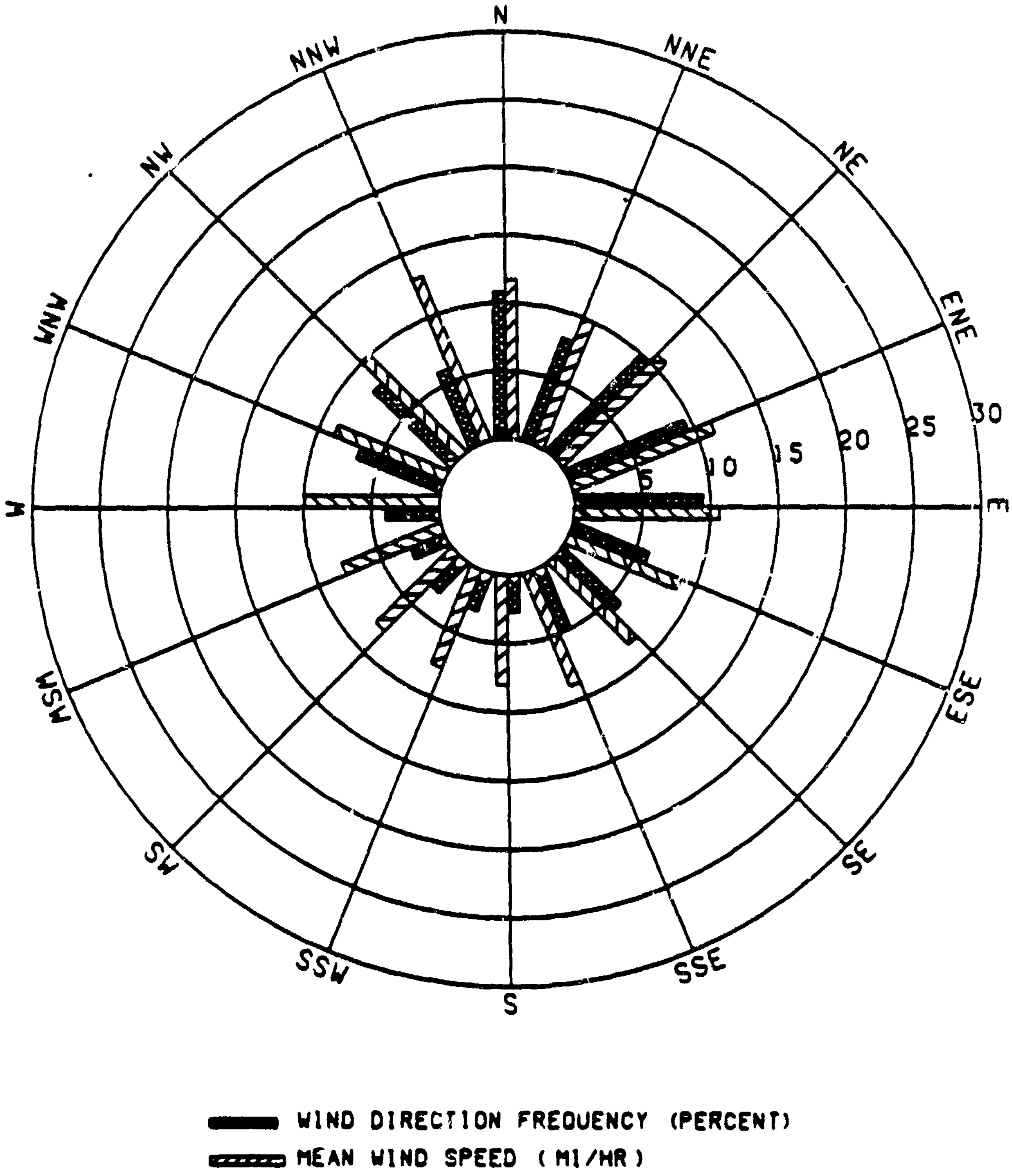

FIGURE D-2.
CAPE CANAVERAL 54-FT
5-YEAR WIND ROSE
(OCTOBER 7 THROUGH NOVEMBER 25)

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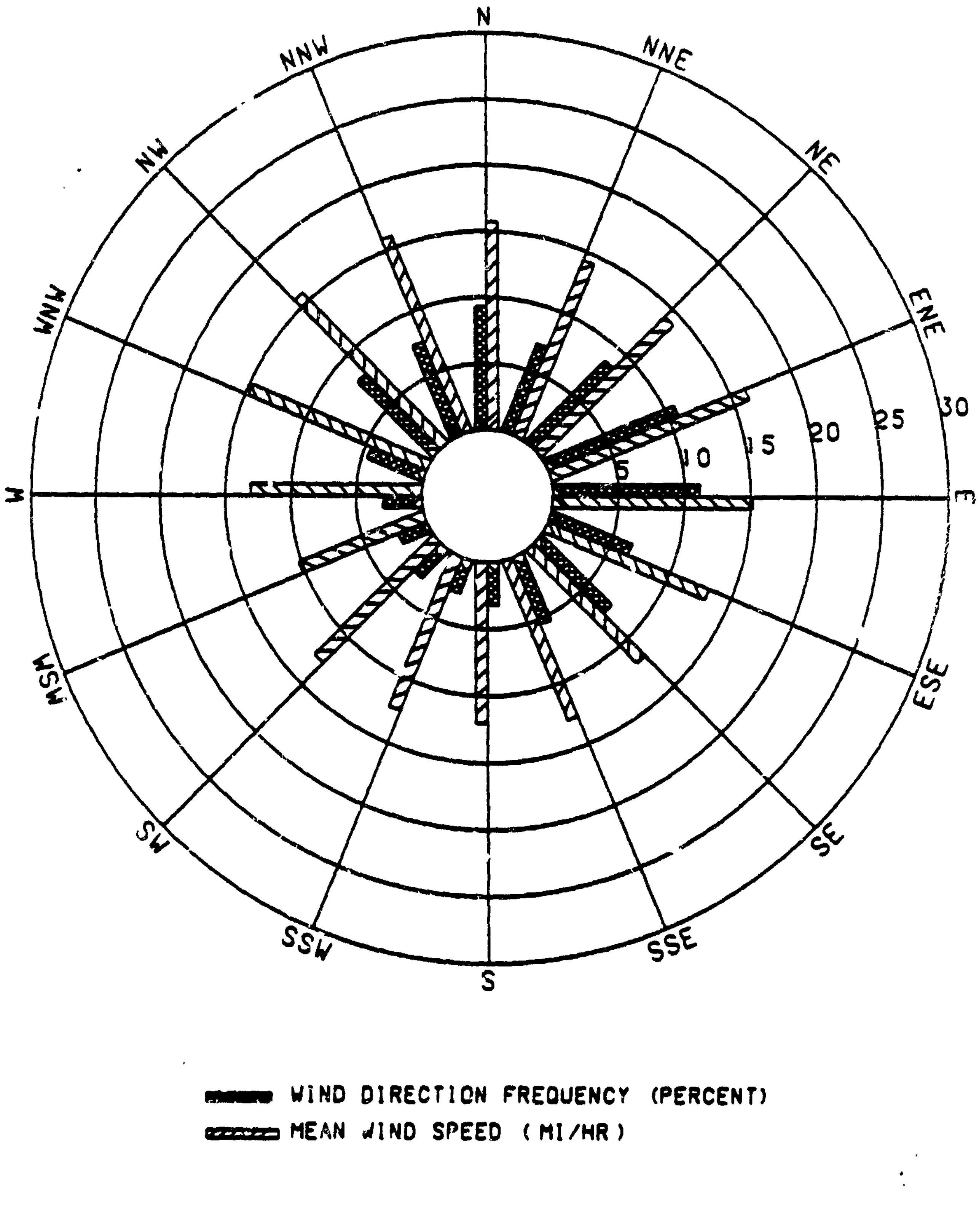

FIGURE D-3.

CAPE CANAVERAL 204-FT
5-YEAR WIND ROSE
(OCTOBER 7 THROUGH NOVEMBER 25)

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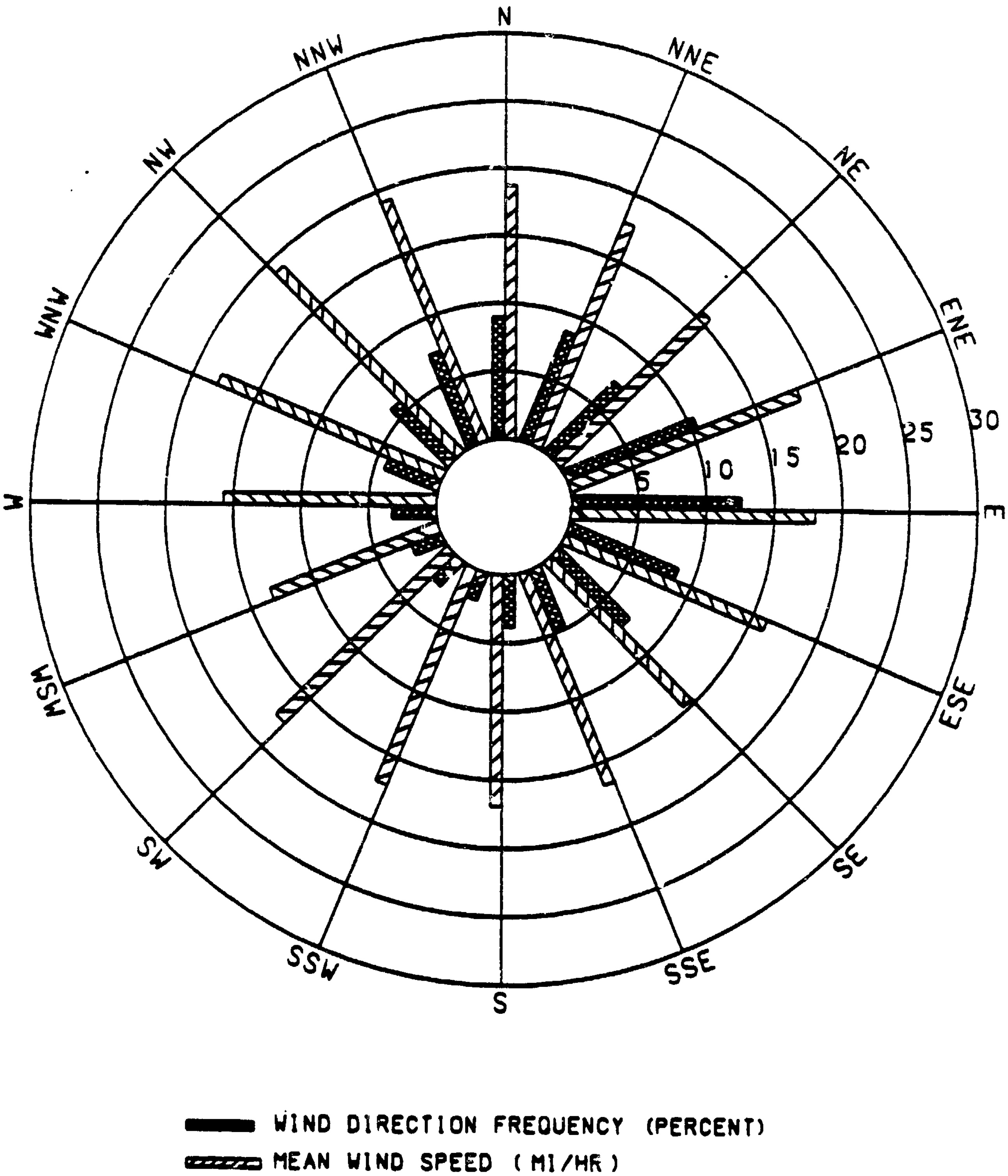
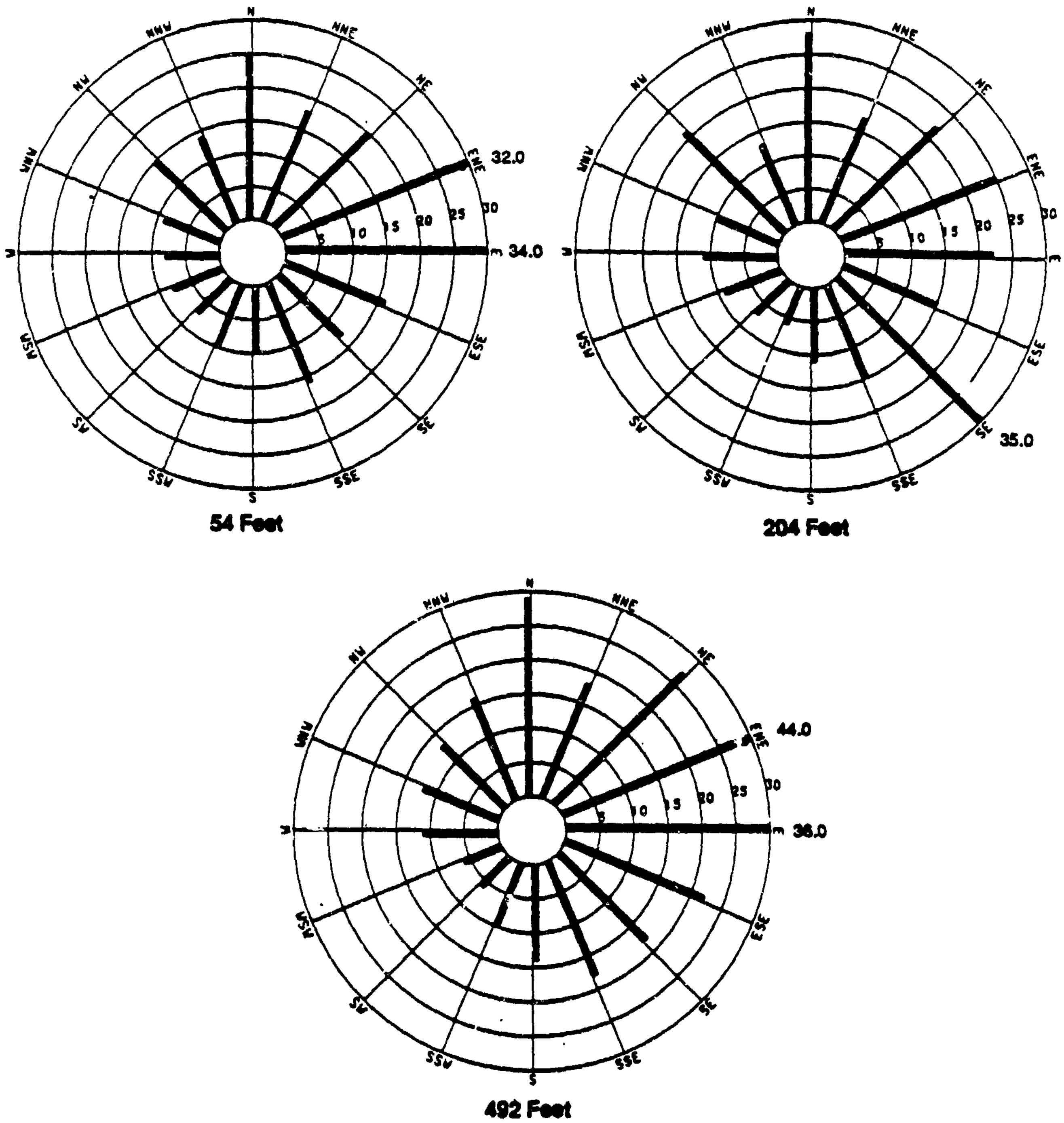


FIGURE D-4

CAPE CANAVERAL 492-FT
5-YEAR WIND ROSE
(OCTOBER 7 THROUGH NOVEMBER 25)

WORKING DRAFT



Rings extend to 30 hours only. Persistence periods greater than or equal to 30 hours are indicated by a bar out to 30 and the numerical value at the end of the bar.

FIGURE D-5.

CAPE CANAVERAL 5-YEAR MAXIMUM DIRECTIONAL WIND PERSISTENCE ROSES (HOURS) (OCTOBER 7 THROUGH NOVEMBER 25)

TABLE D-1.

**Maximum Wind Direction Persistence (Hours)
October 7 through November 25 of 1980 through 1984**

Level	Month, Year	Sector	Persistence Period (Hours)
54-foot	October 1982	E	34
204-foot	October 1984	SE	35
492-foot	October 1984	ENE	44

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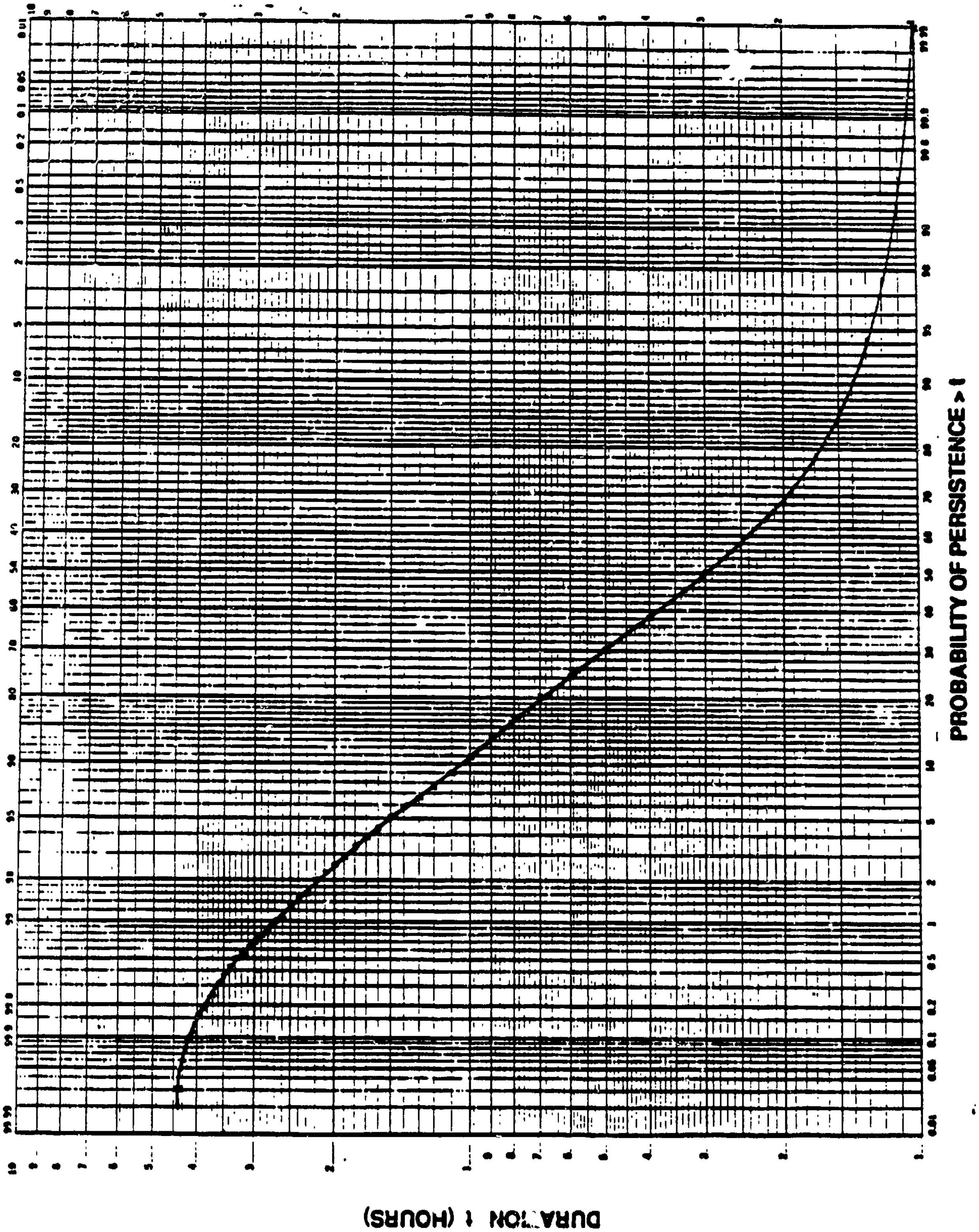

FIGURE D-6.
CAPE CANAVERAL 492-FT 5-YEAR ONSHORE WIND PERSISTENCE
(OCTOBER 7 THROUGH NOVEMBER 25)

2. Strong insolation

3. Daytime air temperatures rising above sea-surface temperatures

4. A shift of surface winds from offshore (perhaps due to a land breeze) to onshore during the day

5. The presence of a definite front or convergence zone with corresponding rising air separating surface air flows with oversea and overland trajectories

6. The presence of an unstable thermal internal boundary layer which begins at the shoreline and increases in depth with increasing distance inland

7. A discernible, though sometimes weak, return flow layer aloft (i.e., offshore wind flows)

8. The combination of onshore surface winds, an inland convergence zone, offshore winds aloft, and subsiding air over the sea completes the sea breeze circulation cell.

The Kennedy Space Center (KSC) WINDS data were reviewed to identify those days during the launch window when sufficient land-sea temperatures differential existed to support the potential for a sea breeze. A total of 47 such days were identified in the 5-year data set. Further analysis of wind data showed that 10 of these cases had the potential to be sea-breeze occurrences.

Onshore flows can also occur during gradient wind conditions. In this case, the characteristic sea breeze circulation cell does not occur and significant shears of wind speed or direction in the vertical are normally not present. Of the eight characteristics of the sea breeze noted above, only the occurrence of the thermal internal boundary layer induced by insolation and/or increasing mechanical turbulence may be present. Therefore, the effects on transport and diffusion induced by the thermal internal boundary layer may be present, but the effects of the circulation cell will not occur.

UPPER AIR DATA

Three years of KSC launch window rawinsonde data (1982-1984) were used to develop the distributions of wind direction and wind speed for the pressure levels of 850, 500, and 350 mb (millibars) (approximately 4,750, 18,250 and 27,500 feet, respectively, in the standard atmosphere). These distributions are presented in Figures D-7 through D-9. These figures demonstrate a significant change in wind direction with height. The 4,750-foot level, which approximates the gradient wind level, continues to exhibit a high-frequency of onshore flows with winds from the northeast clockwise through east dominating. The minimum value at this level is also noteworthy since, within the 3-year data period, there were no occurrences of a northwest wind. The 18,250 and 27,500-foot levels show westerly winds to be highly dominant with easterly winds occurring very infrequently.

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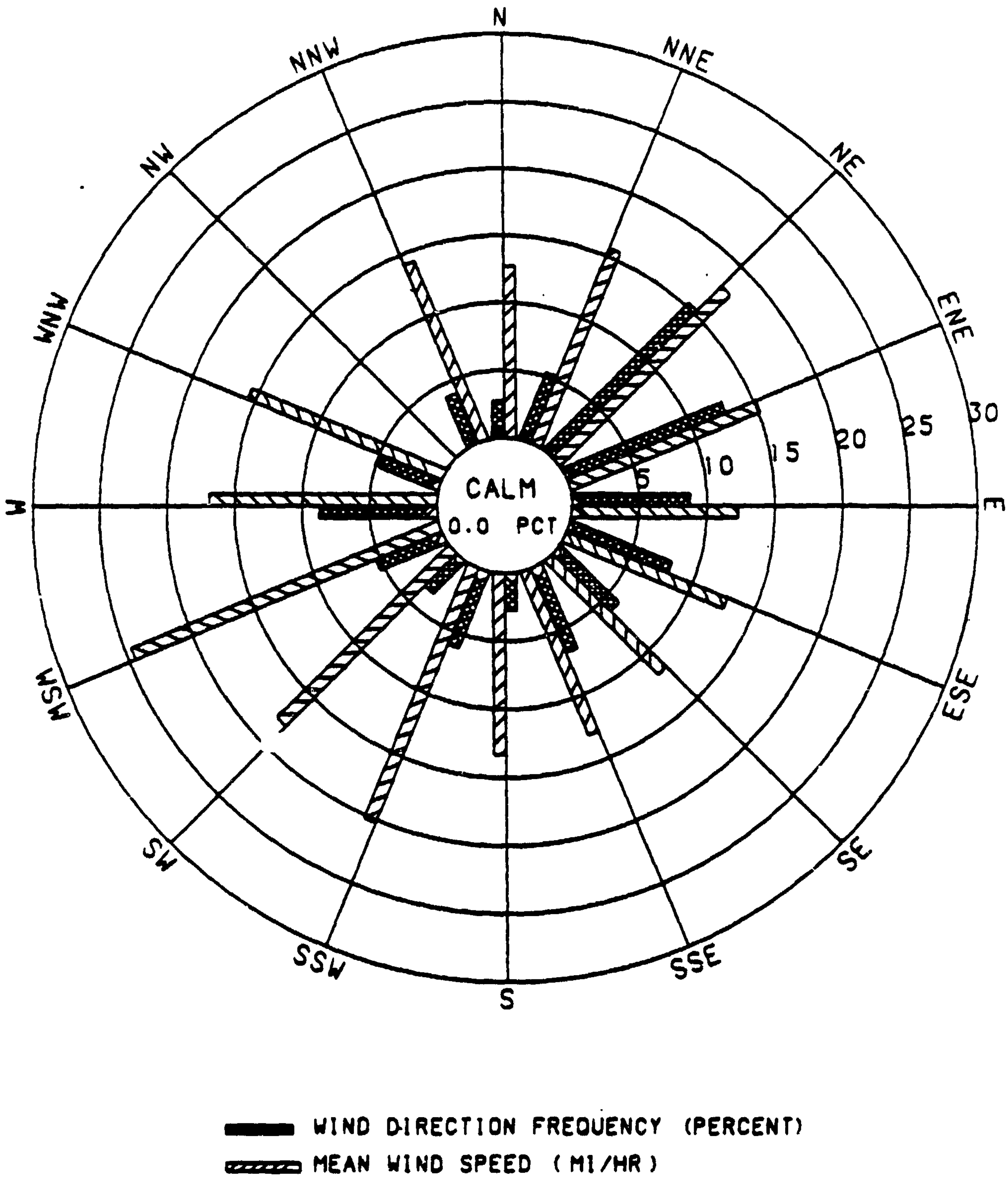
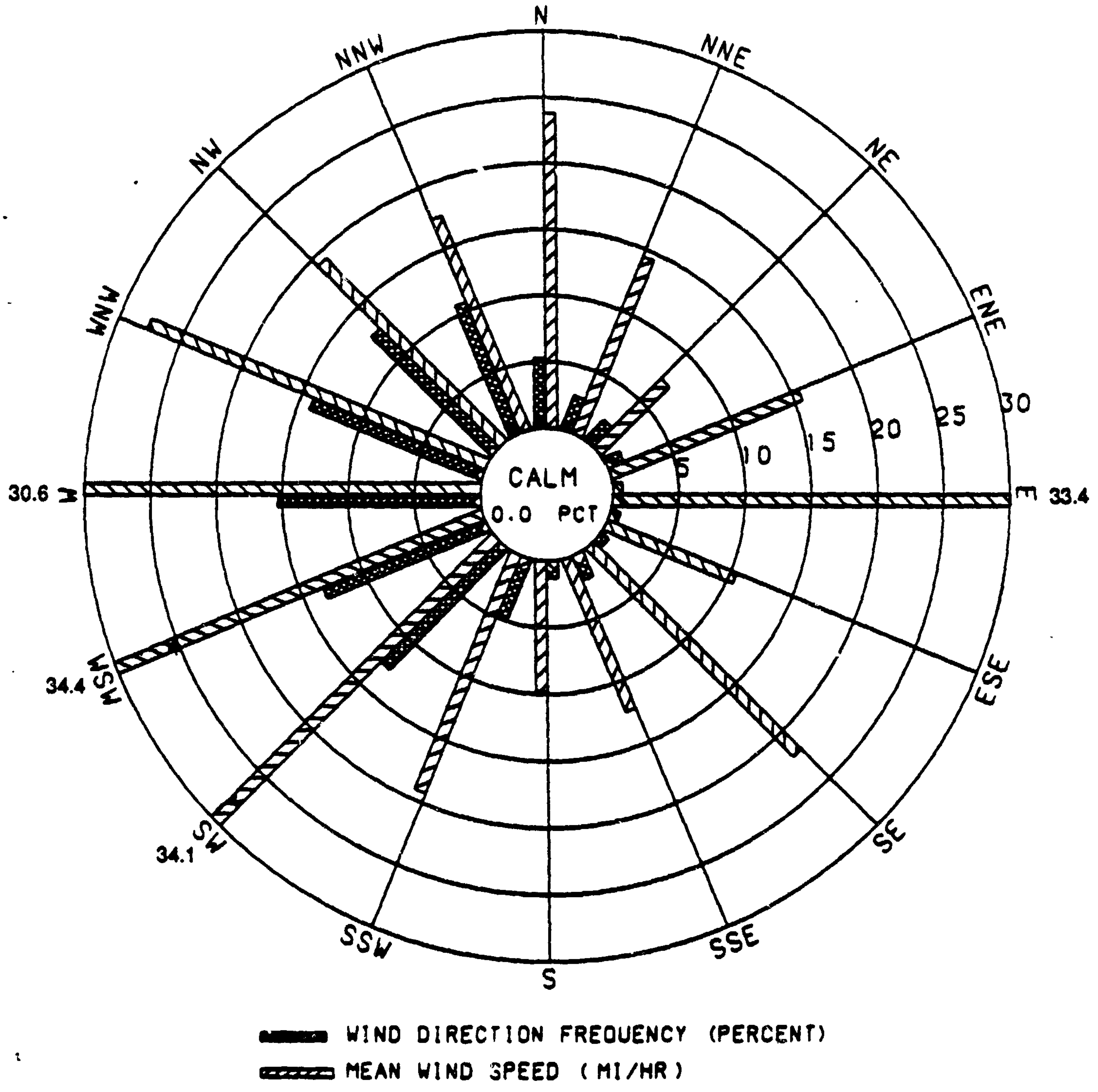


FIGURE D-7.

CAPE CANAVERAL 850-MB (4,750-FT)
3-YEAR WIND ROSE
(OCTOBER 7 THROUGH NOVEMBER 25)

WORKING DRAFT

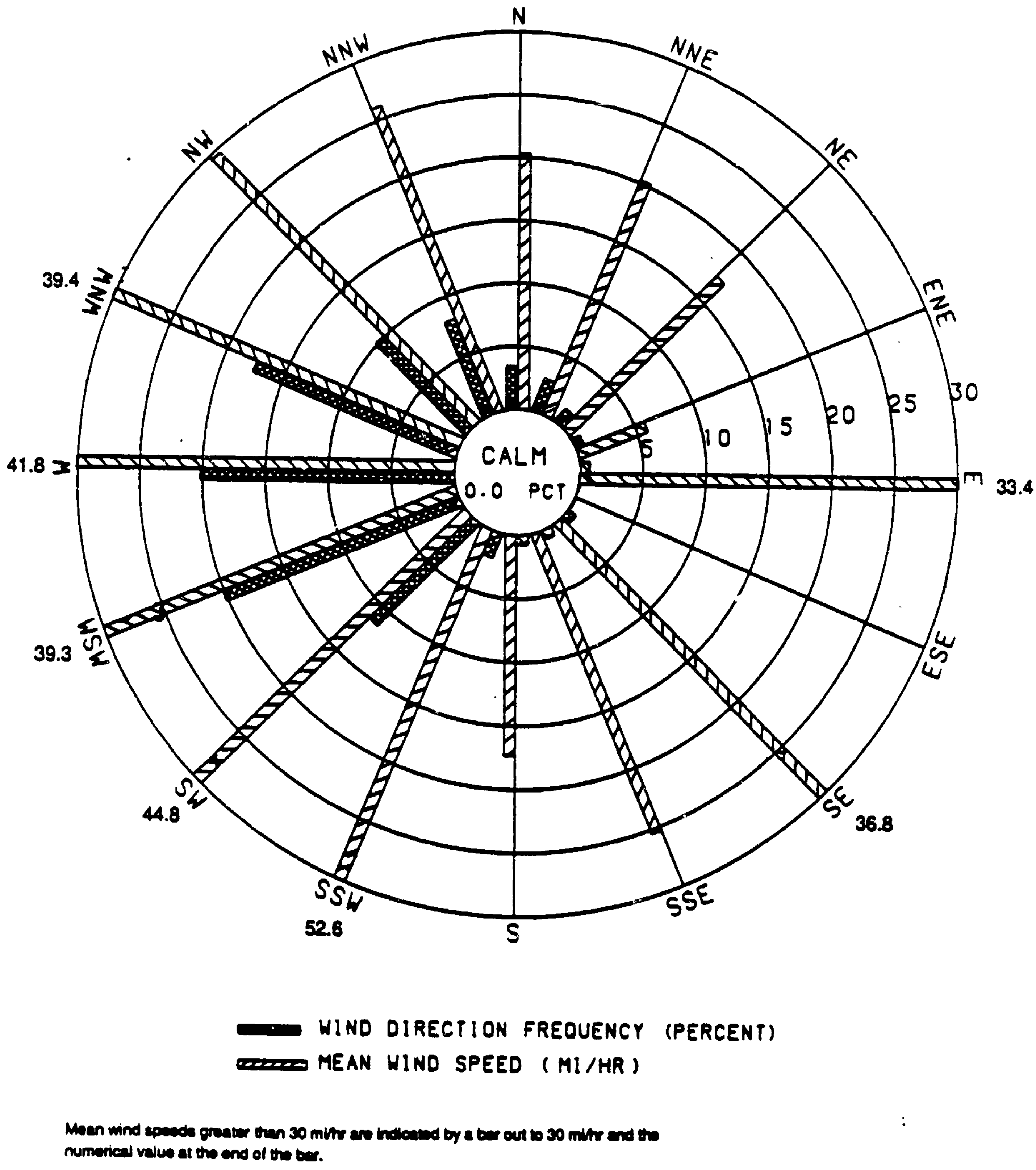


Mean wind speeds greater than 30 mi/hr are indicated by a bar out to 30 mi/hr and the numerical value at the end of the bar.

FIGURE D-8.

CAPE CANAVERAL 500-MB (18,250-FT)
3-YEAR WIND ROSE
(OCTOBER 7 THROUGH NOVEMBER 25)

WORKING DRAFT



Mean wind speeds greater than 30 mi/hr are indicated by a bar out to 30 mi/hr and the numerical value at the end of the bar.

FIGURE D-9.

CAPE CANAVERAL 350-MB (26,500-FT)
3-YEAR WIND ROSE
(OCTOBER 7 THROUGH NOVEMBER 25)

The average wind speeds for the 3-year data period are also seen to change with height. At 4,750 feet, average wind speed is 15.7 mph, increasing to 25.5 and 37.2 mph at 18,250 feet and 27,500 feet respectively. There were no reports of calm winds within the 3-year data period at any of the levels analyzed.

CLIMATOLOGICAL DATA

Historical climatological data for KSC can be found in Table D-2.

TABLE D-2. HISTORICAL CLIMATOLOGICAL DATA FOR THE CAPE CANAVERAL - MERRITT ISLAND LAND MASS

	J	F	M	A	M	J	J	A	S	O	N	D	Ann	Yr Rcd	
Temperature (°C)															
Highest	28.9	30.6	31.7	34.4	35.0	36.7	35.6	35.6	34.4	32.8	30.6	29.4	36.7	11	a
Mean daily max	20.4	20.4	23.1	25.7	28.0	29.9	30.9	30.8	29.9	27.3	24.1	21.3	26.0	11	a
Mean daily min	10.9	10.5	13.7	16.6	19.5	21.9	22.8	22.8	22.8	20.1	15.4	11.8	17.4	11	a
Lowest	-3.3	-3.9	-1.7	1.1	6.7	13.9	13.9	18.3	15.0	4.4	-0.6	-3.9	-3.9	11	a
Mean no. of days															
Max temp >32°C	0	0	0	0	*	4	6	6	1	*	0	0	17	14	b
Min temp < 0°C	*	*	*	0	0	0	0	0	0	0	*	*	1	14	b
Precipitation (no snowfall)															
Mean (cm)	6.60	7.37	7.37	3.56	7.37	13.97	12.95	12.95	17.53	11.94	8.13	5.08	114.8	25	a
Mean no. of days >1.27 cm	2	2	2	1	2	3	4	3	4	3	2	1	31	25	a
Relative humidity (%)															
Mean	79.6	76.7	75.5	72.9	76.9	81.0	81.4	82.5	81.4	76.6	77.2	79.0	78.4	11	a

Maximum 24-hour precipitation 17.42 centimeters (6.86 inches) (records kept for 15 years)b

Flying weather - annual percentages for various categories

A. Ceiling >305 meters and visibility >5 kilometers — 97.6% b

B. Ceiling 152 to 274 meters and visibility >1.6 kilometers or visibility >1.6 kilometers but <5 kilometers and ceiling >152 meters — 1.5% b

C. Ceiling <152 meters and/or visibility <1.6 kilometers — 0.9% b

a Source: Cape Canaveral Air Force Station

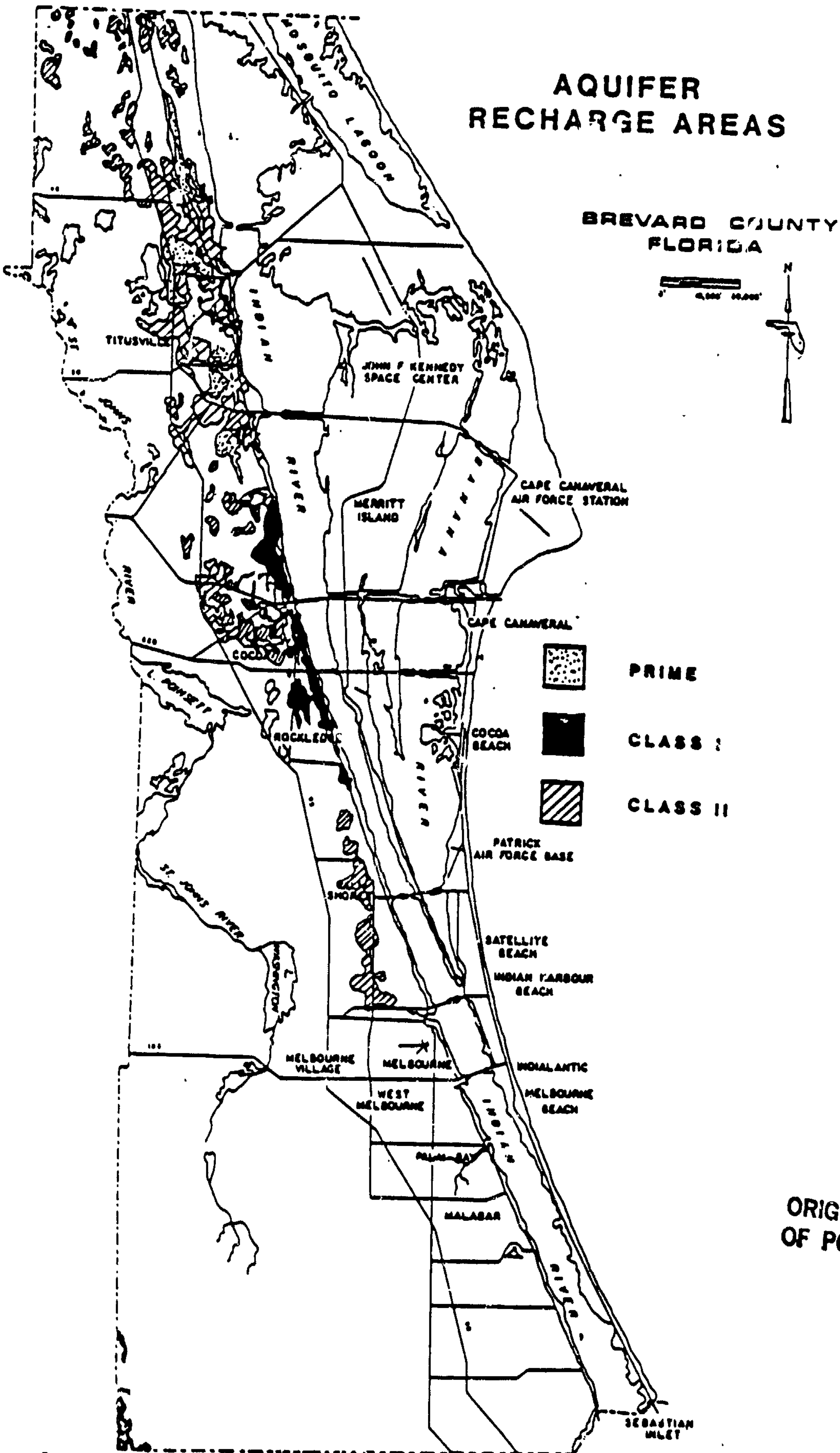
b Source: National Oceanographic and Atmospheric Administration

Note: Asterisk denotes less than 1 day

Source: KSC Environmental Resources Document, 1986.

APPENDIX D-2

AQUIFER RECHARGE AREAS AND POTABLE WATER FACILITIES IN THE VICINITY OF KSC



Source: Brevard County, Fl., Comprehensive Plan, 1988.

FIGURE D-10. AQUIFER RECHARGE AREAS

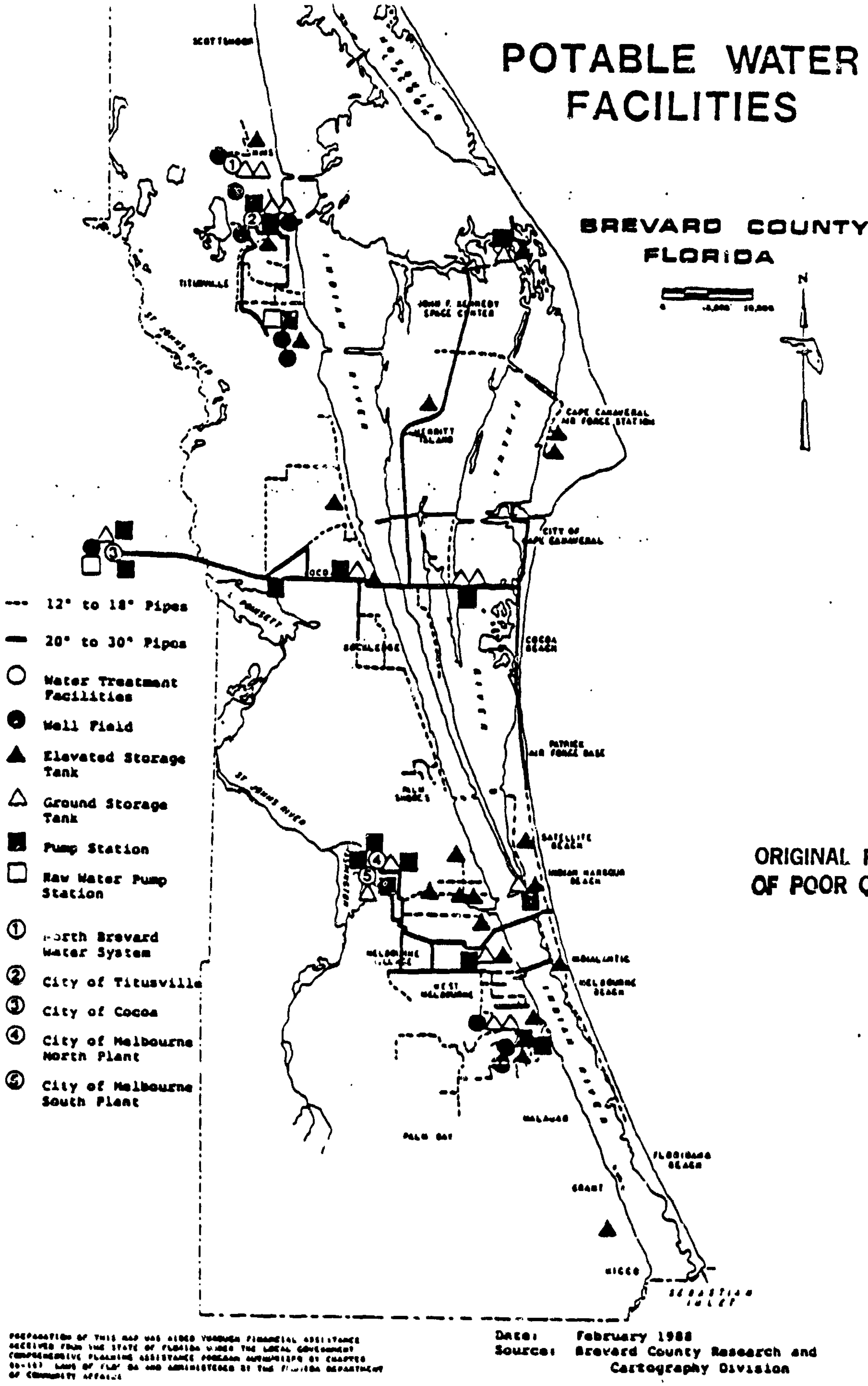


FIGURE D-11. POTABLE WATER FACILITIES

TABLE D-3. POTABLE WATER FACILITIES

NAME	OWNERSHIP	UNITS CAPACITY	UNIC. AREA	"RESTRICTED" SERVICE AREA	COMMENTS
1 - City of Cocoa	PUBLIC	40.0 MGD	BOTH	NO	
2 - City of Melbourne - North Plant	PUBLIC	4.0 MGD	BOTH	NO	
3 - City of Melbourne - South Plant	PUBLIC	16.0 MGD	BOTH	NO	
4 - City of Titusville	PRIVATE	16.0 MGD	BOTH	NO	
5 - General Development Utilities - Malabar	PRIVATE	3.0 MGD	INC	NO	PSC REGULATED
6 - Pinewood Mobile Village	PRIVATE	0.052 MGD	UNINC	YES	TRAILER PARK
7 - Tiki Haven Mobile Park	PRIVATE	0.043 MGD	UNINC	YES	TRAILER PARK
8 - Northgate Mobile Ranch	PRIVATE	0.288 MGD	UNINC	YES	TRAILER PARK & SUBDIVISION
9 - North Brevard Water System	PRIVATE	1.1 MGD	UNINC	NO	
10 - Oak Park Mobile Park	PRIVATE	0.052 MGD	UNINC	YES	TRAILER PARK
11 - Mobile Manor Mobile Park	PRIVATE	0.144 MGD	UNINC	YES	TRAILER PARK
12 - Hibiscus Mobile Park	PRIVATE	0.036 MGD	UNINC	YES	TRAILER PARK
13 - New Haven Mobile Park	PRIVATE	0.064 MGD	UNINC	YES	TRAILER PARK
14 - Evergreen Mobile Park	PRIVATE	0.065 MGD	INC	YES	TRAILER PARK
15 - Enchanted Lake Estates	PRIVATE	0.086 MGD	INC	YES	TRAILER PARK (MALABAR)
16 - Camelot Mobile Park	PRIVATE	0.080 MGD	INC	YES	TRAILER PARK (MALABAR)
17 - Southern Comfort Mobile Park	PRIVATE	0.125 MGD	UNINC	YES	TRAILER PARK
18 - Indian River Shores Mobile Park	PRIVATE	0.050 MGD	UNINC	YES	TRAILER PARK
- Snug Harbor Mobile Park	PRIVATE	0.337 MGD	UNINC	YES	MOBILE HOME SUBDIVISION
20 - Florida Cities Water Company	PRIVATE	1.0 MGD	UNINC	YES	PSC REGULATED
21 - Rivergrove II Mobile Park	PRIVATE	0.072 MGD	UNINC	YES	TRAILER PARK
22 - Rivergrove I Mobile Park	PRIVATE	0.072 MGD	UNINC	YES	TRAILER PARK
23 - Ste Adele	PRIVATE	0.030 MGD	UNINC	YES	CONDOMINIMUM
24 - Riverview Mobile Park	PRIVATE	0.050 MGD	UNINC	YES	TRAILER PARK
25 - Breezeway Mobile Park	PRIVATE	0.030 MGD	UNINC	YES	TRAILER PARK
26 - Cove of South Beaches	PRIVATE	0.020 MGD	UNINC	YES	CONDOMINIUM
27 - Cove of Casseekee	PRIVATE	0.048 MGD	UNINC	YES	CONDOMINIUM
28 - South Brevard Water Co-op	CO-OP	0.080 MGD	UNINC	YES	SUBDIVISIONS & CONDOMINIUMS
29 - Wayfara Restaurant	PRIVATE	0.020 MGD	UNINC	YES	FOOD SERVICE
30 - Stuckey's Pecan Shoppe	PRIVATE	0.020 MGD	UNINC	YES	FOOD SERVICE & RV PARK
31 - Holiday Village R.V. Park	PRIVATE	0.030 MGD	UNINC	YES	RV PARK
32 - The Dugout Bar & Grill	PRIVATE	0.001 MGD	UNINC	YES	BAR & FOOD SERVICE
33 - Harold's Place	PRIVATE	0.001 MGD	UNINC	YES	BAR & FOOD SERVICE
34 - Hick's Riverview Mobile Park	PRIVATE	0.058 MGD	INC	YES	TRAILER PARK
35 - Palm Shores R.V. Park	PRIVATE	0.058 MGD	UNINC	YES	RV PARK
36 - D.O.T. - Southbound	PUBLIC	0.048 MGD	UNINC	YES	REST AREA
37 - D.O.T. - Northbound	PUBLIC	0.048 MGD	UNINC	YES	REST AREA
38 - Harris Corporation	PRIVATE	0.045 MGD	UNINC	YES	INDUSTRY
39 - Summits Landing	PRIVATE	0.20 MGD	UNINC	YES	MARINA
40 - San Sebastian	PRIVATE	0.100 MGD	UNINC	NO	PSC REGULATED
41 - South Shores	PRIVATE	0.040 MGD	UNINC	YES	PUD
42 - Farnum Golf & Ocean Club	PRIVATE	0.500 MGD	UNINC	YES	PUD
43 - Chuck's Steak House	PRIVATE	0.040 MGD	UNINC	YES	FOOD SERVICE
44 - Long Point Park	PUBLIC	0.216 MGD	UNINC	YES	COUNTY PARK
45 - Sebastian Inlet	PUBLIC	0.086 MGD	UNINC	YES	STATE PARK

Source: Brevard County Office of Natural Resources 1987

C-4

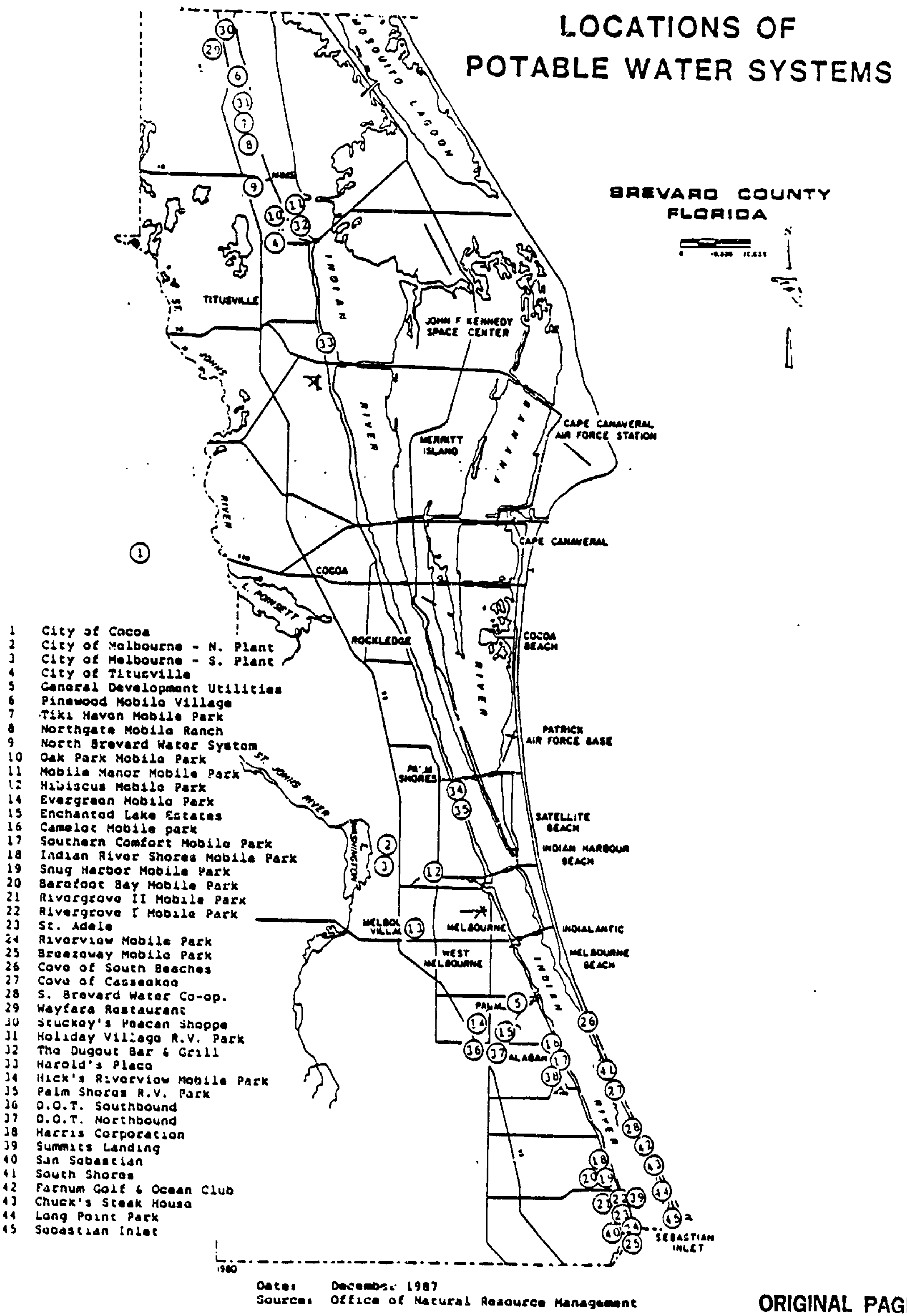


FIGURE D-12. LOCATIONS OF POTABLE WATER SYSTEMS

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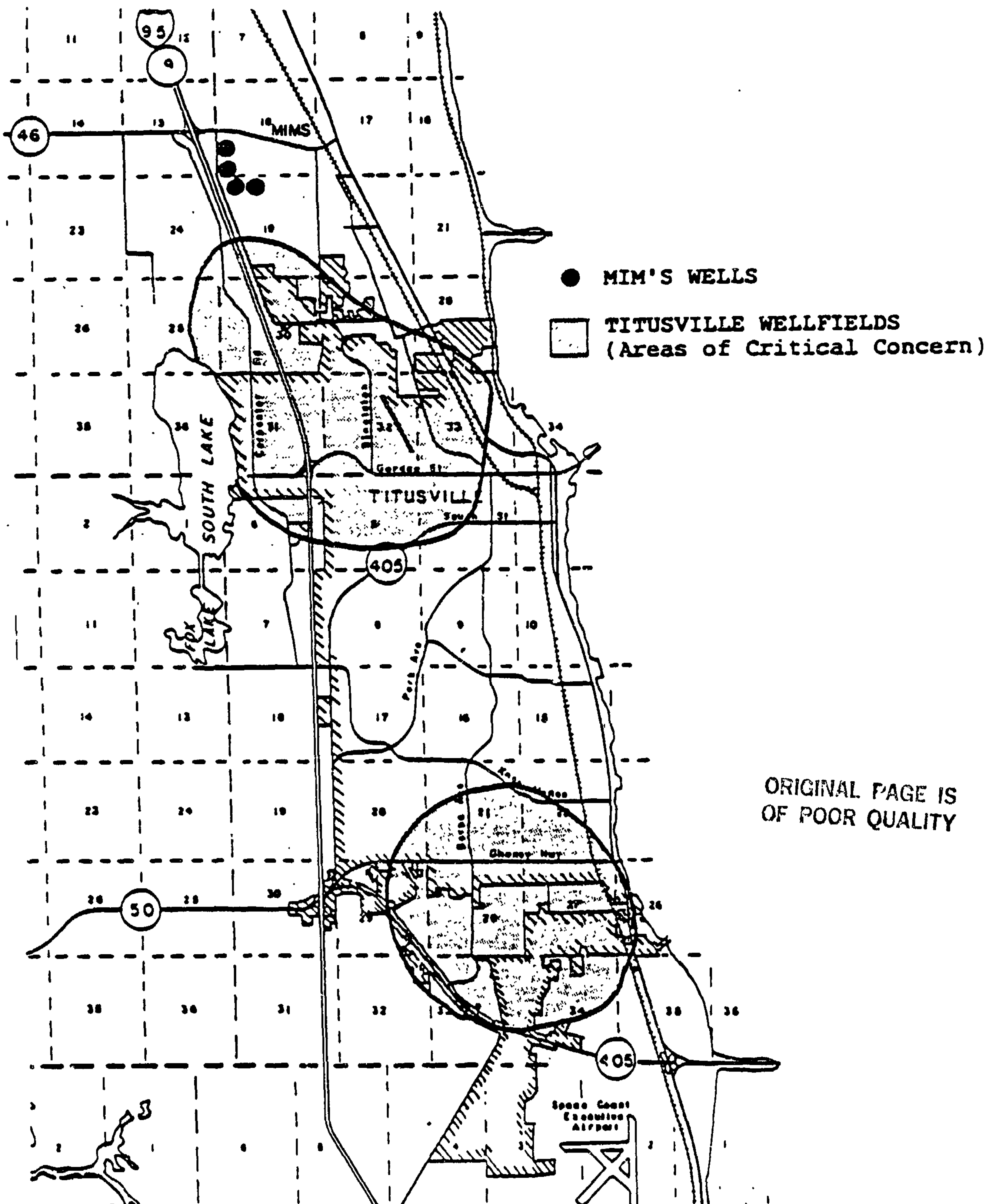
CITY OF TITUSVILLE & MIM'S WELLFIELDS

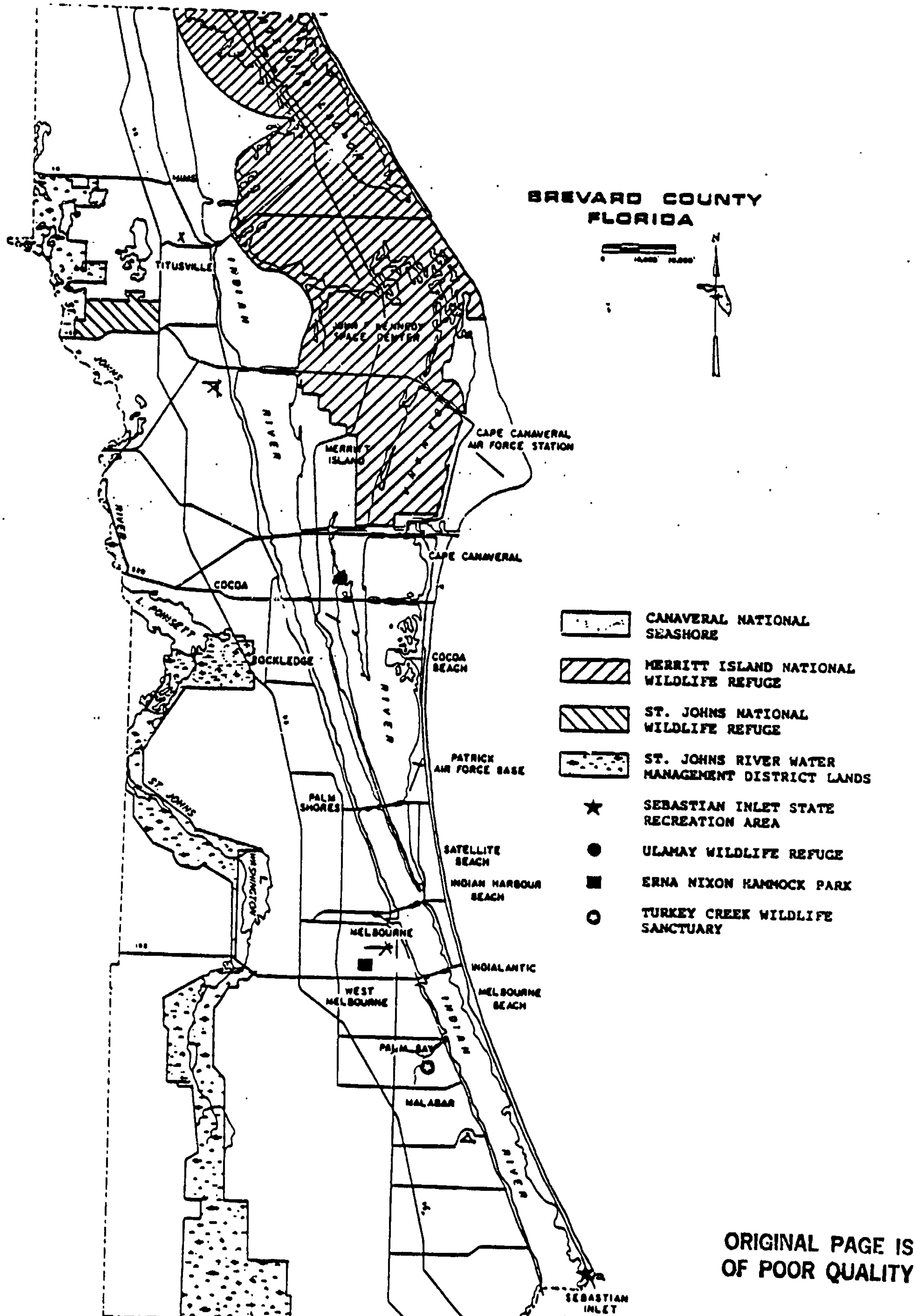


Source: Brevard County, Fl., Comprehensive Plan, 1988.

FIGURE D-13. CITY OF TITUSVILLE & MIM'S WELLFIELDS

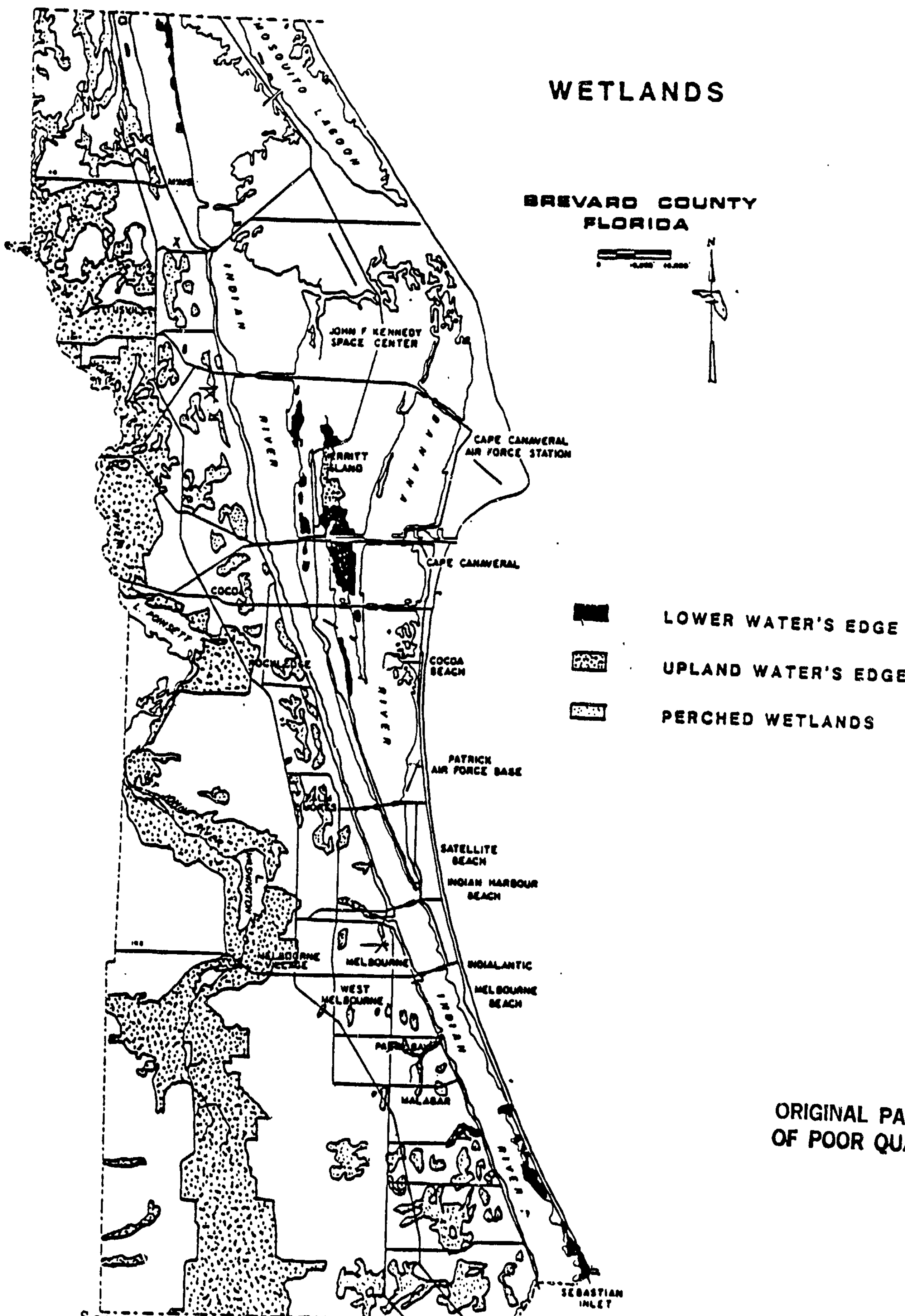
APPENDIX D-3

ADDITIONAL CHARACTERISTICS OF BREVARD COUNTY NEAR KSC



Source: St. Johns River Water Management Dist. 1988
Brevard County Comprehensive Plan 198?

FIGURE D-14. BREVARD COUNTY CONSERVATION AREAS D-20



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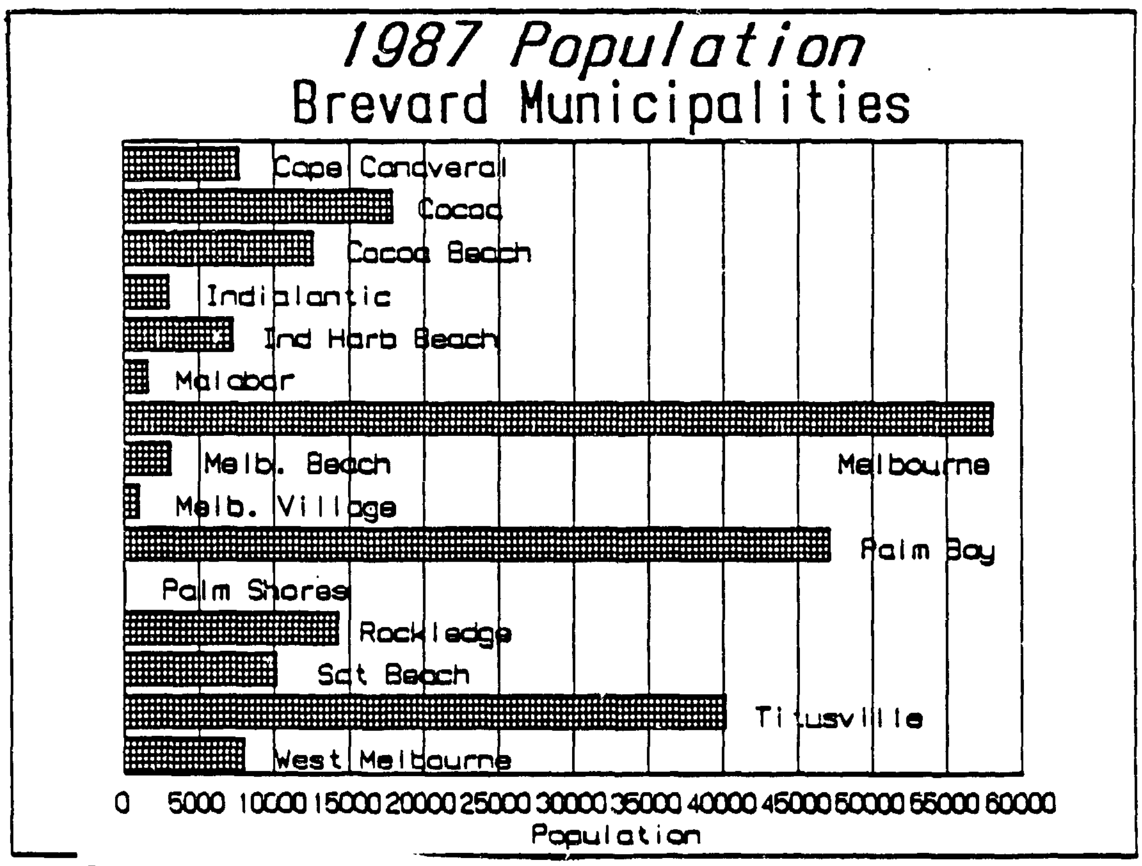
Source: Brevard County, Fl., Comprehensive Plan, 1988.

FIGURE D-15. WETLANDS

TABLE D-17. POPULATION OF BREVARD CITIES

City	1980	1987	# Change	% Change
BREVARD	**272,959**	**371,735**	**98,776**	**36.2**
Cape Canaveral	5,733	7,744	2,011	35.1
Cocoa	16.096	17,908	1,812	11.2
Cocoa Beach	10,926	12,638	1,712	15.7
Indialantic	2,883	3,029	146	5.1
Indian Harbour Beach	5,967	7,329	1,362	22.9
Malabar	1,118	1,589	471	42.1
Melbourne	46,536	58,116	11,580	24.9
Melbourne Beach	2,713	3,094	381	14.0
Melbourne Village	1,004	1,042	38	3.8
Palm Bay	18,560	47,096	28,536	153.8
Palm Shores	77	90	13	16.9
Rockledge	11,877	14,260	2,383	20.0
Satellite Beach	9,163	10.167	1,004	11.0
Titusville	31,910	40,213	3,303	26.0
West Melbourne	5,078	8,067	2,989	58.9
UNINCORPORATED	103,318	139,353	36,035	34.9

SOURCE: University of Florida, BEBR, Florida Estimates of Population 1986.



Source: Brevard County Data Abstract, 1988.

FIGURE D-16. POPULATION BY MUNICIPALITY, 1987

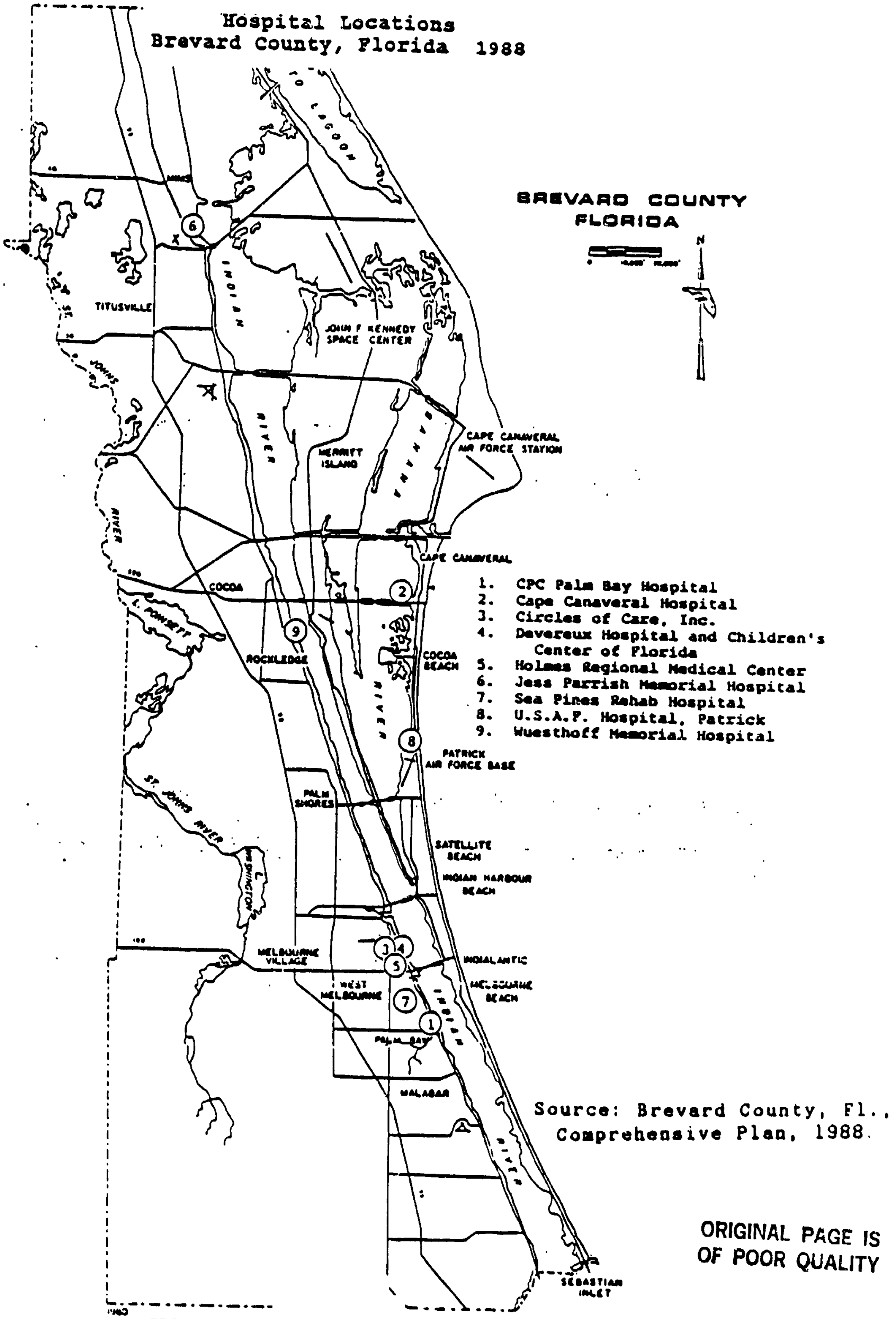
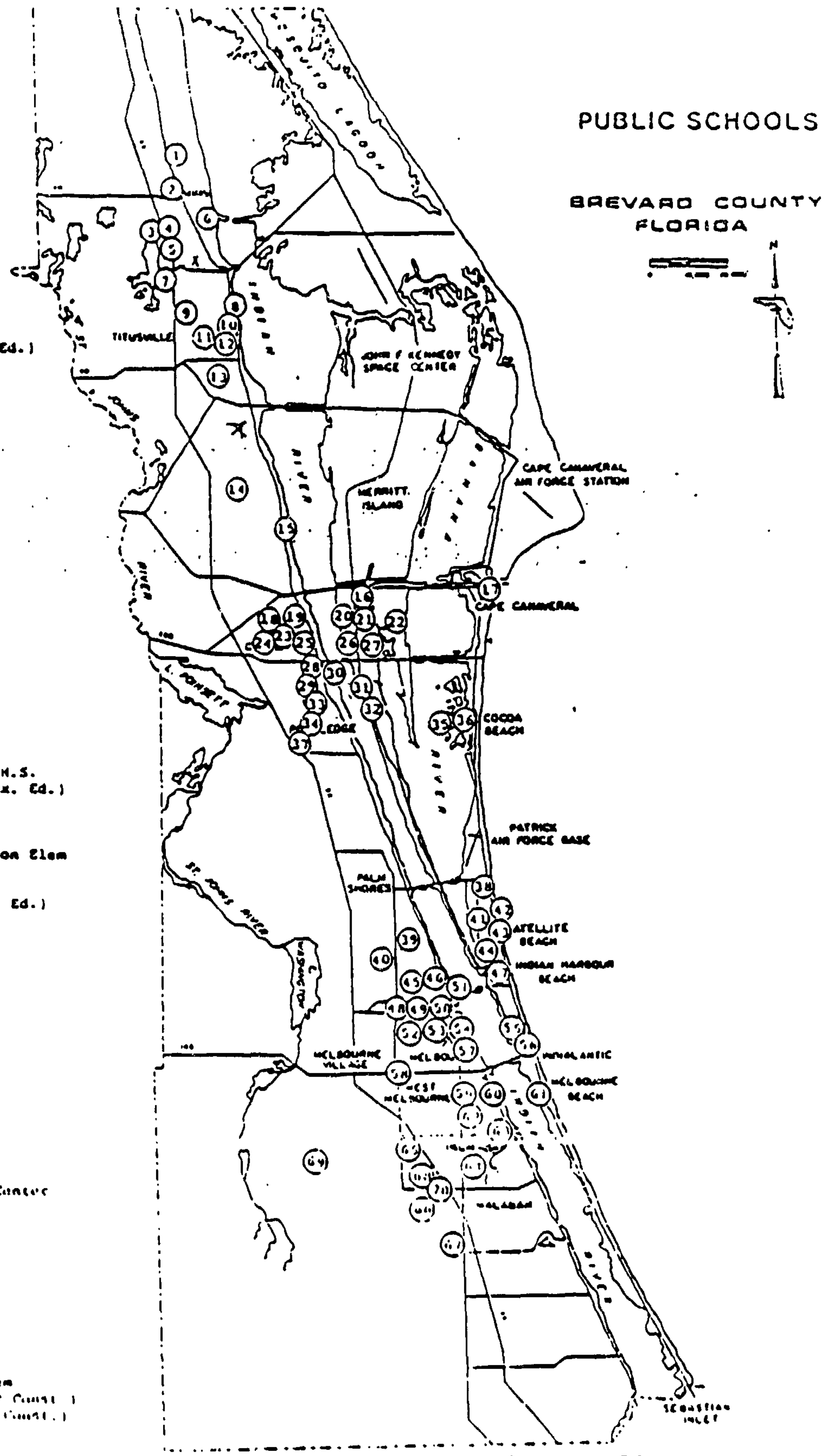


FIGURE D-17. HOSPITAL LOCATIONS

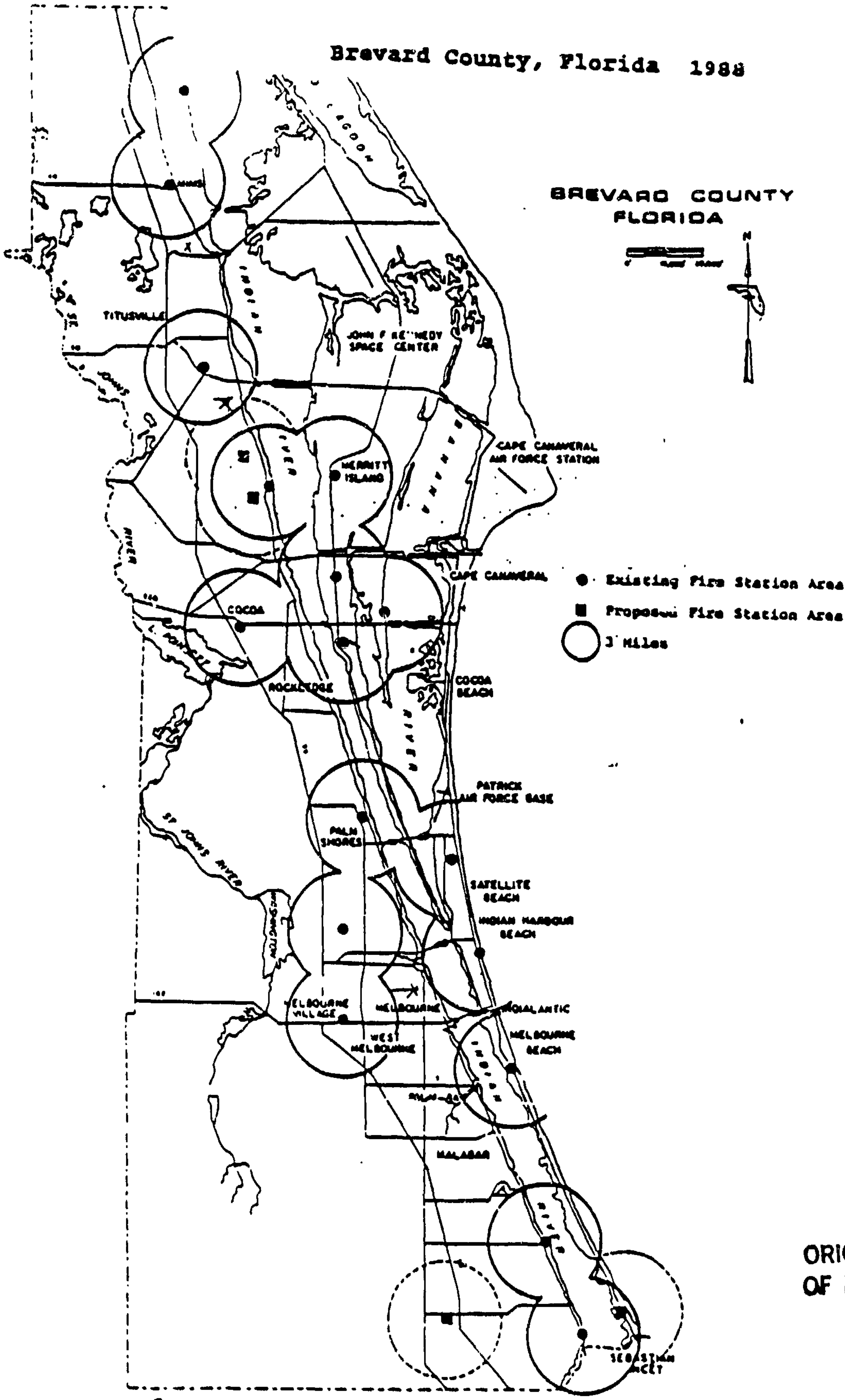


LEGEND

1. Pinewood Elem
2. Mims Elem
3. Oakpark Elem
4. James Madison M.S.
5. Astronaut H.S.
6. Normandy School (Ex. Ed.)
7. South Lake Elem
8. Titusville H.S.
9. Apollo Elem
10. Riverview Elem
11. Andrew Jackson M.S.
12. Coquina Elem
13. Imperial Estates Elem
14. Challenger 7 Elem
15. Fairglen Elem
16. Lewis Carroll Elem
17. Capeview Elem
18. Cocoa H.S.
19. Cambridge Elem
20. Gardendale Elem
21. Merritt Island H.S.
22. Audubon Elem
23. Clearlake M.S.
24. Saturn Elem
25. Pineda Elem
26. Mila Elem
27. Edgewood Jr. H.S.
28. McNair M.S.
29. Golfview Elem
30. Rockledge H.S.
31. Tropical Elem
32. Thomas Jefferson Jr. H.S.
33. Central Pine Grove (Ex. Ed.)
34. J.F. Kennedy M.S.
35. Cocoa Beach H.S.
36. Roosevelt M.S.
37. Hans Christian Anderson Elem
38. Seapark Elem
39. Sherwood Elem
40. South Pine Grove (Ex. Ed.)
41. Holland Elem
42. Satellite H.S.
43. DeLaura Jr. H.S.
44. Surfside Elem
45. Johnson Jr. H.S.
46. Dr. W.J. Creel Elem
47. Ocean Breeze Elem
48. Sabal Elem
49. Croton Elem
50. Eau Gallie H.S.
51. South Area Community Education Center
52. Roy Allen Elem
53. Harbor City Elem
54. Central Jr. H.S.
55. Indialantic Elem
56. Hoover Jr. H.S./Adult Community Education Center
57. Melbourne H.S.
58. Meadowlane Elem
59. University Park Elem
60. Stone M.S.
61. Gemini Elem
62. Palm Bay H.S.
63. Palm Bay Elem
64. Port Malabar Elem
65. Lockmar Elem
66. John Turner Elem
67. Columbia Elem
68. Christa McAuliffe Elem
69. Discovery Elem (Under Const.)
70. S.W. Jr. H.S. (Under Const.)

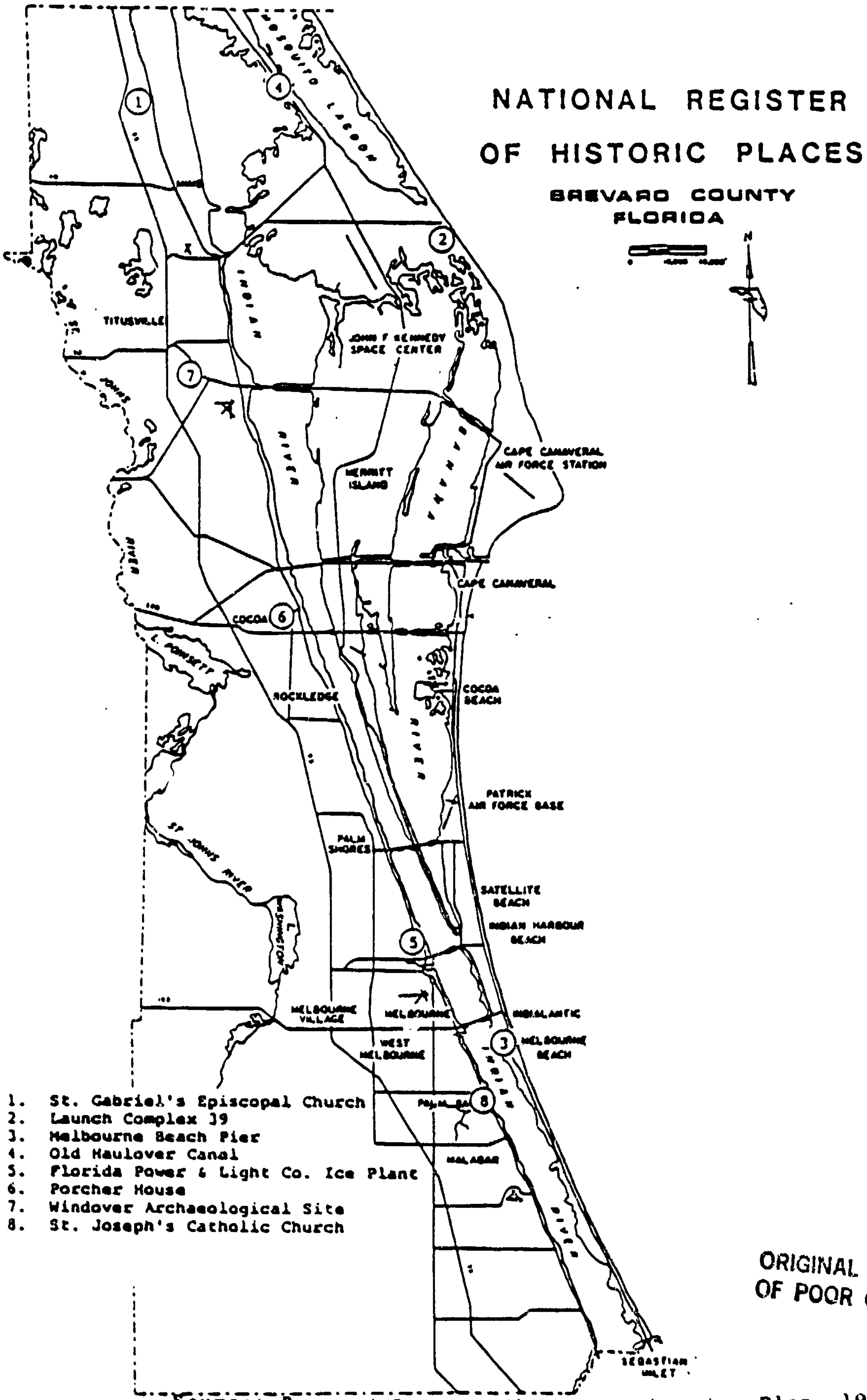
Source: Brevard County, Fl., Comprehensive Plan, 1988.

FIGURE D-18. LOCATION OF PUBLIC EDUCATIONAL FACILITIES



Source: Brevard County, Fl., Comprehensive Plan, 1988.

FIGURE D-19. FIRE STATIONS AND GEOGRAPHIC SERVICE AREAS FOR EMERGENCY SERVICES

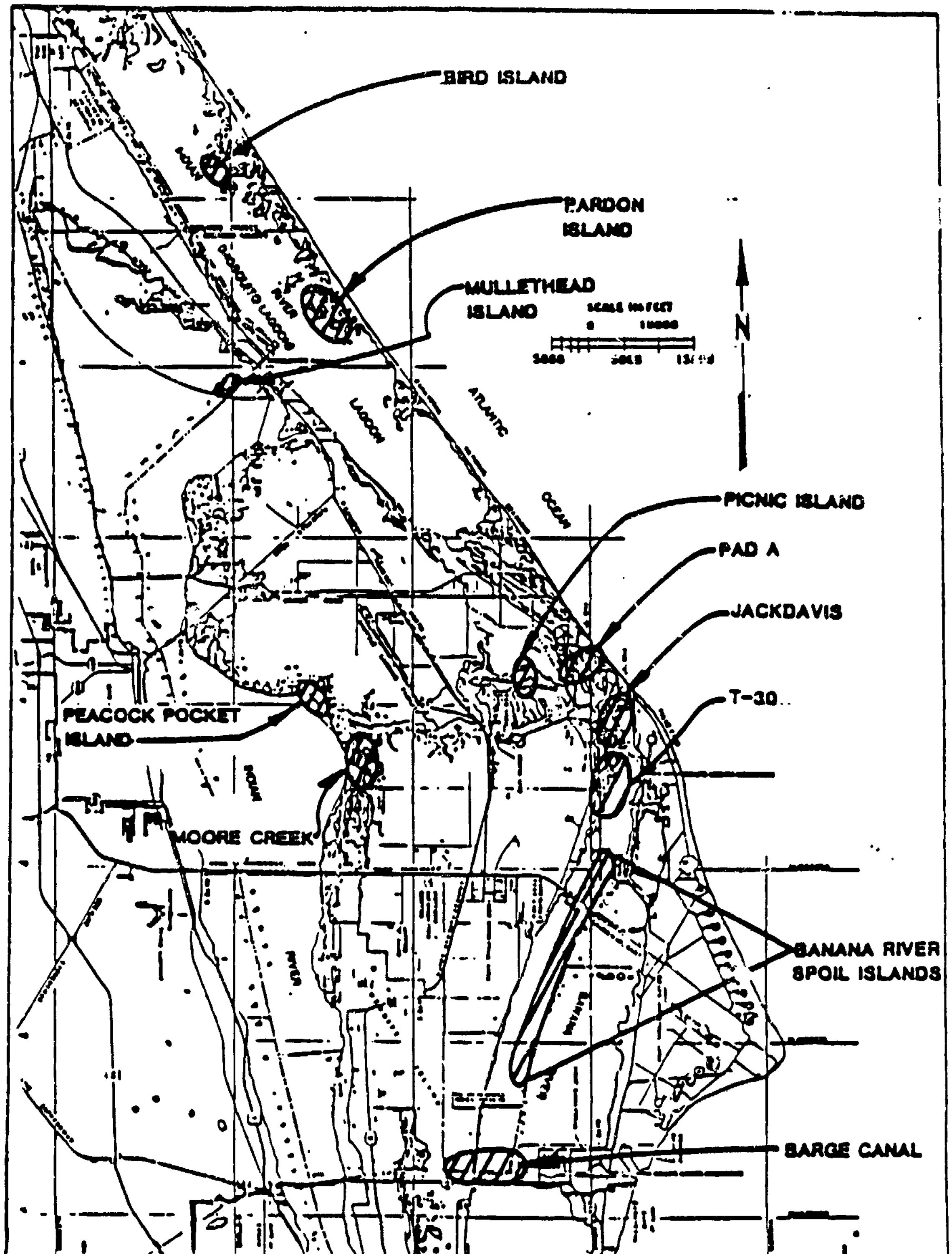


Source: Brevard County, Fl., Comprehensive Plan, 1988.

FIGURE D-20. NATIONAL REGISTER OF HISTORIC PLACES

APPENDIX D-4

ENDANGERED AND THREATENED SPECIES AT KSC



Source: KSC Environmental Resources Document, 1986.

FIGURE D-21. APPROXIMATE LOCATIONS OF COLONIAL NESTING BIRD AREAS

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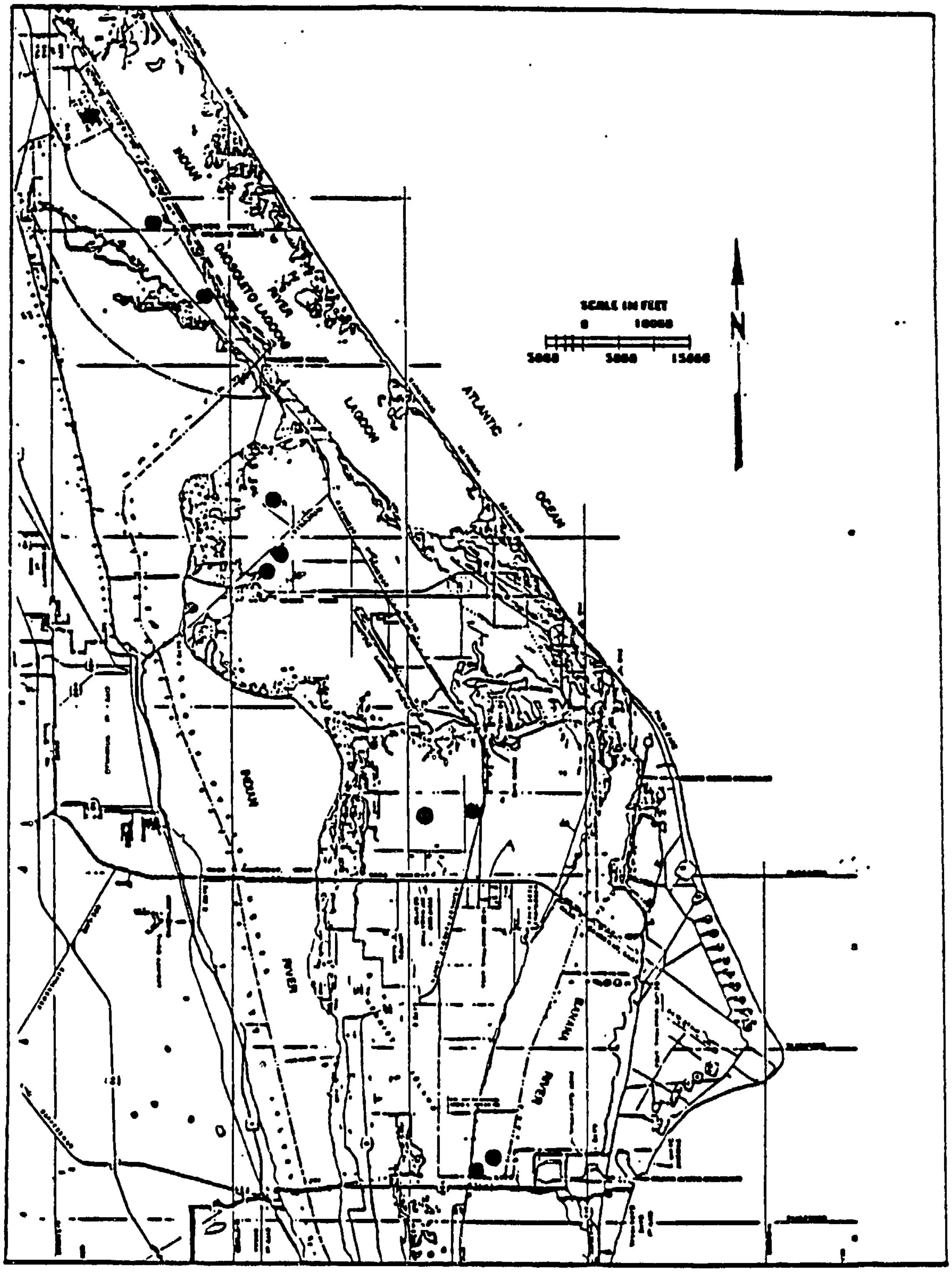
TABLE D-4. COLONIAL NESTING BIRDS ON MINWR 1985

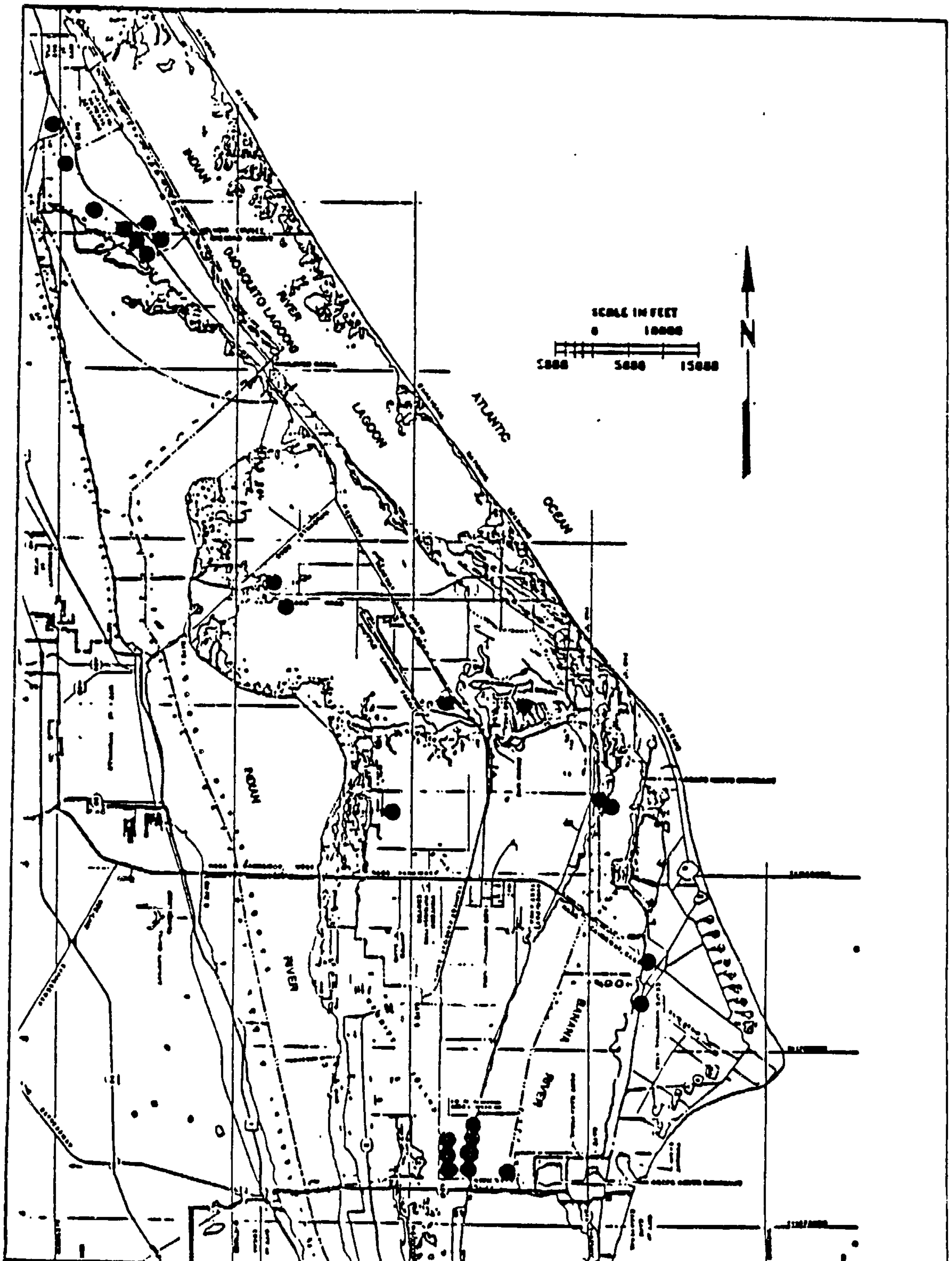
	ROOKERY						
	BIRD ILD.	MULLETTHEAD ISLAND	PEACOCKS POCKET	MOORE CREEK	PICNIC ISLAND	SPOIL ISLAND	TOTAL
E. Brown Pelican	130	250					380
Common Egret	100	175	65	100	54	20	504
Snowy Egret	30	150	20	50	30	20	300
Cattle Egret		1000		600	100		1700
White Ibis		700	5	50	35	40	820
Glossy Ibis		50			10	30	90
Tricolor Heron		100		50	3		153
Green-Backed Heron					4		4
Great Blue Heron	20	50	20	35	20		145
Reddish Egret		1					1
Double-crested Cormorant	75	125	35	125	36		395
Anhinga				100	40		140
Black-Crowned Night Heron				25			25
Yellow-Crowned Night Heron					5		5
Little Blue Heron		50		75	5		130
Wood Stork				235			235

Source: KSC Environmental Resources Document, 1986.



Source: KSC Environmental Resources Document, 1986.

FIGURE D-22. LOCATIONS OF BALD EAGLE NESTING ACTIVITIES



Source: KSC Environmental Resources Document, 1986.

FIGURE D-23. APPROXIMATE LOCATION OF OSPREY NESTING SITES - 1986

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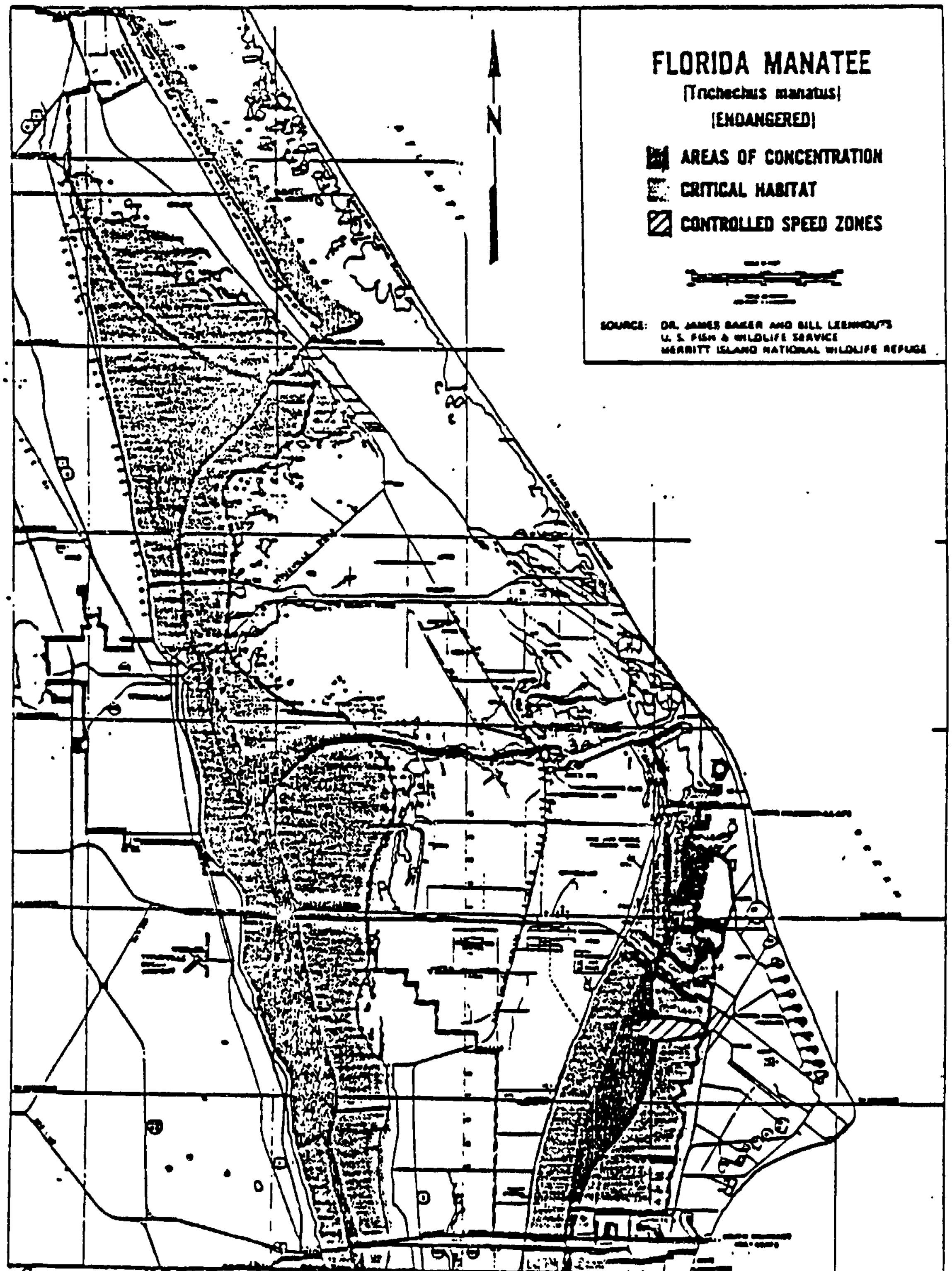

Source: KSC Environmental Resources Document, 1986.

FIGURE D-24. KSC RANGE OF THE FLORIDA MANATEE

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TABLE D-5. FLORA AND FAUNA PROTECTED AT KSC

INDEX OF PROTECTED FLORA(1)

Page	Scientific Name	Common Name	Designated Status				
			USFWS	CITES	FDA	FCREPA	FNAI
D-7	Acrostichum danaeifolium	Giant leather fern			T		
D-8	Amyris balsamifera	Balsam torchwood					SP
D-9	*Asclepias curtissii	Curtis milkweed			T	T	SP
D-10	Asplenium platyneuron	Ebony spleenwort			T		
D-11	*Avicennia germinans	Black mangrove				SP	
D-12	Azolla caroliniana	Mosquito fern			T		
D-13	Calamovilfa curtissii	Curtiss reedgrass	UR				SP
D-14	Calopogon tuberosus	Grass pink (unnamed)		II	T		
D-15	Cereus eriophorus var. fragrans	Fragrant wool-bearing cereus	E	II	E		SP
D-16	Cereus gracilis	West Coast Prickly-apple	UR	II	E	T	SP
D-17	*Chrysophyllum olivaeforme	Satinleaf			E		
D-18	Cocos nucifera	Coconut palm			T		
D-19	Conradina grandiflora	Large-flowered rosemary	UR				SP
D-20	Dichromena floridensis	Florida white-top sedge					SP
D-21	Dryopteris ludoviciana	Florida shield fern			T		
D-22	Encyclia tampensis	Butterfly orchid		II	T		
D-23	Eulophia alta	Wild coco		II	T		
D-24	Habenaria odontopetala	Rein orchid (unnamed)		II	T		
D-25	Habenaria repens	Water spider orchid or creeping orchid		II	T		
D-26	Harrisella porrecta	Orchid (unnamed)		II	T		
D-27	Hexalectris spicata	Crested coralroot		II	T		
D-28	Hymenocallis latifolia	Broad-leaved spider lily	UR				SP
D-29	Ilex ambigua	Carolina holly or sand holly			T		
D-30	Lechea cernua	Nodding pinweed	UR				SP
D-31	Lycopodium alopecuroides	Foxtail club moss			T		
D-32	Lycopodium appressum	Southern club moss			T		
D-33	Lycopodium carolinianum	Slender club moss			T		
D-34	Malaxis spicata	Florida malaxis		II	T		
D-35	Nephrolepis biserrata	Boston fern (unnamed)			T		
D-36	*Ophioglossum palmatum	Adder's tongue fern (unnamed)	UR		E	E	SP
D-37	Ophioglossum petiolatum	Adder's tongue fern (unnamed)			T		
D-38	Opuntia compressa	Prickly pear cactus (unnamed)		II	T		

TABLE D-5 (continued).

Page	Scientific Name	Common Name	Designated Status USFWS	CITES	FDA	FCREPA	FNAI
D-39	Opuntia stricta	Prickly pear cactus (unnamed)		II	T		
D-40	Osmunda regalis var. spectabilis	Royal fern			C		
D-41	Peperomia humilis	Pepper (unnamed)			E		
D-42	*Peperomia obtusifolia	Florida peperomia			E		
D-43	Pereskia aculeata	Lemon vine		II	T		
D-44	Persea borbonia var. humilis	Dwarf redbay or redbay persea	UR				SP
D-45	Phlebodium aureum	Golden polypody			T		
D-46	Pogonia ophioglossoides	Rose pogonia		II	T		
D-47	Ponthieva racemosa	Shadow witch		II	T		
D-48	Psilotum nudum	Whisk fern or fork fern			T		
D-49	*Rhizophora mangle	Red mangrove				SP	
D-50	Rhynchosia cinerea	Brown-haired snoutbean	UR				SP
D-51	Salvinia rotundifolia	Water spangles			T		
D-52	Scaevola plumieri	Scaevola			T		SP
D-53	Selaginella arenicola	Sand spikemoss			T		
D-54	Sophora tomentosa	Necklace pod					SP
D-55	Spiranthes laciniata	Lace-lip ladies'-tresses or lace-lip spiral orchid		II	T		
D-56	Suriana maritima	Bay cedar			E		SP
D-57	Thelypteris interrupta	Aspidium fern (Unnamed)			T		
D-58	Thelypteris palustris	Marsh fern			T		
D-59	Thelypteris quadrangularis	Aspidium fern (unnamed)			T		
D-60	Tillandsia simulata	Wild pine or air plant (unnamed)			T		
D-61	*Tournefortia gnaphalodes	Sea lavender				T	SP
D-62	Verbena maritima	Coastal vervain	UR				SP
D-63	Verbena tampensis	Tampa vervain	UR				SP
D-64	Vittaria lineata	Shoestring fern			T		
D-65	Woodwardia aerolata	Netted chain fern			T		
D-66	*Zamia umbrosa	East coast coontie		II	C	T	
D-67	Zeuxine strateumatica	Orchid (unnamed)		II			
			E-1 UR-10 11	I-0 II-18 18	E-7 T-37 C-2 46	E-1 T-4 SP-2 7	SP-18 18

TABLE D-5 (continued).

INDEX OF PROTECTED FAUNA(1)

Page	Scientific Name	Common Name	USFWS	CITES	FGFWFC	FCREPA
	FISH					
C-8	Centropomus undecimalis	Common snook			SSC	
	REPTILES AND AMPHIBIANS					
C-9	*Alligator mississippiensis	American alligator	T(S/A)	II	SSC	SSC
C-10	*Caretta caretta caretta	Atlantic loggerhead turtle	T	I	T	T
C-11	*Chelonia mydas mydas	Atlantic green turtle	E	I	E	E
C-12	Dermochelys coriacea	Leatherback turtle	E	I	E	R
C-13	*Drymarchon corais couperi	Eastern indigo snake	T		T	SSC
C-14	*Gopherus polyphemus	Gopher turtle	UR	II	SSC	T
C-15	Eretmochelys imbricata imbricata	Atlantic hawksbill turtle	E	I	E	E
C-16	*Lepidochelys kempi	Atlantic ridley turtle	E	I	E	E
C-17	*Nerodia fasciata taeniata	Atlantic salt marsh water snake	T		T	E
C-18	Pituophis melanoleucus mugitus	Florida pine snake	UR		SSC	
C-19	Rana areolata	Gopher frog	UR		SSC	
C-20	Sceloporus woodii	Florida scrub lizard				R
	BIRDS					
C-21	Accipiter cooperii	Cooper's hawk				SSC
C-22	Aimophila aestivalis	Bachman's sparrow	UR			
C-23	Ajaia ajaja	Roseate spoonbill			SSC	R
C-24	*Ammospiza maritima nigriscens	Dusky seaside sparrow	E		E	E
C-25	*Aphelocoma coerulescens coerulescens	Florida scrub jay	UR		T	T
C-26	Aramus guarauna	Limpkin			SSC	SSC
C-27	Athene cunicularia	Burrowing owl			SSC	SSC
C-28	Buteo swainsoni	Swainson's hawk	UR			
C-29	Casmerodius albus	Great egret				SSC
C-30	Charadrius melodus	Piping plover	T		T	SSC
C-31	Circus cyaneus	American harrier or Marsh hawk		II		
C-32	Dendroica discolor paludicola	Florida prairie warbler				SSC
C-33	Egretta caerulea	Little blue heron			SSC	SSC
C-34	Egretta rufescens	Reddish egret	UR		SSC	R
C-35	Egretta thula	Snowy egret			SSC	SSC

Designated Status: USFWS, CITES, FGFWFC, FCREPA

TABLE D-5 (continued).

Page	Scientific Name	Common Name	Designated Status USFWS	CITES	FGFWFC	FCREPA
C-36	Egretta tricolor	Tricolored heron or Louisiana heron			SSC	SSC
C-37	Elanoides forficatus	Swallow-tailed kite	UR			
C-38	Eudocimus albus	White ibis				SSC
C-39	Falco columbarius	Merlin or pigeon hawk		II		SUD
C-40	*Falco peregrinus tundrius	Arctic peregrine falcon	T	I	E	E
C-41	*Falco sparverius paulus	Southeastern kestrel	UR	II	T	T
C-42	Falco sparverius sparverius	Eastern kestrel		II		
C-43	*Fregata magnificens rothschildi	Rothchild's magnificent frigate bird				T
C-44	Grus canadensis pratensis	Florida sandhill crane		II	T	T
C-45	*Haematopus palliatus	American oyster-catcher			SSC	T
C-46	*Haliaeetus leucocephalus	Bald Eagle	E	I	T	T
C-47	Helmitheros vermivorus	Worm-eating warbler				SSC
C-48	Ixobrychus exilis exilis	Least bittern				SSC
C-49	Laterallus jamaicensus	Black rail				SUD
C-50	*Mycteria americana	Wood stork	E		E	E
C-51	Nyctanassa violacea	Yellow-crowned night heron				SSC
C-52	Nycticorax nycticorax	Black-crowned night heron				SSC
C-53	*Pandion haliaetus	Osprey		II		T
C-54	*Pelecanus occidentalis carolinensis	Eastern brown pelican			SSC	
C-55	Picoides borealis	Red-cockaded woodpecker	E		T	E
C-56	Picoides villosus auduboni	Hairy woodpecker				SSC
C-57	Plegadis falcinellus falcinellus	Glossy ibis				SSC
C-58	Recurvirostra americana	American avocet				SSC
C-59	Rynchops niger	Black skimmer				SSC
C-60	Seiurus motacilla	Louisiana waterthrush				R
C-61	Setophagon ruticilla ruticillas	American redstart				R
C-62	*Sterna antillarum	Least tern			T	T
C-63	Sterna caspia	Caspian tern				SSC
C-64	*Sterna dougallii	Roseate tern	UR		T	T
C-65	Sterna fuscata	Sooty tern				SSC
C-66	Sterna maxima	Royal tern				SSC
C-67	Sterna sandvicensis	Sandwich tern				SSC
C-68	Vireo altiloquus	Black-whiskered vireo				R

TABLE D-5 (continued).

Page	Scientific Name	Common Name	Designated Status USFWS	CITES	FGFWFC	FCREPA
	MAMMALS					
C-69	Felis concolor coryi	Florida panther	E	I	E	E
C-70	Lutra canadensis	River otter		II		
C-71	Lynx rufus	Bobcat		II		
C-72	Mustela frenata penisulae	Florida weasel				R
C-73	Mustela vison lutensis	Florida mink				R
C-74	Neofiber alleni	Round-tailed muskrat				SSC
C-75	*Peromyscus floridanus	Florida mouse	UR		SSC	T
C-76	*Trichechus manatus latirostris	West Indian manatee	E	I	E	T
C-77	Ursus americanus floridanus	Florida black bear	UR		T	T
			E-10 T- 5 T(S/A)- 1 UR-13 29	I- 9 II-10 19	T- 9 T-12 SSC-15 36	E- 9 T-15 SSC-25 R- 9 SUD- 2 59

USFWS = United States Fish and Wildlife Service: List of Endangered and Threatened Wildlife and Plants, 50 CFR 17.11-12 (official United States List).

CITES = Convention on International Trade in Endangered Species of Wild Fauna and Flora.

FGFWFC = Florida Game and Fresh Water Fish Commission: Section 39-27.03-05, FAC (official State of Florida animal list).

FCREPA = Florida Committee on Rare and Endangered Plants and Animals.

* Listed in KSC Final Environmental Impact Statement (1979)

E= Endangerd; T= threatened; SSC= Species of Special Concern; UR= Under Review (for possible listing); I= included in Appendix I; II= included in Appendix II (of CITES); R= Rare, SUD= Status Undertermined, T(S/A)= Threatened due to simlarity of appearance.

(1) Source: Breininger et al, 1984.

APPENDIX D-5

SPECIAL DESIGNATION LAND USES IN THE KSC REGION

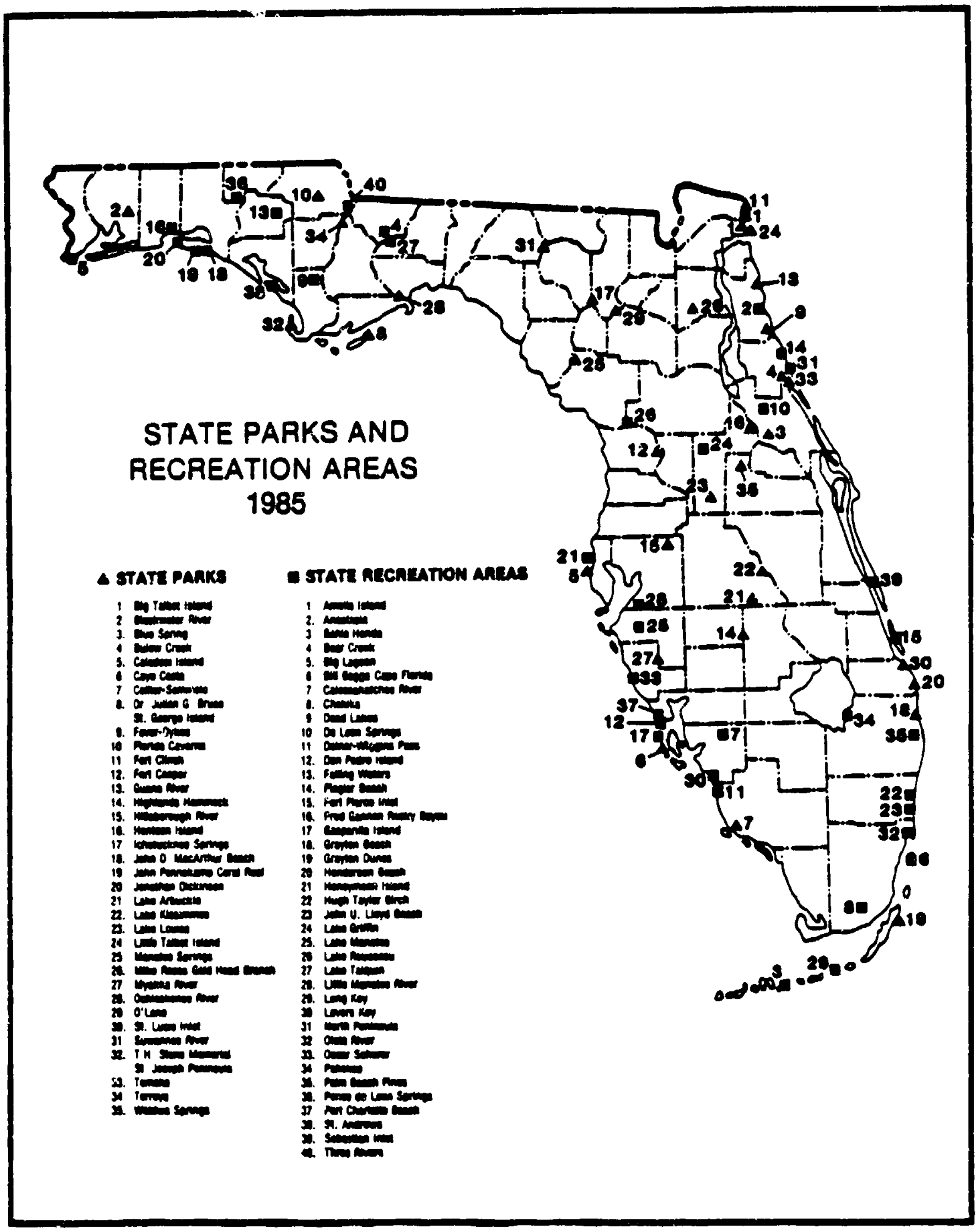

FIGURE D-25. STATE PARKS AND RECREATION AREAS

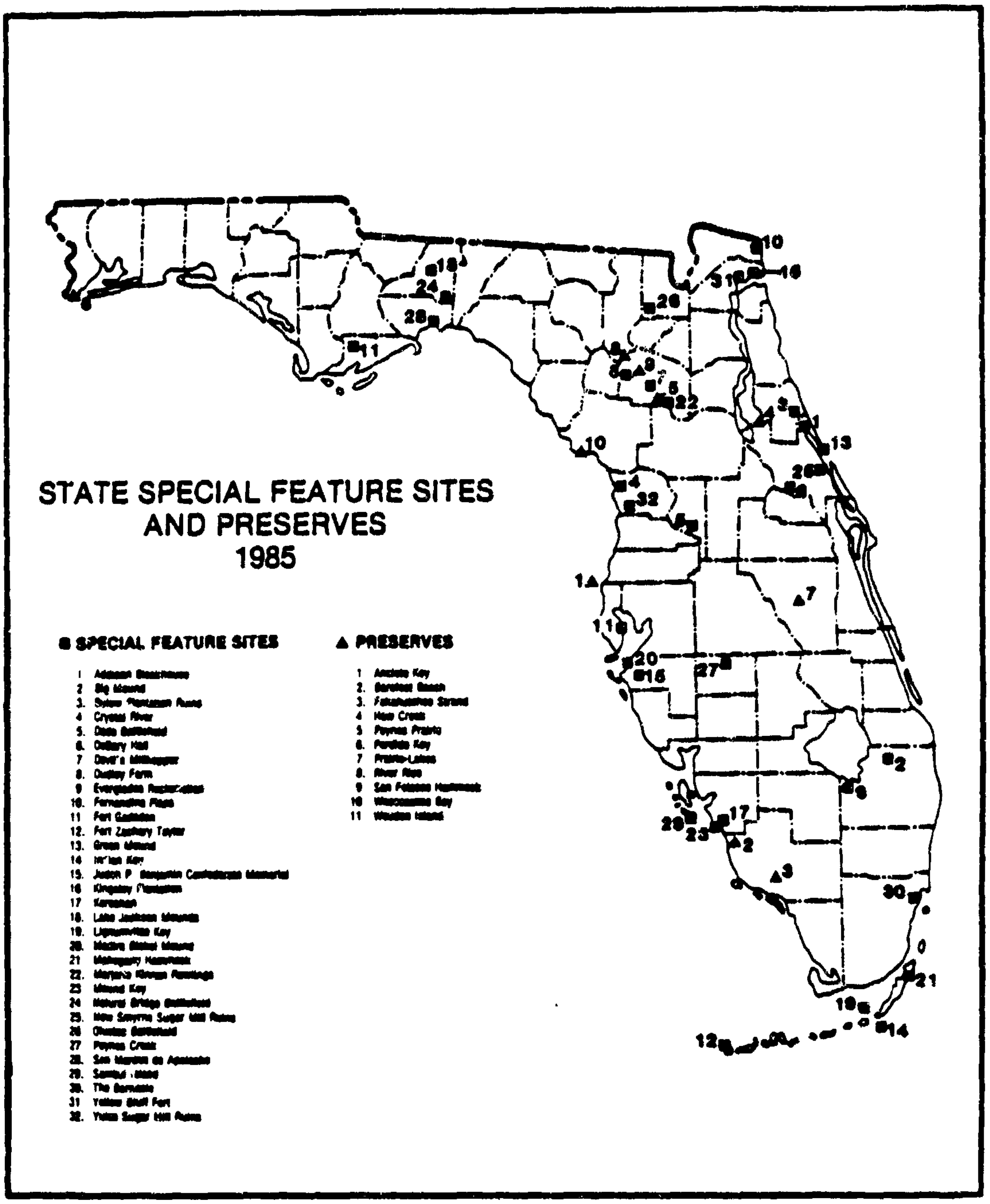

FIGURE D-26. STATE SPECIAL FEATURE SITES AND PRESERVE

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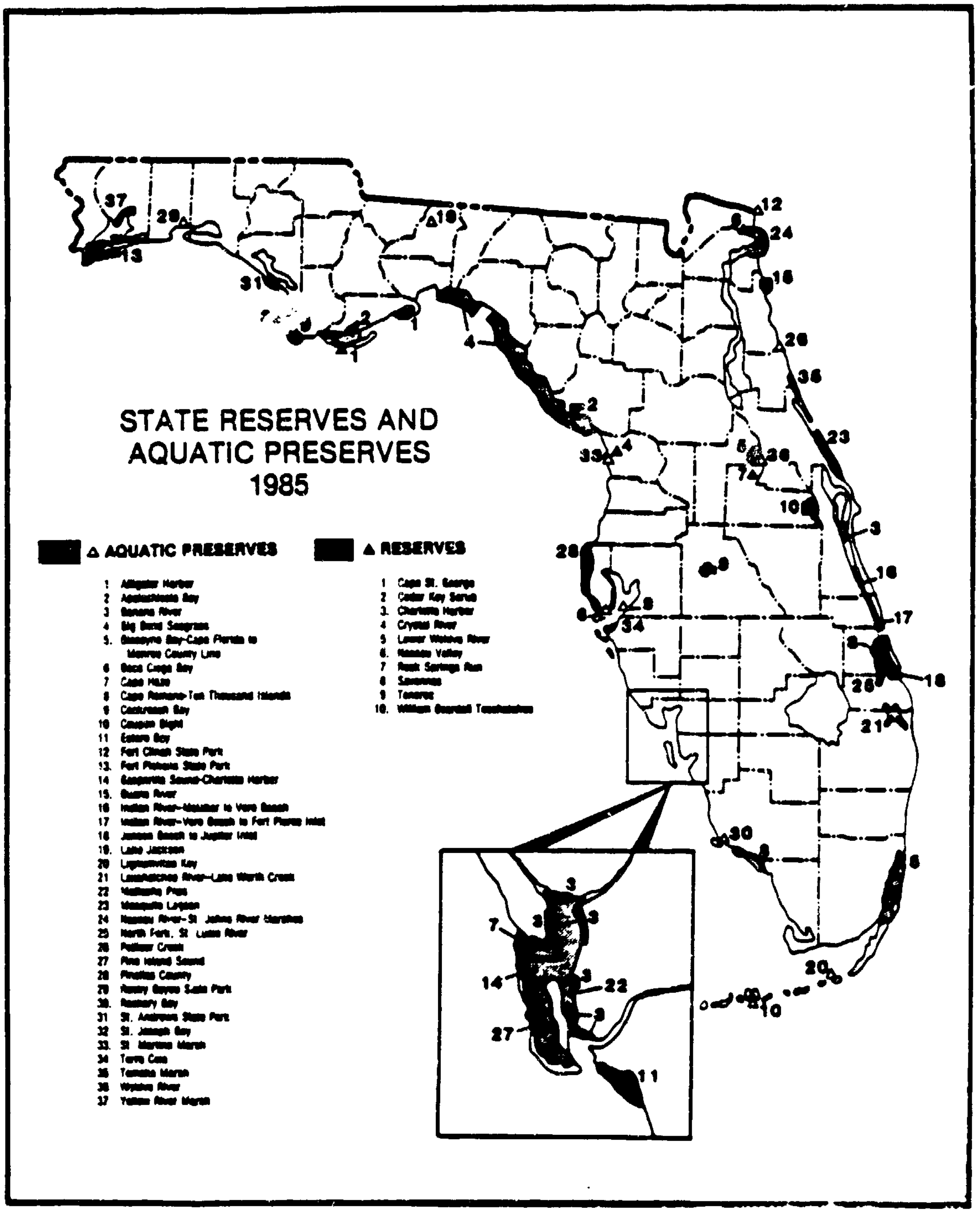

FIGURE D-27. STATE RESERVES AND AQUATIC PRESERVES

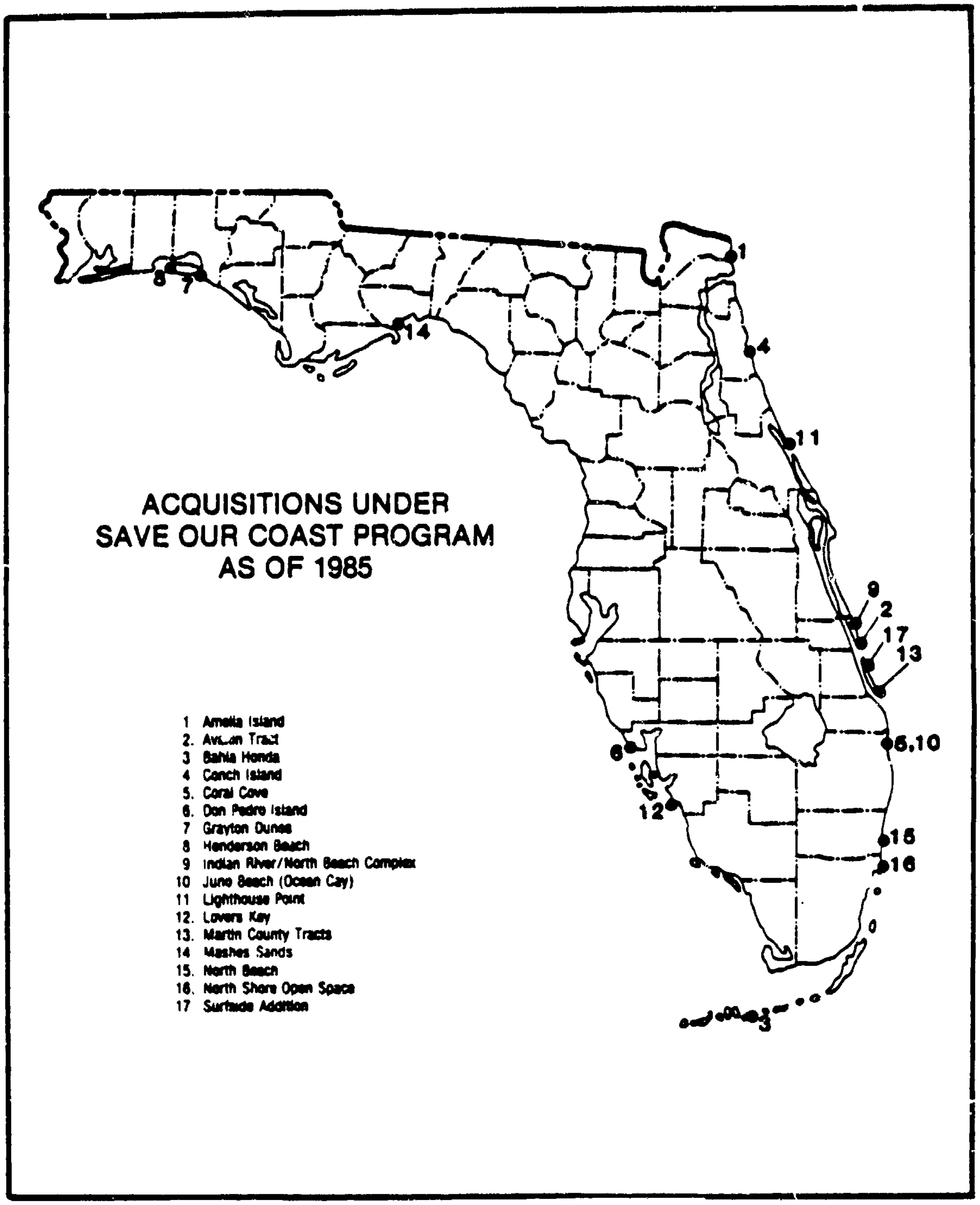

FIGURE D-28. ACQUISITIONS UNDER SAVE OUR COAST PROGRAM

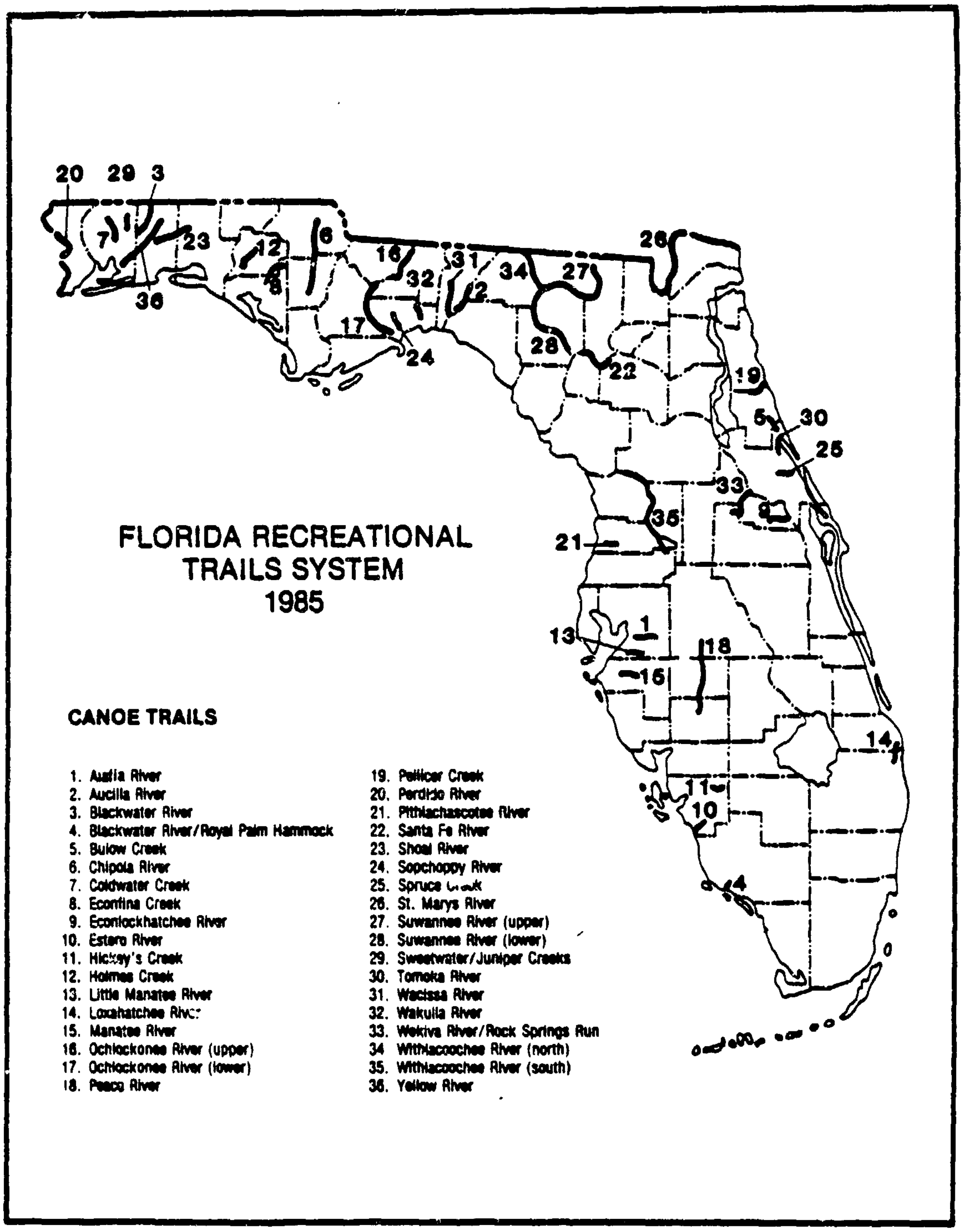

FIGURE D-29. FLORIDA RECREATIONAL TRAILS SYSTEM

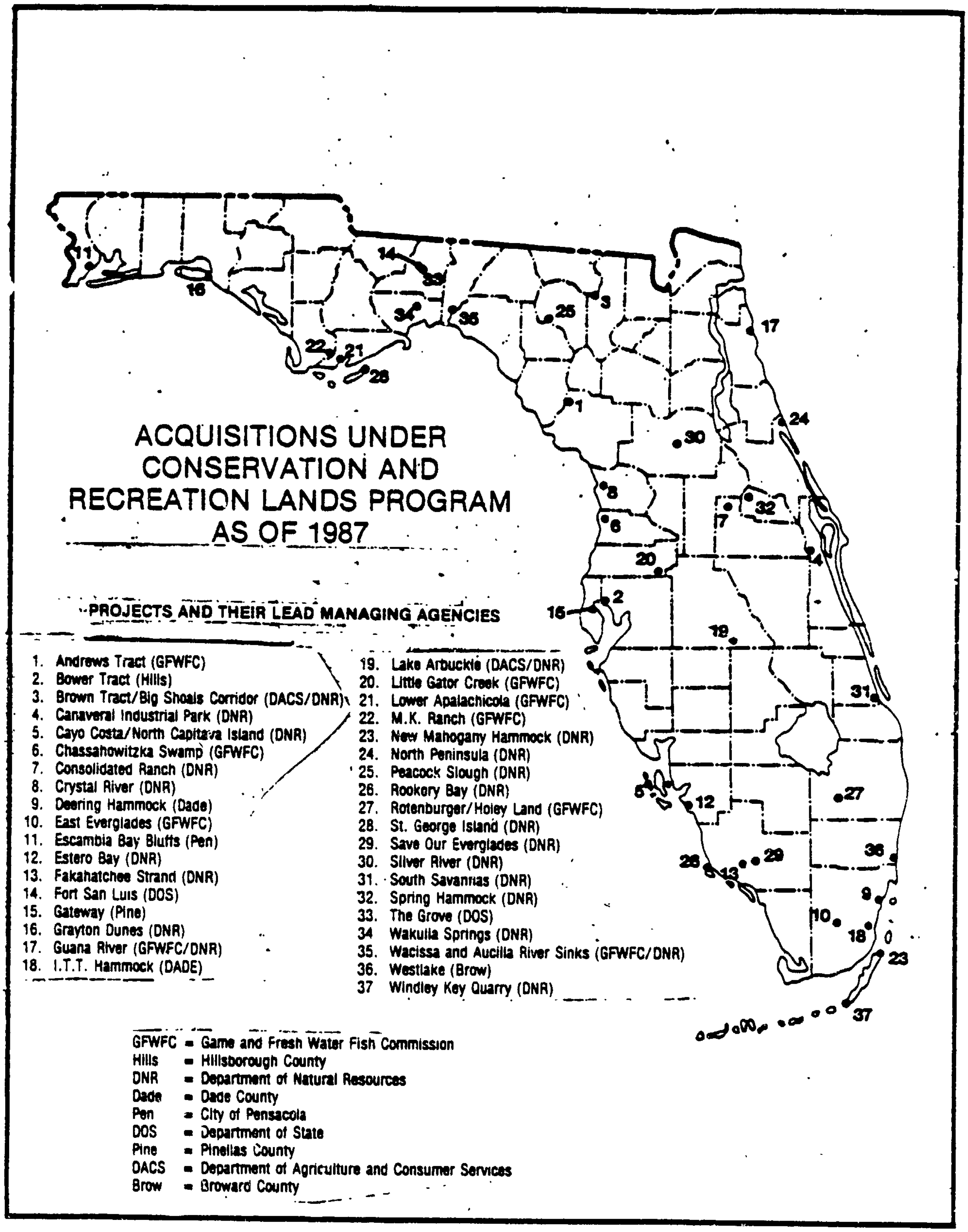

FIGURE D-30. ACQUISITIONS UNDER CONSERVATION AND RECREATION LANDS PROGRAM

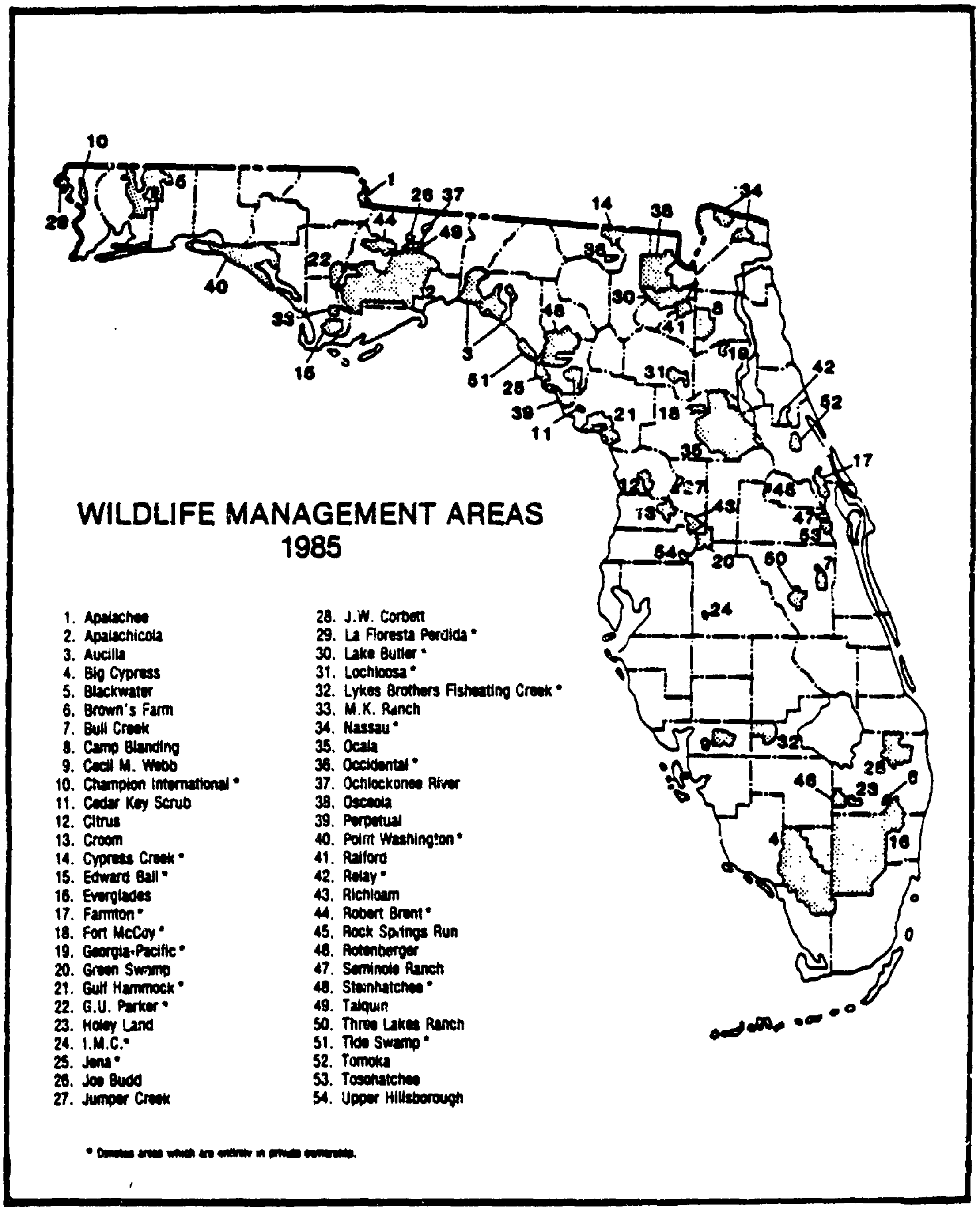

FIGURE D-31. WILDLIFE MANAGEMENT AREAS

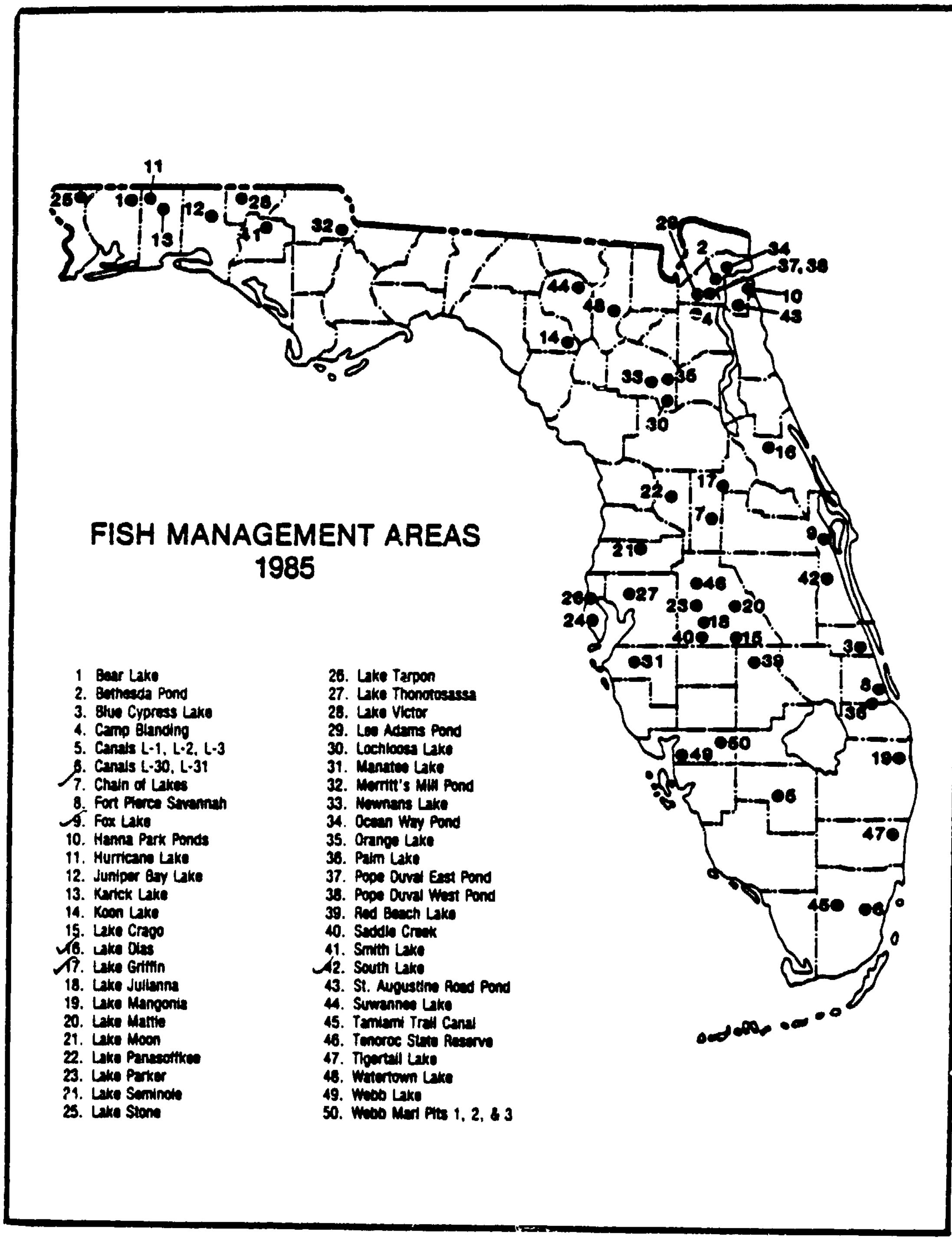

FIGURE D-32. FISH MANAGEMENT AREAS

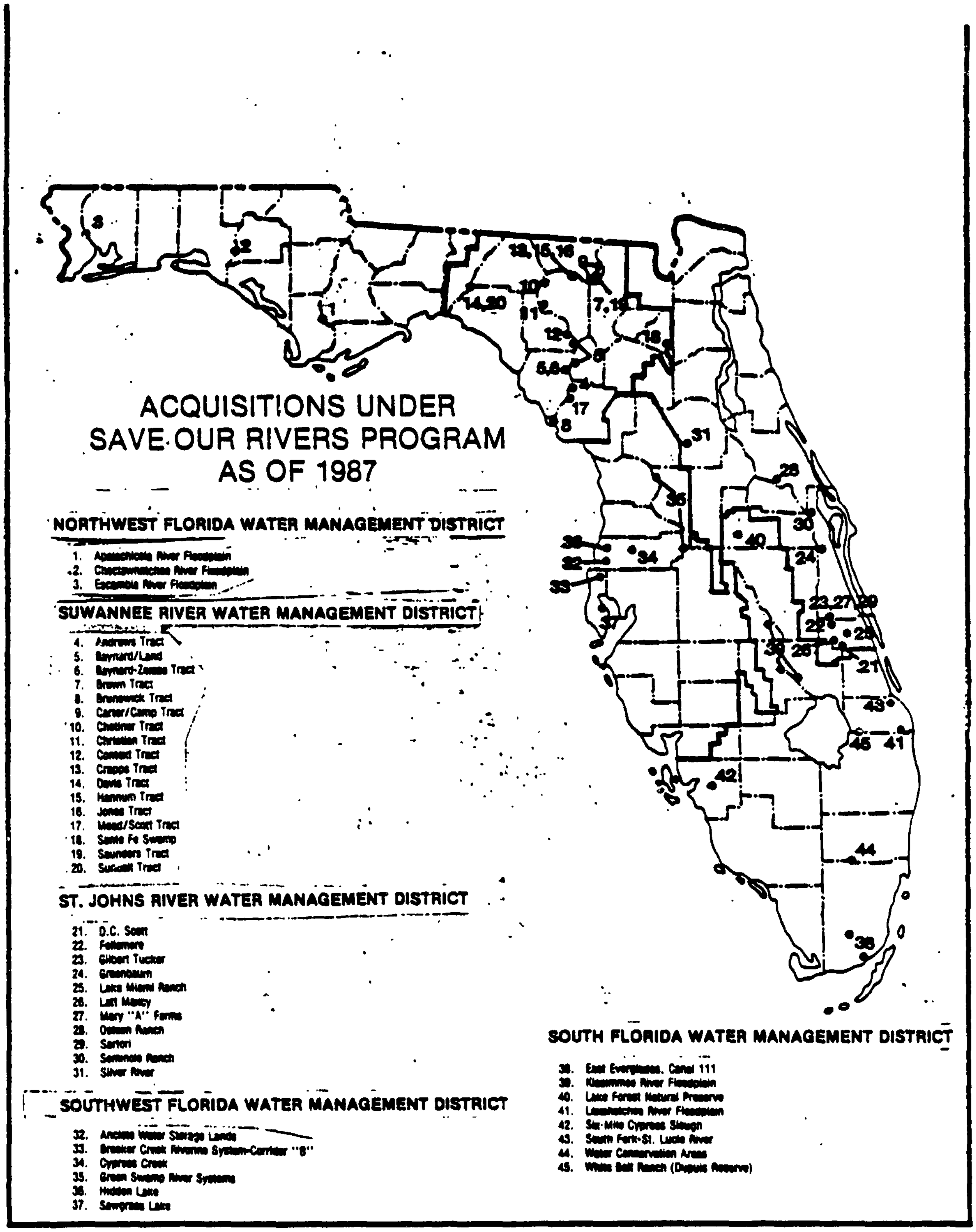

FIGURE D-33. ACQUISITIONS UNDER SAVE OUR RIVERS PROGRAM

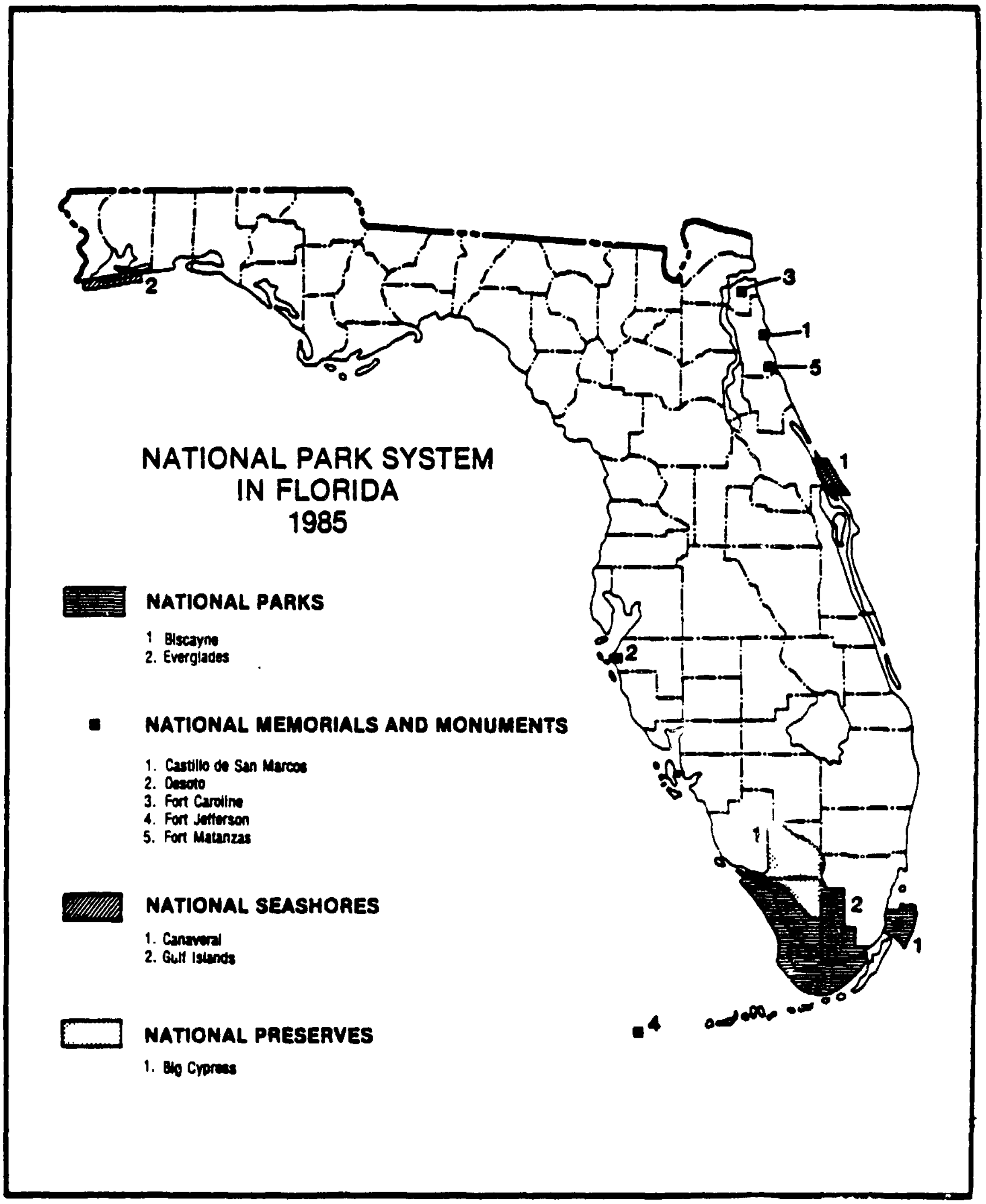

FIGURE D-34. NATIONAL PARK SYSTEM IN FLORIDA

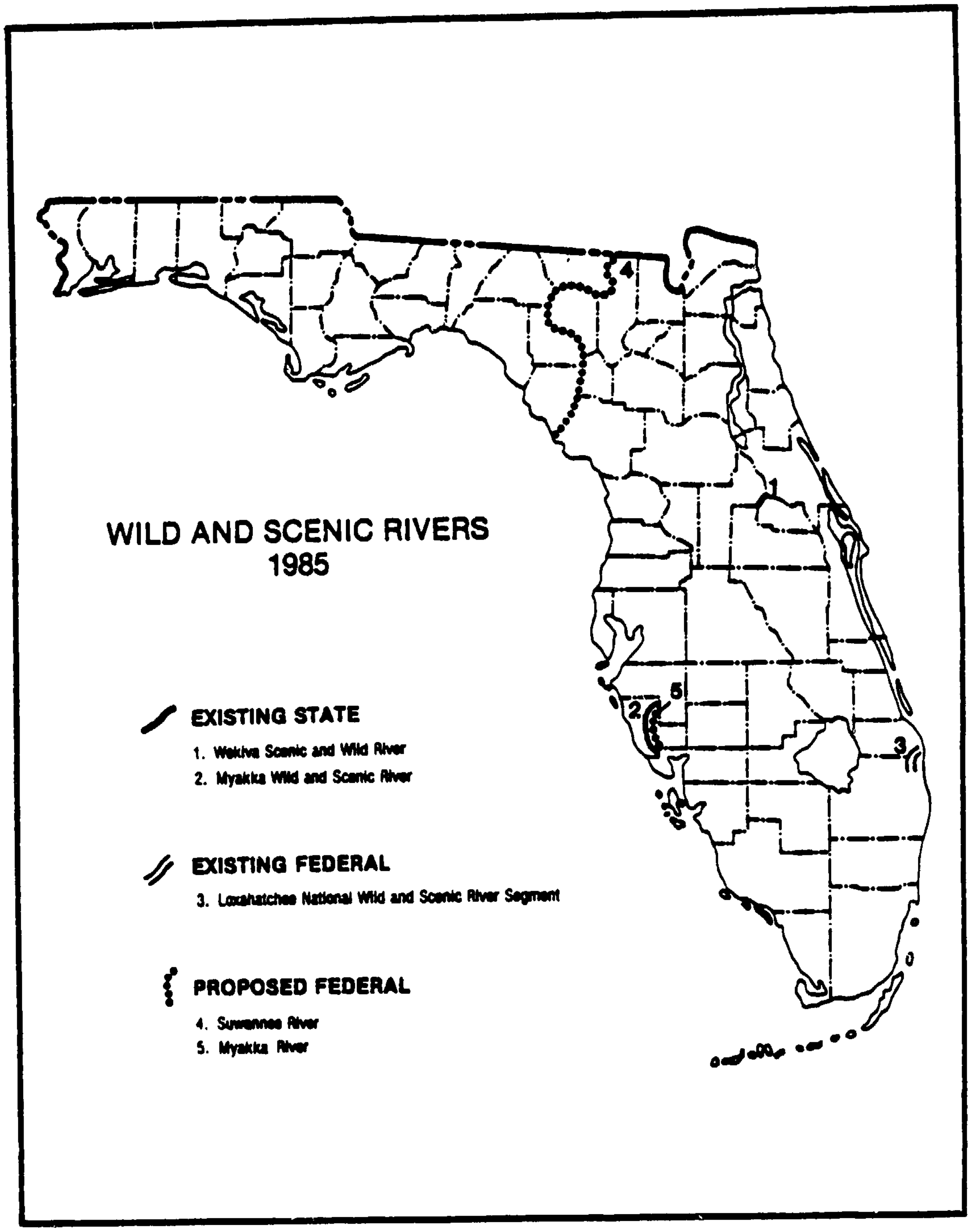

FIGURE D-35. WILD AND SCENIC RIVERS

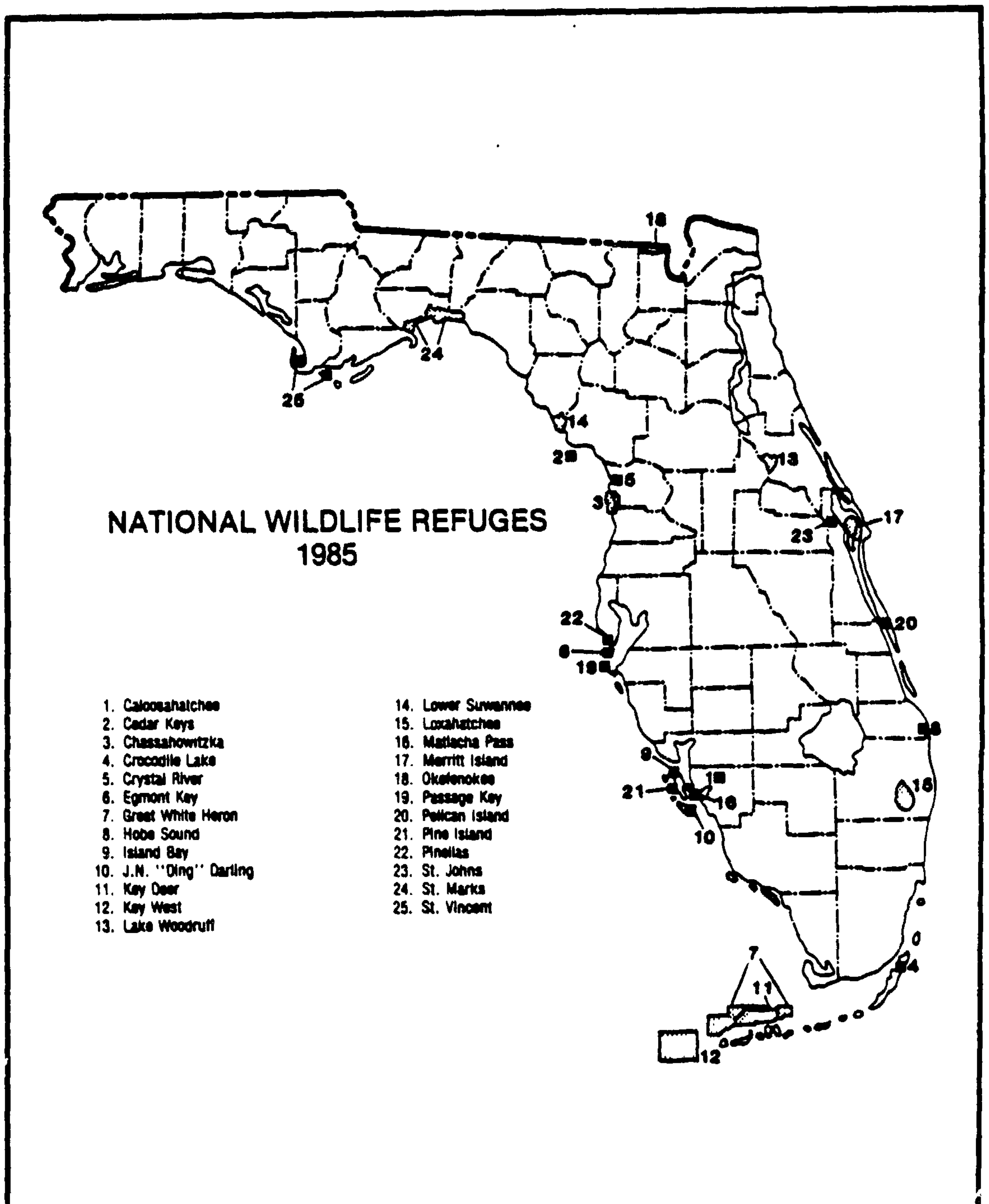

FIGURE D-36. NATIONAL WILDLIFE REFUGES

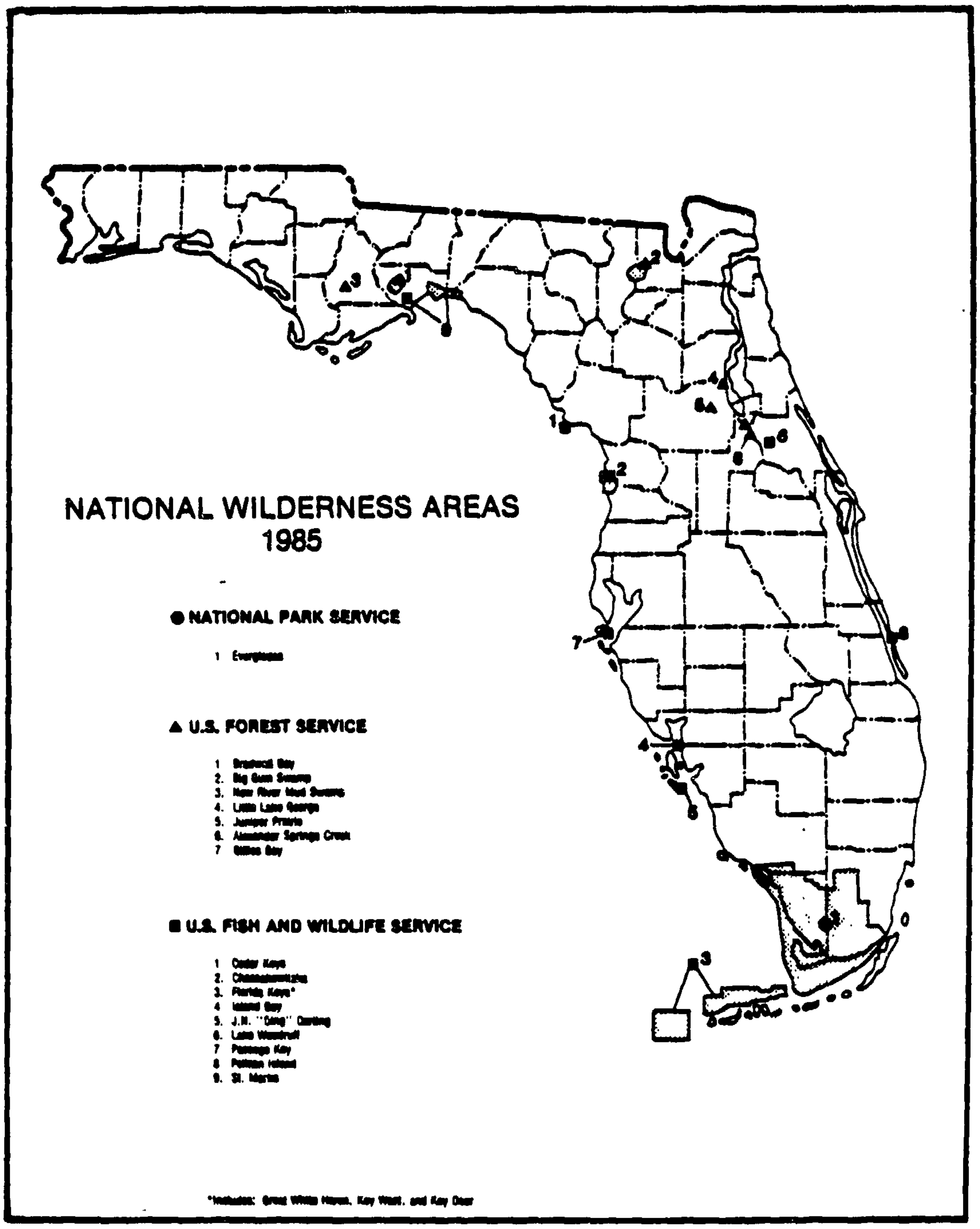

FIGURE D-37. NATIONAL WILDERNESS AREAS

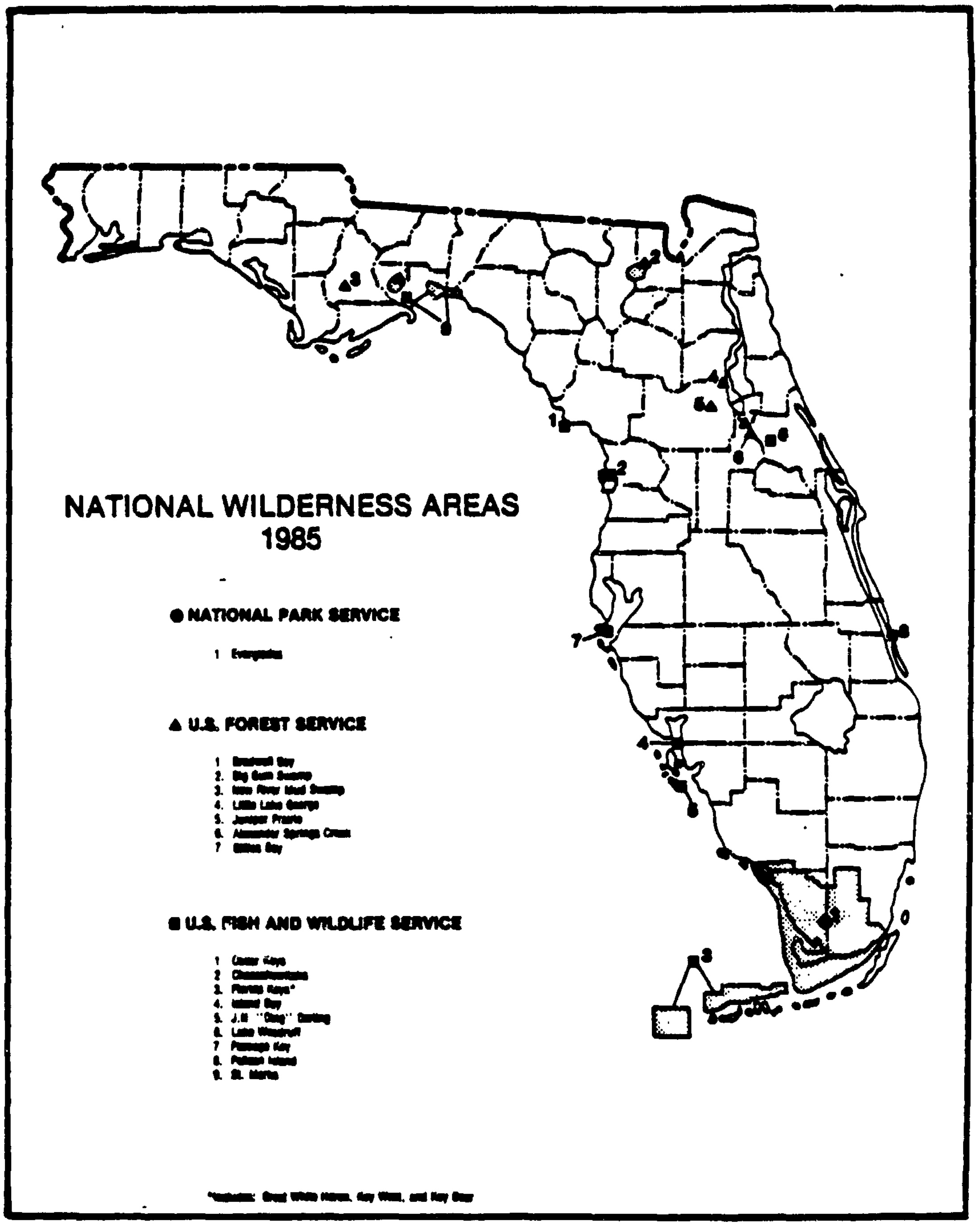

FIGURE D-38. NATIONAL WILDERNESS AREAS

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APPENDIX D-6

OVERVIEW OF KSC RADIOLOGICAL CONTROLS

RADIOLOGICAL CONTROLS

The use of radioactive materials at KSC requires appropriate licenses, special permits and/or use authorizations. All activities involving the use, handling or decommissioning of radioactive sources, apparatus or work areas are strictly controlled, monitored and inspected by health physics personnel. Among the numerous controls enforced at KSC area: (1) establishment of time, distance and shielding requirements as well as personnel protection devices, equipment and measures to restrict personnel exposures to below regulatory limits and to as low as reasonably achievable (ALARA) levels; (2) leak test, contamination surveys, personnel and work area monitoring; (3) training and orientation of all personnel engaged in activities involving potential exposure to radiological sources; (4) certification and training of all personnel directly working with sources, including training in emergency procedures; and (5) strict control over visitors and other non-radiological personnel and workers entering radiological control areas.

Accidents or incidents during routine ground operations resulting in damage, rupture or breach of major radiological sources or associated minor radioactive sources require immediate actions to protect operational personnel, the general public, and the environment. In the event of such an incident or accident, the KSC radiation protection officer would be notified immediately and radiological emergency response elements would be initiated.

A number of precautions and requirements applicable to emergency response activities include the following. Radiation air monitoring equipment and instrumentation with an audible alarm will be available in any storage or use area established for major sources. Portable radiation monitoring instruments and communications equipment will be available during transport of major sources on KSC. All workers and personnel engaged in activities involving major sources and entering radiologically controlled areas, or in areas immediately adjacent to areas controlled due to presence of major sources will be oriented regarding potential radiological hazards, characteristics of immediate evacuation warning signals, fire and radiation alarms, and of the appropriate response to such warnings or alarms. Tests of radiation detection equipment alarms will be conducted prior to commencement of operations involving major radiological sources and daily during such operations to assure that systems are operable and reliable. Radiological equipment, instrumentation and monitoring devices, protective clothing/equipment and associated supplies and materials will be available at locations of storage or use of major sources. Emergency response personnel will be trained and certified in the use of emergency kits and equipment. The Radiological Control Center will be activated for dealing with any ground processing emergency involving major radiological sources.

In addition, written emergency response procedures will be posted and will include procedures to warn, instruct and evacuate individuals in endangered areas, provisions for shutdown of work areas, facilities, and associated ventilation and air conditioning intake systems upon verification of a radiological release, and requirements for associated response activities and re-establishment of radiation controls and recovery from the emergency condition.

In the event of an accident involving a potential release, the Radiation Control Center (RADCC) is the onsite focal point for contingency operations and is the point from which direction is provided to the radiological field teams. For accidents involving offsite areas, a Federal Radiological Monitoring and Assessment Center has been established by DOE to coordinate Federal offsite monitoring and assessment activities. Key personnel will be predeployed at various specified sites in the field prior to launch activities, and will be in communication with the RADCC. All emergency response personnel will receive training and orientation to familiarize them with the physical, chemical, and radiological hazards, as well as radiation protection equipment and techniques.

Three classification levels will be used to indicate the degree of severity relative to radioactive material releases expected in a given incident or accident situation. An "Alert" will be declared if an incident/accident has occurred or is in progress and no release of radioactive material has occurred or is expected to occur. An "Emergency" status is assigned if an incident/accident has occurred and a release of radioactive material onsite has occurred or is expected to occur but release of radioactive material offsite has not occurred and is not expected to occur. A "General Emergency" will be declared if an incident/accident has occurred and a release of radioactive material onsite and offsite has occurred or is expected to occur.

Upon notification of any abnormal situation that could result in a release of radioactive material, the following immediate actions will be taken. The RADCC will coordinate appropriate notifications regarding potential or real radiological incidents. Surveillance aircraft will make an assessment of airborne and ground level radiological conditions. Onsite radiation monitoring teams and the on-scene commander will be deployed to assist in a preliminary assessment of the situation. Fire, rescue, security, and damage measures will be implemented as necessary. Health physics representatives will define access points to the affected area and control the passage of response personnel through these access points. All personnel not directly engaged in damage control will be prevented from entering the controlled area. Emergency crews and evacuees leaving radiation controlled areas will be monitored by radiological field teams at appropriately located access points.

In coordination with, or subsequent to, the immediate actions described above, the following actions will be taken dependent upon the consequences of the incident. If there is no breach of the encapsulated radioactive material, a search will be initiated and the intact devices will be removed and placed in temporary storage containers. Radiation monitoring teams will conduct thorough area contamination surveys as directed by the RADCC. The State and offsite support elements will perform confirmatory surveys in the offsite areas to verify no release or contamination, the following actions will be taken. The onsite and offsite radiation monitoring teams will monitor the cloud path and identify contaminated areas. Radiological assessment aircraft will track airborne radioactive material, identify the cloud path, and assess airborne radioactive material concentrations. Because of the many possible variations in incidents and circumstances, additional actions to be performed by onsite radiation monitoring teams will be at the direction of the RADCC. Procedures will be determined by the health physics staff.

APPENDIX D REFERENCES

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