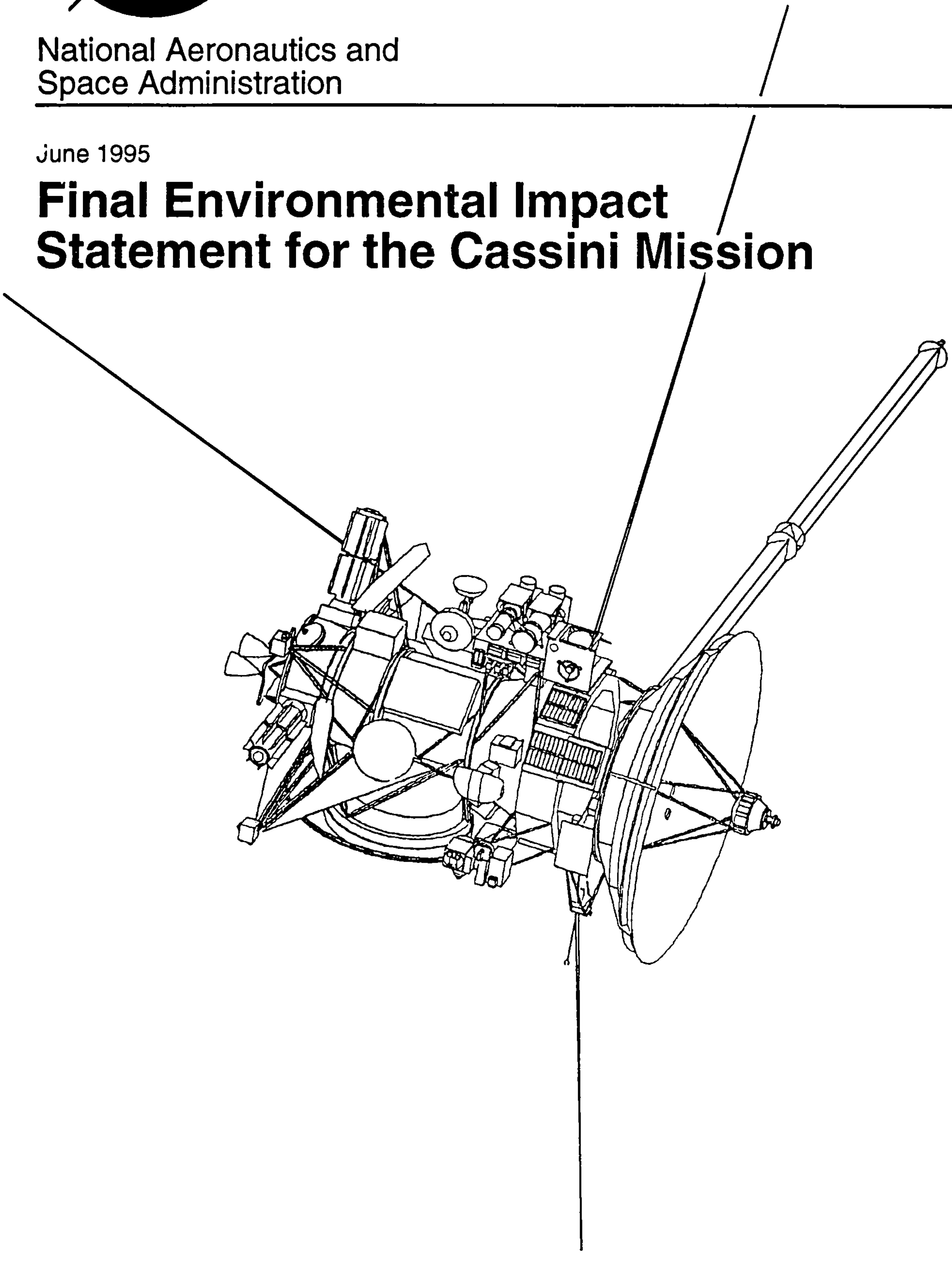
National Aeronautics and
Space Administration

June 1995

Final Environmental Impact Statement for the Cassini Mission



Final Environmental Impact Statement for the Cassini Mission

Solar System Exploration Division
Office of Space Science
National Aeronautics and Space Administration
Washington, DC 20546

June 1995

This document is printed on recycled paper.

ABSTRACT

LEAD AGENCY:	National Aeronautics and Space Administration Washington, DC 20546
COOPERATING AGENCY:	U.S. Department of Energy Washington, DC 20585
POINT OF CONTACT FOR INFORMATION:	Dr. Peter B. Ulrich Solar System Exploration Division Office of Space Science NASA Headquarters Washington, DC 20546 (202) 358-0290
DATE:	June 1995

This Final Environmental Impact Statement (FEIS) addresses the potential environmental impacts that may be associated with the implementation of the Cassini mission, a cooperative science effort planned by the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and the Italian Space Agency (ASI). The mission would involve the use of the Cassini spacecraft, including an Orbiter and the detachable Huygens Probe, to conduct a 4-year scientific exploration of the planet Saturn, its atmosphere, moons, rings, and magnetosphere. The Huygens Probe would be released to collect data from the atmosphere of Saturn's largest moon, Titan.

The Proposed Action addressed in this FEIS consists of preparing for and implementing the Cassini mission. The Cassini spacecraft would be launched from the Cape Canaveral Air Station (CCAS) using the Titan IV (Solid Rocket Motor Upgrade [SRMU] or Solid Rocket Motor [SRM])/Centaur. The primary launch opportunity would be in October 1997 with contingency launch opportunities in December 1997 (secondary) or March 1999 (backup). The primary launch opportunity would place the spacecraft into a 6.7-year Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn. The secondary and backup launch opportunities would use an 8.8-year and a 9.8-year Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory, respectively. The amount of science return (i.e., data) from either contingency launch opportunity would be less than the return associated with the primary launch opportunity. In the event that the Titan IV (SRMU) were not available, a Titan IV (SRM) would be used. The launch opportunities would remain the same.

The alternatives to the Proposed Action evaluated in detail are a 1999 mission alternative, a 2001 mission alternative, and the No-Action alternative (i.e., cancellation of the mission). The 1999 mission alternative would involve dual Shuttle launches from the Kennedy Space Center (KSC) in which the first launch would predeploy an upper stage(s) into low Earth orbit, and a second launch, 21 to 51 days later, would deliver the Cassini spacecraft and the remaining upper stage(s). An on-orbit mating of the upper stage(s)

with the Cassini spacecraft would be followed by upper stage ignition and insertion of the Cassini spacecraft into its 9.8-year VEEGA interplanetary trajectory. A backup launch opportunity, with a 9.4-year VEEGA, would occur in August 2000. The science return from this alternative would be less than that expected for the 1997 primary launch opportunity in the Proposed Action.

The primary launch opportunity for the 2001 mission alternative would not require an Earth swingby. It would, however, require the spacecraft to be equipped with 20 percent larger propellant tanks and completing the development and flight testing of a high performance rhenium spacecraft propulsion engine. The Cassini spacecraft would be launched by the Titan IV (SRMU)/Centaur from CCAS into a 10.3-year Venus-Venus-Venus-Gravity-Assist (VVVGA) trajectory. An 11.4-year VEEGA backup launch opportunity for this alternative would occur in May 2002. The level of science return associated with this alternative would be reduced when compared with the return associated with the Proposed Action.

The only expected environmental impacts of the Proposed Action and of the 1999 and 2001 mission alternatives would be associated with the normal launch of the Titan IV (SRMU or SRM)/Centaur or the Shuttle. The impacts for the 1999 mission alternative would occur twice for the dual Shuttle launches. The impacts would primarily be short-term in nature affecting the air quality and water resources near the launch site.

The principal concern associated with the launch of the Cassini spacecraft would be a potential accident involving the three radioisotope thermoelectric generators (RTGs) used onboard the spacecraft to provide electrical power and the radioisotope heater units (RHUs) used to control the thermal environment onboard the spacecraft and the Probe. In the unlikely event that a launch accident causes sufficient damage to the RTGs, plutonium dioxide fuel contained within the RTGs could be released to the environment. Extensive U.S. Department of Energy (DOE) testing and evaluation programs have demonstrated the effectiveness of the RTGs and the RHUs to contain the fuel under a wide range of accident test conditions. Therefore, only small fuel releases are postulated if a launch accident occurred.

Representative launch accident scenarios were evaluated for the Proposed Action and the other mission launch alternatives. Of these accident scenarios, the accident environments sufficient to cause a release of plutonium dioxide fuel from the RTGs could occur in the CCAS/KSC region, limited areas under the vehicle flight path while over Africa, and indeterminate locations within the global area.

NASA has postulated two low probability accident scenarios that could occur during the interplanetary cruise portions of the VVEJGA and VEEGA trajectories. These scenarios would result in either a short-term or long-term inadvertent reentry of the Cassini spacecraft. The Proposed Action and the 1999 mission alternative have the potential for both a short-term and long-term inadvertent reentry. The 2001 alternative, because of its VVVGA trajectory, does not have the potential for a short-term inadvertent reentry. However, this trajectory would not rule out the possibility of a long-term inadvertent reentry.

No environmental impacts would be associated with the No-Action alternative. NASA, ESA, and ASI would experience adverse mission-specific impacts if the No-Action alternative is adopted. The science return specific to this mission would be lost, and the ability of the United States to enter into future international agreements for cooperative space activities could be impaired.

EXECUTIVE SUMMARY

This Final Environmental Impact Statement (FEIS) has been prepared in accordance with the National Environmental Policy Act of 1969 (NEPA) (42 U.S.C. 4321 et seq.), as amended; the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of NEPA (40 CFR Parts 1500-1508); and the National Aeronautics and Space Administration's (NASA) policy and regulations (14 CFR Subpart 1216.3) to support the decision-making process concerning the Proposed Action and alternatives for NASA's Cassini space exploration mission.

PURPOSE AND NEED FOR THE ACTION

The Cassini mission is an international cooperative effort being planned by NASA, the European Space Agency (ESA), and the Italian Space Agency (ASI) to explore the planet Saturn and its environment. The mission would involve a 4-year tour of Saturn, its atmosphere, moons, rings, and magnetosphere by the Cassini spacecraft, which consists of the Orbiter and the detachable Huygens Probe. The Huygens Probe would be released from the Cassini Orbiter to descend by parachute through the atmosphere of Saturn's largest moon, Titan. During the descent, instruments on the Probe would directly sample the atmosphere and determine its composition. The Probe would also gather data on Titan's landscape.

The Cassini spacecraft would carry three radioisotope thermoelectric generators (RTGs) that use the heat from the decay of plutonium (Pu-238) dioxide fuel to generate electric power for the spacecraft and its instruments. The spacecraft would use radioisotope heater units (RHUs) (157 are planned), also containing plutonium dioxide, to generate heat for controlling the thermal environment onboard the spacecraft and several of its instruments. The U.S. Department of Energy (DOE) would supply the RTGs and RHUs to NASA.

NASA would provide the ground communications network and two scientific instruments for the Huygens Probe. ESA would provide the Huygens Probe, and ASI would provide major elements of the Cassini Orbiter's communications equipment and elements of several science instruments.

The Cassini mission is part of NASA's program for exploration of the solar system. The goal of the program is to understand the birth and evolution of the solar system. Initially, this program concentrated on flyby or reconnaissance-type missions to the outer solar system. With the launch of the Galileo spacecraft in 1989, the program began its transition to exploration-type missions to the outer planets using orbiters and atmospheric probes. The Cassini spacecraft would make remote and close-up measurements of Saturn, its atmosphere, moons, rings, and magnetosphere. This information could also provide significant insights into the formation of the solar system and the conditions that led to life on Earth.

ALTERNATIVES EVALUATED

The Proposed Action addressed by this FEIS consists of preparing for and implementing the Cassini mission to Saturn to conduct a 4-year scientific exploration of the planet, its atmosphere, moons, rings, and magnetosphere. NASA proposes to launch the spacecraft from Cape Canaveral Air Station (CCAS) (formerly Cape Canaveral Air Force Station [CCAFS]) in October 1997 using a Titan IV (Solid Rocket Motor Upgrade [SRMU]) and a Centaur upper stage (i.e., Titan IV (SRMU)/Centaur) to place the Cassini spacecraft into a 6.7-year Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn. The SRMU is the most recent upgrade of the solid rocket motor [SRM] used on the Titan IV. If the October 1997 launch opportunity were missed, a secondary launch opportunity exists in December 1997 using an 8.8-year Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory and a backup launch opportunity exists in March 1999 using a 9.8-year VEEGA trajectory. In the event that the Titan IV (SRMU)/Centaur were not available, a Titan IV (SRM)/Centaur would be used. The launch opportunities would remain the same.

The alternatives to the Proposed Action evaluated in detail are a 1999 mission alternative, a 2001 mission alternative, and the No-Action alternative (i.e., the cancellation of the mission). The 1999 mission alternative would entail dual Shuttle launches from the Kennedy Space Center (KSC), separated by 21 to 51 days, to deliver the Cassini spacecraft and the upper stage(s) into low Earth orbit. An on-orbit mating of the upper stage(s) and the spacecraft would be performed by astronauts followed by insertion of the spacecraft in March 1999 into its 9.8-year VEEGA interplanetary trajectory to Saturn. A backup launch opportunity, a 9.4-year VEEGA, occurs in August 2000. The 2001 mission alternative would use the Titan IV (SRMU)/Centaur to launch the Cassini spacecraft into a 10.3-year Venus-Venus-Venus-Gravity-Assist (VVVGA) trajectory to Saturn. The spacecraft would require 20 percent additional propellant, as well as completing development of and flight testing a high performance rhenium engine for spacecraft propulsion to accommodate the amount of maneuvering associated with the VVVGA trajectory. An 11.4-year VEEGA backup launch opportunity occurs in May 2002. The No-Action alternative would cancel the mission.

In developing the alternatives (i.e., the Proposed Action and the 1999 and 2001 missions), the available options for the following key components of the mission design were evaluated: launch vehicles, interplanetary trajectories, and power sources for spacecraft electrical needs.

Several criteria were used to evaluate the options: technological feasibility and availability of the option for implementing the mission at the earliest opportunity, impact of the option on the ability of the spacecraft to achieve the mission science objectives, and potential of the option for reducing or eliminating environmental impacts that could be associated with the mission. The evaluation provided the following results: (1) the Titan IV (SRMU)/Centaur is the most capable U.S. launch vehicle available to implement the mission; (2) the Cassini mission to Saturn requires planetary gravity-assist trajectories; and (3) the spacecraft requires the use of RTGs to satisfy the mission electrical power needs.

The overall result of the options evaluated indicates that implementation of the Proposed Action, with its three launch opportunities (i.e., primary in October 1997, secondary in December 1997, or backup in March 1999), provides the greatest opportunity to achieve the mission science objectives. The 1999 mission alternative and the 2001 mission alternative also are technically feasible and provide opportunities to achieve most of the science objectives planned for the mission but with less science return (i.e., data).

ENVIRONMENTAL IMPACTS

The only expected environmental impacts of the Proposed Action, as well as the 1999 and 2001 mission alternatives, would be associated with the normal launch of the Cassini spacecraft on the Titan IV (SRMU or SRM)/Centaur or the Shuttle. These impacts have been addressed in previous NEPA documents prepared by the U.S. Air Force (USAF) for its Titan IV launch operations at the CCAS (USAF 1986, USAF 1988a, USAF 1988b) and for the Titan IV using the SRMU (USAF 1990) and prepared by NASA for the Shuttle launches (NASA 1978, NASA 1979, NASA 1988b, NASA 1989b, NASA 1990). The evaluation of these alternatives also used other NEPA-related documentation, including the EIS for the Kennedy Space Center (KSC) (NASA 1979) and the KSC *Environmental Resources Document* (NASA 1994).

For the Proposed Action, the environmental impacts of a normal launch of the Cassini spacecraft on a Titan IV (SRMU or SRM)/Centaur would result from exhaust emissions (i.e., the exhaust cloud) from the two solid rocket motors (principally aluminum oxide particulates [Al_2O_3], hydrogen chloride [HCl], and carbon monoxide [CO]), which would have a short-term impact on air quality in the vicinity of the launch site; noise from the SRMUs or SRMs, which would not adversely impact the nearest unprotected person (or the general public); deposition of acidic SRMU or SRM exhaust products, largely on the launch complex itself, but which could reach nearby marsh and surface water areas where natural buffering would substantially reduce any impacts; and short-term impacts on stratospheric ozone along the launch vehicle's flight path from the SRMU or SRM exhaust products. No substantial long-term environmental impacts would be associated with a normal launch of the Cassini spacecraft for any of the launch opportunities.

The radiological concern associated with the mission is the potential release of some of the approximately 32 kg (71 lb) of plutonium dioxide (consisting of around 71 percent by weight Pu-238 at launch) in the RTGs and RHUs onboard the spacecraft. In the unlikely event that an accident were to occur during the launch of the spacecraft (i.e., from the time of ignition of the SRMUs or SRMs, through the insertion of the spacecraft into its interplanetary trajectory), the safety features incorporated into the RTGs and RHUs, in most cases, would limit or prevent any release of the plutonium dioxide fuel. However, in the unlikely event of a launch phase accident causing a release of plutonium dioxide fuel, no health effects (i.e., excess latent cancer fatalities [above the normally observed cancer fatalities]) would be expected to occur if members of the population were exposed to the released radioactive fuel.

For launch Phases 1 through 6 on the Titan IV (SRMU)/Centaur, four accident scenarios were identified as representative of the categories of failures that could release plutonium dioxide fuel to the environment. In addition, two postulated very low probability (i.e., much lower than the probabilities for Phases 1 through 6) accident scenarios that could occur during the interplanetary portions of the VVEJGA and VEEGA trajectories were identified as the short-term and long-term inadvertent reentry scenarios. The short-term scenario would involve the inadvertent reentry of the spacecraft into the Earth's atmosphere during a planned Earth swingby, and the long-term scenario would involve a spacecraft failure that leaves the spacecraft drifting in an Earth-crossing orbit and potentially reentering the Earth's atmosphere a decade to millennia later. Preliminary estimates for a Titan IV (SRM)/Centaur launch indicate that the radiological consequences and the risk would be similar to those for the Titan IV (SRMU)/Centaur.

Depending on the accident scenario, the CCAS/KSC regional area, limited portions of the African continent under the vehicle flight path, or indeterminate locations within the global area could be impacted by plutonium dioxide fuel releases. The CCAS/KSC regional area could be impacted if a Phase 1 accident were to result in a release. Areas outside the region (i.e., portions of the African continent; areas elsewhere around the world) could be impacted if an accident resulting in a release were to occur in Phase 5 or 6. Considering potential accidents that could result in a release across all launch phases, no excess cancer fatalities would be expected in the exposed population. No releases of plutonium from the RTGs to the environment are postulated if any of the representative accident scenarios occurred in Phases 2, 3, or 4.

During the interplanetary portions of the mission, postulated short- and long-term inadvertent reentry accident scenarios could result in releases of plutonium dioxide to the environment. However, NASA is designing the mission to avoid the potential for such accidents. The mission's design ensures that the expected probability of an inadvertent reentry would be less than one in a million. If such an accident were to occur, plutonium dioxide could be released in the upper atmosphere and/or scattered in indeterminate locations on the Earth's surface. Within the exposed population of 5 billion people, approximately 1 billion people (i.e., 20 percent or 1/5 of the population) would be expected to die of cancer due to other causes. The estimated fatalities that could result from an inadvertent reentry with release would represent an additional 0.0005 percent above the normally observed 1 billion cancer fatalities.

The principal method used in this document for characterizing the radiological impacts of each alternative evaluated is health effects risk. Health effects are expressed as the number of excess latent cancer fatalities (above the normally observed cancer fatalities) caused by exposure to the plutonium dioxide fuel. As used in this FEIS, health effects mission risk is the probability of an accident with a plutonium dioxide fuel release (i.e., the probability of an initiating accident times the probability of that accident causing a release of plutonium dioxide, since not all accidents would result in a plutonium dioxide release) multiplied by the consequences of that accident (i.e., the health effects that could be caused by the exposure of individuals to the plutonium dioxide), summed over all postulated accidents. Estimates of health effects mission risk, as discussed in this FEIS, represent the expectation latent cancer fatalities. The expectation health effects mission risk over all mission phases (i.e., the total or overall health effects mission risk) does not include contributions to risk from the long-term reentry scenario.

For the Proposed Action, the health effects mission risk considering all launch phases for the primary launch opportunity would be 8.4 x 10^{-7}. The health effects mission risk from the short-term inadvertent reentry accident during the Earth swingby portion of the primary launch opportunity's VVEJGA trajectory would be 1.7 x 10^{-3} and for the secondary and backup opportunities' VEEGA trajectories would be 1.8 x 10^{-3}. The total health effects mission risk (considering all launch phases and the Earth-Gravity-Assist trajectories) from the primary launch opportunity would be 1.7 x 10^{-3} and from the backup launch opportunity would be 1.8 x 10^{-3}. The health effects mission risks from the Cassini mission would be small and less than the total health risks faced by the public from construction and/or operation of large industrial projects.

The environmental impacts of a normal launch of the 1999 mission would be associated with the normal operations of the Shuttle. These Shuttle operations would result in temporary impacts on air and water quality near the launch site. Because this alternative would require two Shuttle launches, impacts would occur two times separated by 21 to 51 days.

During the second Shuttle launch for this mission alternative, certain accidents that may occur could result in a release of a portion of the plutonium dioxide from the RTGs to the environment. The local CCAS/KSC regional area could be impacted if a Phase 1 accident resulted in a release. Limited portions of the African land mass could be impacted by a Phase 2 accident, and Phases 3 and 4 accidents could impact indeterminate locations within the global area. In addition, releases could occur from an accident occurring during a short-term inadvertent reentry.

Potential failures and radiological consequences associated with the Earth swingby portions of the VEEGA trajectory would be expected to be identical to those analyzed for the VEEGA swingbys for the 1999 backup launch opportunity of the Proposed Action.

Using estimation methods similar to that for the Proposed Action, the health effects mission risk over all the mission launch phases for the 1999 mission alternative is 2.1 x 10^{-6}. The corresponding risk from a short-term inadvertent reentry during the Earth swingby portion of the VEEGA trajectories would be 1.8 x 10^{-3}, and the total health effects mission risk would be 1.8 x 10^{-3}.

The environmental impacts of a normal launch of the 2001 mission alternative would be similar to those estimated for the Proposed Action. The spacecraft with a high performance rhenium propulsion engine would be launched on the Titan IV (SRMU)/Centaur. The launch accident scenarios that could result in a release of plutonium dioxide fuel and the associated consequences and risks would be identical to those evaluated for the Proposed Action. The overall health effects mission risk from the launch phases is 8.4 x 10^{-7}. The primary launch opportunity of this 2001 mission alternative would not use the Earth for a gravity-assist (the trajectory is a VVVGA); subsequently, there would be no consequences and health effects mission risks associated with a short-term inadvertent reentry. Because there is no non-EGA backup launch opportunity for the 2001 mission alternative, the backup opportunity would use a VEEGA. The health effects mission risk from the backup short-term inadvertent reentry is 1.8 x 10^{-3}. The overall health effects mission risk from the primary opportunity is 8.4×10^{-7} and from the backup is 1.8×10^{-3}.

For all launch opportunities, should the spacecraft become uncommandable any time after injection into its interplanetary trajectory and before the final planetary gravity-assist, the spacecraft could eventually reenter the Earth's atmosphere a decade to centuries later (i.e., long-term inadvertent reentry scenario). The health effects mission risk of such an event is assumed to be similar (i.e., same order of magnitude) to that estimated for the short-term inadvertent reentry for the primary launch opportunity associated with the Proposed Action.

No environmental impacts would be associated with the No-Action alternative.

MISSION-SPECIFIC CONSIDERATIONS

The Proposed Action has the greatest potential to accomplish the mission and its scientific objectives. In addition, because the Proposed Action would ensure that adequate performance margins are available (e.g., spacecraft propellant available for maneuvers during the Saturn science tour), it would have the greatest likelihood to take advantage of both planned and unplanned opportunities for science return. The expected science return for the Proposed Action's December 1997 and March 1999 contingency launch opportunities would be less due to the later arrival time at Saturn. For similar reasons, the expected science return for the 1999 mission alternative using the two-Shuttle launch would be less than the return obtained from the Proposed Action.

Although the 2001 mission alternative would achieve most of the planned science objectives, it would not return as much science as the Proposed Action. The larger propellant tank and propellant load would reduce the overall mission performance, requiring the use of a specially developed rhenium spacecraft propulsion engine. Even with the use of this more efficient propulsion engine, the number of Titan flybys would be reduced from 35 to 21. Other trajectory adjustments would be necessary to conserve propellant. In addition to reducing the opportunity for obtaining the planned science return, the ability of the spacecraft to take advantage of unplanned discoveries would be limited. Because this alternative requires a longer flight time than the Proposed Action, and the launch would be delayed relative to the primary launch opportunity, the international partnerships formed to develop the Cassini spacecraft, Huygens Probe, and other space-related projects could be disrupted.

Because the No-Action alternative would cancel the mission, the science return would be lost, and the ability of the United States to enter into future international agreements for cooperative space activities could be impaired.

TABLE OF CONTENTS

Section Page

TABLE OF CONTENTS (Continued)

Section Page

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Section Page

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

Section Page

APPENDICES:

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

ABBREVIATIONS AND ACRONYMS

A

a	Acre
AACS	Attitude and Articulation Control Subsystem
ACS	Active Cooling System
ADS	Automatic Destruct System
AGE	Aerospace Ground Equipment (Building)
AIAA	American Institute of Aeronautics and Astronautics
AIHA	American Industrial Hygiene Association
Al_2O_3	aluminum oxide
AMTEC	alkali metal thermoelectric converter
APSA	Advanced Photovoltaic Solar Array
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
ASRM	advanced solid rocket motor
AU	astronomical unit(s)

B

BACT	Best Available Control Technology
BEIR	biological effects of ionizing radiation
Bq	becquerel

C

°C	degrees centigrade (Celsius)
CAA	Clean Air Act
CBCF	carbon-bonded carbon fiber
CCAFS	Cape Canaveral Air Force Station
CCAS	Cape Canaveral Air Station
CDF	cumulative distribution function
CDS	Command and Data Subsystem
CED	Committed Effective Dose
CELV	Complementary Expendable Launch Vehicle
CFR	Code of Federal Regulations
Ci	Curie
Cl_2	Chlorine
cm	centimeter
cm^3	cubic centimeters
Cm-244	Curium-244
CO	carbon monoxide
CO_2	carbon dioxide

CSA	concentrated solar array
CSD	Command Shutdown and Destruct
CSDS	Command Shutdown and Destruct System
CRAF	Comet Rendezvous Asteroid Flyby

D

dBA	decibels (A-weighted)
DCU	digital control unit
DEIS	Draft Environmental Impact Statement
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
DOT	U.S. Department of Transportation

E

EA	Environmental Assessment
ECFRPC	East Central Florida Regional Planning Council
EGA	Earth-Gravity-Assist
EJGA	Earth-Jupiter-Gravity-Assist
EIS	Environmental Impact Statement
EMC	electromagnetic compatibility
EPA	U.S. Environmental Protection Agency
ESA	European Space Agency
ESD	electrostatic discharge
ET	external tank

F

FCO	Flight Control Officer
FDEP	Florida Department of Environmental Protection
FDNR	Florida Department of Natural Resources
FEIS	Final Environmental Impact Statement
FGFWFC	Florida Game and Fresh Water Fish Commission
FMEA	Failure Mode Effects and Analysis
FOV	field-of-view
FR	Federal Register
FSAR	Final Safety Analysis Report
FSU	Florida State University
ft/s	feet per second
FTS	Flight Termination System
FVIS	fuel vapor incineration system
FWPF	fine weave pierced fabric

FWS	Fish and Wildlife Service
FY	fiscal year

G

g	gram
GaAs	gallium arsenide
GE	General Electric Company
Ge	germanium
GIS	graphite impact shell
GPHS	General Purpose Heat Source

H

H_2	hydrogen
H_2O	water
ha	hectare
HCl	hydrochloric acid or hydrogen chloride
HNO_3	nitric acid
HTPB	hydroxyl terminated polybutadiene

I

IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IIP	instantaneous impact point
INSRP	Interagency Nuclear Safety Review Panel
ISDS	inadvertent separation and destruct system
ITL	Integrate Transfer and Launch
IUS	Inertial Upper Stage

J

JGA	Jupiter-Gravity-Assist
JPL	Jet Propulsion Laboratory, California Institute of Technology
JSC	Johnson Space Center, NASA

K

kg	kilogram(s)
km/s	kilometers per second
km^2	square kilometer(s)
KSC	Kennedy Space Center, NASA

L

LASEP	Launch Accident Scenario Evaluation Program
lb	pounds
LEO	low earth orbit
LH_2	liquid hydrogen
LILT	low (insolation) intensity and low temperature
LO_2	liquid oxygen
LWRHU	lightweight radioisotope heater units

M

MECO	Main Engine Cutoff
MET	mission elapsed time
mg/l	milligram per liter
MHW	Multi-Hundred-Watt
MIL-STD	Military Standard
MINWR	Merritt Island National Wildlife Refuge
mm	millimeter
MMH	monomethylhydrazine
MPa	10^6 pascals
mrem	millirem
m/s	meters per second
MSA	Metropolitan Statistical Area
MST	Mobile Service Tower

N

N	Newton
N_2H_4	hydrazine
N_2O_4	nitrogen tetroxide (NTO)
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection and Measurements
NEP	Nuclear Electric Propulsion
NEPA	National Environmental Policy Act

NESHAP	National Emissions Standards for Hazardous Air Pollutants
NOAA	National Oceanic and Atmospheric Administration
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NOI	Notice of Intent
NRC	U.S. Nuclear Regulatory Commission
NSI	NASA standard initiator
NTO	nitrogen tetroxide (N_2O_4)

O

O_2	oxygen
O_3	ozone
OFW	Outstanding Florida Waters
OH^-	hydroxide ion
OMS	Orbital Maneuvering System
OSSE	Outer Solar System Exploration Program
OSTP	Office of Science and Technology Policy
OVSS	oxidizer vapor scrubber system

P

P	probability
PAFB	Patrick Air Force Base, USAF
PAMS	Permanent Air Monitoring Station
PAM-S	Payload Assist Module - Special
PBAN	polybutadiene acrylonitrile
PCAD	Products of Combustion and Dispersion Air Quality Model
pCi/l	picocurie/liter
PD/NSC-25	Presidential Directive/National Security Council Memorandum #25
PEL	permissible exposure limits
PG	pyrolytic graphite
pH	measure of acidity of $-\log[H^+]$
PHSF	Payload Hazardous Servicing Facility
PLF	payload fairing
PMS	propulsion module subsystem
ppb	parts per billion
ppm	parts per million
PQM-1	Preliminary Qualification Motor No. 1
PSAR	Preliminary Safety Analysis Report
psi	pounds per square inch
Pt	platinum
Pu	plutonium
PuO_2	plutonium dioxide

R

REEDM	Rocket Effluent Exhaust Dispersion Model
rem	roentgen equivalent man
RHU	radioisotope heater unit
ROD	Record of Decision
RTG	radioisotope thermoelectric generator

S

s	seconds
SAEF	Spacecraft Assembly and Encapsulation Facility
SAR	Safety Analysis Report
SCS	Soil Conservation Service, U.S. Department of Agriculture
SEP	Solar-Electric Propulsion
SER	Safety Evaluation Report
Si	silicon
SiGe	silicon germanium
SNAP	Systems for Nuclear Auxiliary Power
SO_2	sulfur dioxide
SOI	Saturn Orbit Insertion
SR	State Route
Sr-90	strontium-90
SRB	solid rocket booster
SRM	solid rocket motor
SRMU	solid rocket motor upgrade
SSME	Space Shuttle main engines
STP	sewage treatment plant
STP	Solar-Thermal Propulsion
STS	Space Transportation System (Shuttle)
STS-IUS	Space Transportation System - Inertial Upper Stage
Sv	Sievert
SV	Satellite Vehicle
SVDS	space vehicle destruct system

T

TOMS	total ozone mapping spectrometer
TP	total phosphate

U

μCi	microcuries
μg/m^3	micrograms per cubic meter
UDMH	unsymmetrical dimethylhydrazine
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USAEC	U.S. Atomic Energy Commission
USAF	U.S. Air Force
UT	Umbilical Tower

V

VAB	Vehicle Assembly Building
VEEGA	Venus-Earth-Earth-Gravity-Assist
VIB	Vertical Integration Building
VVEJGA	Venus-Venus-Earth-Jupiter-Gravity-Assist
VVVGA	Venus-Venus-Venus-Gravity-Assist
VVVJGA	Venus-Venus-Venus-Jupiter-Gravity-Assist

W

W	Watt
WIND	Weather Information Network Display
WMO	World Meteorological Organization

1. PURPOSE AND NEED FOR ACTION

This Final Environmental Impact Statement (FEIS) has been prepared by the National Aeronautics and Space Administration (NASA) to support the decision-making process as required by the National Environmental Policy Act (NEPA) and provides information associated with potential environmental impacts that could be caused by implementation of the Cassini mission and feasible alternatives. The Proposed Action consists of preparing for and implementing the Cassini mission to conduct a 4-year scientific exploration of Saturn, its atmosphere, moons, rings, and magnetosphere. In addition, the Huygens Probe would be released from the Cassini spacecraft into the atmosphere of Saturn's largest moon, Titan, to collect data. The primary launch opportunity is planned for October 1997 from Cape Canaveral Air Station (CCAS), Florida, on a Titan IV (Solid Rocket Motor Upgrade [SRMU] or Solid Rocket Motor [SRM])/Centaur. The Centaur would inject the Cassini spacecraft into a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn. If the spacecraft could not be launched in October 1997, it would be launched from CCAS during one of the two contingency launch opportunities (December 1997 and March 1999) and would use a Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory. In the event that the Titan IV (SRMU)/Centaur configuration were not available, a Titan IV (SRM)/Centaur configuration would be used. The Titan IV (SRM)/Centaur launch opportunities and associated trajectories for the Proposed Action would essentially be the same as those for the SRMU. Section 2 of this EIS evaluates the alternatives considered to achieve the mission.

1.1 BACKGROUND

The Cassini mission is an international cooperative effort of NASA, the European Space Agency (ESA), and the Italian Space Agency (ASI) to explore the planet Saturn and its moons, particularly its largest moon, Titan. The mission would include a 4-year tour of the Saturnian system. A few months after arrival at Saturn, the Cassini spacecraft would release the Huygens Probe for its descent through the atmosphere of Titan. The Probe would collect data on the composition of Titan's atmosphere and haze layers and could also create images of Titan's surface. These data would be essential in determining the properties of Titan. After delivering the Probe, the Cassini spacecraft would perform several swingbys of Saturn's icy satellites, acquire data on Saturn's rings from several angles, perform radar mapping of Titan's surface, and take measurements of Saturn's magnetosphere and charged-particle environment.

Depending upon the mission alternative, the launch vehicle and launch services would be provided either by NASA or the U.S. Air Force. NASA would provide the ground communications network and two scientific instruments for the Huygens Probe. ESA would provide the Huygens Probe, and ASI would provide major elements of the Cassini Orbiter's communications equipment and elements of several science instruments. Several of the ESA member states would make independent contributions to the Cassini science investigation.

The Cassini mission is part of NASA's program for the exploration of the solar system. The goal of this program is to understand the birth and evolution of the planetary system using a strategy that requires an orderly progression in the level of investigation. This progression involves initial planetary reconnaissance missions, followed by more intensive exploratory missions within each of the three regions of the solar system: the inner solar system (terrestrial planets), the primitive bodies (comets and asteroids), and the outer solar system (the gas giants and Pluto). General scientific objectives for exploration of the outer planets, and of the Saturnian system in particular, have been established by the appropriate scientific advisory committees, including the Committee on Planetary and Lunar Exploration of the National Research Council's Space Science Board (currently Space Studies Board) and the NASA Advisory Council's Solar System Exploration Committee. Until recently, missions to the outer solar system concentrated on flyby or reconnaissance-type missions. With the launch of the Galileo mission to Jupiter in 1989, however, NASA began the transition to more detailed orbital and *in-situ* probe missions. The Cassini mission to Saturn continues the more detailed exploration of the outer solar system.

Whenever a Federal agency proposes to undertake a major action that can significantly affect the quality of the human environment, NEPA of 1969 (42 USC 4321 et seq.), as amended, and the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of NEPA (40 CFR Parts 1500-1508) require the agency to undertake the systematic examination of possible and probable environmental consequences of the Proposed Action and its alternatives. NASA's policy and regulations (14 CFR Subpart 1216.3) require the preparation of an EIS for the development or operation of nuclear systems as provided for at 14 CFR 1216.305(c)(3). This EIS provides the required environmental documentation associated with the decision-making process for the Cassini mission.

The approach to providing environmental documentation for the Cassini mission, including this mission-specific EIS, has been the product of an evolving process. On February 27, 1991, NASA published a Notice of Intent in the *Federal Register* (56 FR 8219) to prepare a programmatic EIS for future activities under NASA's Outer Solar System Exploration (OSSE) program, as well as for two OSSE missions that were planned in February 1991—the Comet Rendezvous Asteroid Flyby (CRAF) mission and the Cassini mission. At that time, these two missions, as well as other future OSSE missions under consideration (e.g., the Comet Nucleus Sample Return mission and the Neptune Orbiter-Triton Probe), were to share a number of similar requirements for launch energy, electrical power, onboard propulsion, and guidance and control. A common multipurpose, multimission spacecraft design, the Mariner Mark II, was being developed to satisfy these similar requirements for reducing the overall cost of each OSSE program.

In January 1992, budget proposals deleted funding for the CRAF mission, future OSSE missions were being reassessed, and the multipurpose Mariner Mark II spacecraft design efforts were redirected toward lighter, cheaper mission-specific spacecraft. These changes, particularly the move toward mission-specific spacecraft, reduced and/or eliminated many of the commonalities in near-term and future OSSE missions that formed the basis for the Mariner Mark II and the programmatic EIS.

On October 7, 1992, NASA published an information update in the *Federal Register* (57 FR 46198) outlining the developments and changes noted above and indicated that, because of these changes, the EIS effort would be redirected to a mission-specific EIS for the Cassini mission only. The mission-specific EIS for the Cassini mission was started shortly after this update was published. The environmental issues raised during the scoping period included numerous comments specific to the Cassini mission. Relevant issues raised during the scoping period, as well as timely comments on the Draft EIS, are addressed in this mission-specific Final EIS.

The analyses in this EIS rely upon numerous supporting studies that address operational parameters and hypothetical accident scenarios that could be associated with the mission. The studies were prepared by contractors for NASA (Martin Marietta Space Launch Systems (currently Lockheed Martin) and the Jet Propulsion Laboratory [JPL]) and by contractors for the U.S. Department of Energy (DOE) (Martin Marietta Astro Space and Halliburton NUS). Martin Marietta Space Launch Systems developed the *Titan IV CRAF/Cassini EIS Databook* (Martin Marietta 1992), which identifies operational parameters for the Titan IV (SRMU)/Centaur and describes the representative launch accident scenarios, accident environments, and initiating probabilities. The JPL supporting studies (JPL 1993a, JPL 1993f, JPL 1994a), originally initiated to support the programmatic EIS, address the Cassini spacecraft and the major elements of overall mission design. The JPL supporting studies evaluate major mission components, such as spacecraft electrical power systems and propulsion systems, as well as trajectories and launch vehicles. The DOE-sponsored studies (Martin Marietta Astro Space 1993, Martin Marietta Astro Space 1994b, Martin Marietta Astro Space 1994c, Halliburton NUS 1994a, Halliburton NUS 1994b) specific to the Cassini mission focus on the consequences of the potential accidents involving the plutonium dioxide-fueled radioisotope thermoelectric generators (RTGs) onboard the spacecraft.

The major components of the proposed Cassini mission including spacecraft electrical power systems, trajectories to Saturn, and available launch vehicles, were evaluated in detail in developing the overall mission profile for the Proposed Action (JPL 1993a, JPL 1993f, JPL 1994a). Section 2 of this EIS summarizes these evaluations. The Proposed Action consists of preparing for and implementing the Cassini mission during the primary launch opportunity in October 1997 (or during a secondary opportunity in December 1997 or during the backup launch opportunity in March 1999) to conduct a 4-year scientific exploration of the planet Saturn, its atmosphere, moons, rings, and magnetosphere. All launch opportunities associated with the Proposed Action would use the Titan IV (SRMU or SRM)/Centaur. The proposed launch site would be either Launch Complex 40 or 41 at CCAS in Florida.

The Cassini mission would use a gravity-assist trajectory to enable it to reach Saturn. The primary launch opportunity in October 1997 would boost Cassini into a 6.7-year VVEJGA trajectory to reach Saturn. The VVEJGA trajectory would use two swingbys of Venus in April 1998 and June 1999, followed by an Earth swingby in August 1999 and a Jupiter swingby in December 2000 to boost speed and reach Saturn in June 2004. The secondary launch opportunity in December 1997 would involve an 8.8-year VEEGA trajectory, arriving at Saturn in October 2006. The backup launch opportunity in March 1999 would place Cassini on a 9.8-year VEEGA trajectory to Saturn. The Venus swingby would occur in June 2000, with the two Earth swingbys occurring in August 2001 and August 2004, arriving at Saturn in 2008. With all launch opportunities, soon after reaching Saturn, the spacecraft would release the Huygens Probe and begin its tour of Saturn and its rings, moons, and magnetosphere.

Spacecraft power systems were extensively evaluated for the Cassini mission (JPL 1994a). RTGs were determined to be the only reliable electric generating technology presently available and tested for use in space. RTGs have the ability to meet the electrical needs of the Cassini spacecraft and its instruments during the 10 or more years required for the spacecraft to reach Saturn and accomplish its science objectives. Three RTGs would be used for the Cassini spacecraft. Each RTG would be fueled with approximately 10.8 kg (23.8 lb) of plutonium dioxide. In addition, a maximum of 157 one-watt thermal radioisotope heater units, each containing 2.7 g (0.006 lb) of plutonium dioxide, would be onboard to maintain the temperatures required for certain scientific instruments, other spacecraft subsystems, and the Huygens Probe.

1.2 PURPOSE OF THE PROPOSED ACTION

The overall objective of the Cassini mission is to conduct an extended investigation of the Saturnian system, making closeup measurements of the planet and its environment (JPL 1993a). Saturn is the second-largest and the second most-massive planet in the solar system. It also has the largest, most visible, dynamic ring structure. Because of these unusual characteristics, Saturn has been the subject of telescopic observations for centuries. The Pioneer 11, Voyager 1, and Voyager 2 swingby missions provided additional data on Saturn. Many questions remain about Saturn and its moons and rings that, if answered, could provide clues to the evolution of the solar system and the origin of life on Earth. Such questions include (JPL 1993a):

- By what processes did Saturn acquire so much orbital debris, what processes organized the debris into the intricate structure of rings and embedded moonlets now surrounding the planet, and what is the composition of this debris?
- How does the chemical and physical composition of Saturn compare with that of Jupiter and Earth?
- What is the nature of Saturn's magnetospheric interactions with dust and moonlets in the ring plane and what would this information tell us about the interactions of plasma, dust, and radiation environment at the beginning of the solar system?
- What chemical processes produced the atmosphere of hydrocarbons and other organic molecules unique to Saturn's largest moon, Titan, and do these hydrocarbons exist in liquid form on Titan's surface?
- Does the dark hemisphere of Iapetus, one of Saturn's icy moons, consist of organic material, and is this material related to the organic material in Titan's atmosphere and to the dark material on comets, asteroids, and the dark moons of Mars (Phobos and Deimos)?

The Cassini mission would gather data to answer these and other questions by investigating five major aspects of the Saturnian system: Saturn's atmosphere; the largest moon, Titan; Saturn's icy satellites (i.e., moons); Saturn's rings; and Saturn's magnetosphere. In pursuing these planned investigations, unplanned opportunities for science returns could also occur. Some of the major discoveries of the Voyager mission (e.g., volcanism on Io; rings at Jupiter, Uranus, and Neptune; ring spokes at Saturn) were not even planned at the time of launch. The Cassini mission has several scientific objectives, which are summarized in Table 1-1. These objectives would be accomplished through two separate mission elements:

- The Cassini spacecraft would tour and study Saturn, its rings, moons, and magnetosphere over a 4-year period. This portion of the mission would include approximately 35 flybys of Titan for the SRMU configuration (or 21 for SRM launch) enabling detailed studies of Titan's atmosphere and surface.
- A detachable atmospheric entry probe, the Huygens Probe, would be released from the Cassini spacecraft to descend through the atmosphere of Titan. Surface properties of Titan would be measured *in-situ* if the Probe survives the parachuted touchdown. The Probe would relay scientific measurements of the conditions of Titan's atmosphere to Earth via the Cassini spacecraft over the 2.5-hour period it would take for the Probe to descend to Titan's surface.

Opportunities for acquiring unplanned science data could occur at any time during the 4-year tour as well. The following subsections provide more detail on the five aspects of the Saturnian system planned to be investigated during the mission.

1.2.1 Investigation of Saturn's Atmosphere

The previous Pioneer and Voyager swingby missions to Saturn obtained only short-duration, remote-sensing measurements of the Saturnian atmosphere. These measurements have been sufficient to generally determine the basic composition, energy balance, temperature profile, and wind speeds in the planet's upper atmosphere. Cassini would further investigate cloud properties and atmospheric composition, wind patterns, and temperatures, as well as Saturn's internal structure, rotation, ionosphere, and origin and evolution. The mission would involve orbits near the equator and the poles of Saturn so that the entire planet could be studied.

1.2.2 Investigation of the Moon Titan

Titan is shrouded by dense clouds; therefore, little is known about its surface. Data collected by the instruments onboard the Cassini orbiter and the Huygens Probe would provide a better understanding of the abundance of elements and compounds in Titan's atmosphere, the distribution of trace gases and aerosols, winds and temperature, and surface state and composition. In particular, the spacecraft's radar would penetrate Titan's dense atmosphere and reveal the moon's surface characteristics, just as the Magellan spacecraft did at Venus. The Huygens Probe, carrying a robotic laboratory, would perform chemical analyses of Titan's atmosphere and clouds. As the Probe descends, the onboard instruments would measure the temperature, pressure, density, and

TABLE 1-1. SUMMARY OF CASSINI MISSION SCIENTIFIC OBJECTIVES

Investigation Focus	Scientific Objectives
Saturn's Atmosphere	• Determine the temperature field, cloud properties, and composition of the atmosphere of Saturn. • Measure the global wind field, including wave and eddy components, and observe synoptic cloud features and processes. • Infer the internal structure and rotation of the deep atmosphere. • Study the diurnal variations and magnetic control of the ionosphere of Saturn. • Provide observational constraints (e.g., gas composition, isotope ratios, and heat flux) on scenarios for the formation and evolution of Saturn. • Investigate the sources and morphology of Saturn lightning, including Saturn electrostatic discharges and lightning whistlers.
Titan	• Determine abundances of atmospheric constituents (including any noble gases), establish isotope ratios for abundant elements, and constrain scenarios of formation and evolution of Titan and its atmosphere. • Observe vertical and horizontal distributions of trace gases, search for more complex organic molecules, investigate energy sources for atmospheric chemistry, model the photochemistry of the stratosphere, and study the formation and composition of aerosols. • Measure winds and global temperatures; investigate cloud physics, general circulation, and seasonal effects in Titan's atmosphere; and search for lightning discharges. • Determine the physical state, topography, and composition of the surface and infer the internal structure of the satellite. • Investigate the upper atmosphere, its ionization, and its role as a source of neutral and ionized material for the magnetosphere of Saturn.
Saturn's Icy Satellites	• Determine the general characteristics and geological histories of the satellites. • Define the mechanisms of crustal and surface modifications, both external and internal. • Investigate the compositions and distributions of surface materials, particularly dark, organically rich materials and condensed volatiles with low melting points. • Constrain models of bulk compositions and internal structures. • Investigate interactions with the magnetosphere and ring systems and possible gas injections into the magnetosphere.
Saturn's Rings	• Study the configuration of the rings and dynamical processes (gravitational, viscous, erosional, and electromagnetic) responsible for ring structure. • Map the composition and size distribution of ring material. • Investigate the interrelation between the rings and satellites, including imbedded satellites. • Determine the dust and meteoroid distribution both in the vicinity of the rings and in near-Saturn interplanetary space. • Study the interactions between the rings and Saturn's magnetosphere, ionosphere, and atmosphere.
Saturn's Magnetosphere	• Determine the configuration of the nearly axially symmetric magnetic field and its relation to the modulation of Saturn Kilometric Radiation. • Determine the current systems, composition, sources, and sinks of magnetosphere-charged particles. • Investigate wave-particle interactions and dynamics of the day-side magnetosphere and the magnetotail of Saturn and their interactions with the solar wind, satellites, and rings. • Study the effect of Titan's interaction with the solar wind and magnetospheric plasma. • Investigate the interactions of Titan's atmosphere and exosphere with the surrounding plasma.

Source: JPL 1993a

energy balance through the atmosphere to the moon's surface. The surface properties would be measured remotely, and a camera would photograph the Titan panorama and relay the images to Earth via the Cassini Orbiter.

1.2.3 Investigation of Saturn's Icy Satellites

Saturn's other satellites (i.e., moons) are ice-covered bodies. Cassini would investigate their physical characteristics, the composition and distribution of materials on their surfaces, their internal structure, and how they interact with Saturn's magnetosphere. Of particular interest is the half-dark and half-light moon, Iapetus. The light side of the moon is believed to be composed of ice and the dark side possibly of some organic material. The data obtained by Cassini would assist in determining the geological histories of the satellites and the evolution of their surface characteristics.

1.2.4 Investigation of Saturn's Rings

The Voyager swingbys in 1980 and 1981 proved Saturn's ring system to be much more complex than previously realized, with intricate dynamic interactions in most parts of the system. The short-term Voyager studies showed a wide range of unexplained phenomena in the rings, including various wave patterns, small and large gaps, clumping of material and small, so-called "moonlets" embedded in the rings. Long-term, close-up observations of the rings by Cassini could help resolve whether the rings are material left over from Saturn's original formation, or whether they are remnants of one or more moons shattered by comet or meteor strikes. Applied to larger-scale disk-shaped systems, the detailed studies of Saturn's rings proposed for Cassini would provide important contributions to theories of the origin and evolution of the dust and gas from which the planets first formed.

The tilt of Saturn's ring plane changes as the planet orbits the Sun, and the changing angle of sunlight illuminating the rings dramatically alters their visibility. Cassini's arrival at Saturn is timed for optimum viewing of the rings, during a period when they will be well illuminated by sunlight. Upon arrival at Saturn in 2004 when launched in October 1997, the tilt of the ring plane and resulting illumination angle would allow Cassini's instruments an unsurpassed view of the ring disk.

Cassini would allow detailed studies of ring structure and composition, dynamic processes, dust and micrometeoroid environments, and interactions among the ring systems, magnetosphere, and satellites.

1.2.5 Investigation of Saturn's Magnetosphere

Saturn's magnetosphere is the region of space under the dominant influence of the planet's magnetic field. Cassini would carry instruments to study the configuration and dynamics of the magnetosphere; the nature, source, and fate of its trapped particles; and its interactions with the solar wind and Saturn's satellites and rings. A particular phenomenon of interest is the Saturn Kilometric Radiation—a poorly understood, very low frequency, electromagnetic radiation—which scientists believe is emitted by the auroral regions in Saturn's high latitudes.

1.2.6 Summary of Mission Purpose

The mission would not only provide clues to the evolution of the solar system but would also help increase the current understanding of the origin of life. Because the giant planets (i.e., Jupiter and Saturn) are so massive, they have retained essentially all the material from which they were originally formed. Consequently, these planets are expected to contain some record of early planetary formation. For example, the chemistry in Titan's atmosphere is thought to resemble Earth's atmosphere before life began. The icy satellites of the planets (Jupiter and Saturn) are cold, frozen worlds that record an evolution that, in some ways, parallels the evolution of the solar system as a whole. The examination of materials from such bodies could reveal clues about the substances present during the formation of the solar system and about the basic building blocks of life, such as the complex organic materials believed to be on Saturn's satellites. The exploration of the outer solar system by the Cassini mission is essential to answering some fundamental questions about the origins of life and our solar system.

1.3 NEED FOR THE ACTION

Conducting long-term, closeup measurements of Saturn and its moons, rings, and magnetosphere in the outer solar system represents an important step in the exploratory phase of planetary science. For example, the Huygens Probe would return data on the composition, temperature, and pressure of the atmosphere of Titan, Saturn's major moon. These data can be obtained by no other means. Although scientists would continue to study Saturn from Earth orbit and ground-based telescopes, the closeup measurements from the 4-year science tour and the Huygens Probe data that the Cassini mission would provide are otherwise unattainable. The detailed data would also provide a vital basis for our continuing Earth-based studies.

It is important that the Cassini mission is accomplished while the Voyager exploration results are recent and much of the associated scientific expertise is still available. There would be more than 23 years between the 1980 and 1981 flybys of Saturn by Voyagers 1 and 2 and the 2004 arrival of Cassini (for the primary launch opportunity) and an even longer period for the secondary or backup opportunities. It is also advantageous to complete the orbital tour before 2010 when Saturn's rings present themselves nearly edge-on to the Earth and Sun, severely limiting the ability for detailed observations.

1.4 INDIRECT BENEFITS FROM CASSINI MISSION PLANNING ACTIVITIES

1.4.1 Technology Utilization Benefits

Challenging scientific enterprises routinely result in technological advances which are applicable to other, unrelated fields. Some unexpected tangible benefits from planning for the Cassini mission have already been realized, as summarized below. Others will accrue as the preparation and implementation continue. Project planning and preliminary research and development activities for the mission have resulted in several significant technological innovations of direct benefit to industry, business, and environmental regulation.

Resource Trading System. A "resource trading system" was developed by the Cassini project planners to help resolve the conflicting cost, data rate and electrical power needs for the spacecraft's science instruments and other subsystems. The electronically-based planning tool has been utilized by California's South Coast Air Quality Management District in its implementation of a new market-based approach to regulating emissions in the Los Angeles Basin. Cassini's resource trading system was adapted by the Air Quality Management District to facilitate the buying and selling of emissions allowances by regulated facilities to help achieve federally-mandated emissions reductions. The states of Illinois, Indiana, Massachusetts, Texas and Wisconsin, and the city of Vancouver, B.C., Canada, have expressed interest in the Cassini system for use in similar environmental regulations programs.

Solid-State Recorder. One innovation developed for Cassini is a solid-state data recorder with no moving parts. The recorder has great potential for use in a variety of fields, from aerospace to the entertainment industry, and is expected eventually to find wide applicability in consumer electronics.

Powerful New Computer Chips. The main onboard computer that would direct operations of the Cassini Orbiter uses a novel design drawing on new families of electronic chips. Among them are very high-speed integrated circuit chips developed under a U.S. government-industry research and development initiative for dual-use technology. Powerful new application-specific integrated circuit parts have also been developed for Cassini; each component replaces a hundred or more traditional chips.

Solid-State Power Switch. An innovative solid-state power switch being developed for Cassini will eliminate rapid fluctuations, called transients, that usually occur with conventional power switches. The new switch also has no moving parts. This should result in significantly improved component lifetime and efficiency. The device is widely applicable to industrial and consumer electrical and electronic products.

Gyros. The Cassini spacecraft inertial reference units now under development represent the first space version of revolutionary new solid-state gyros. The new gyros promise greater reliability and less vulnerability to mechanical failure because they use no moving parts. These more robust gyros may eventually be used on most new spacecraft.

2. ALTERNATIVES, INCLUDING THE PROPOSED ACTION

2.1 ALTERNATIVES EVALUATED

This Final Environmental Impact Statement (FEIS) for the Cassini mission examines mission alternatives available for accomplishing the mission objectives within a reasonable timeframe, as well as the No-Action alternative. In the course of developing the mission alternatives, three major mission components—launch vehicles, mission trajectories to Saturn, and spacecraft electrical power sources—were examined in detail (JPL 1993a, JPL 1993f, JPL 1994a). These three mission components are the principal factors influencing the development of feasible mission designs (mission alternatives) that would allow the Cassini spacecraft to obtain at least the minimum acceptable science return and the overall mission objectives. These components are also the factors determining the potential environmental impacts associated with each mission alternative under normal (incident-free) and accident conditions. Section 2.6 summarizes the evaluations of these three major mission components and their availability in determining the mission alternatives.

The Cassini mission would continue the evolution of the National Aeronautics and Space Administration's (NASA) program for solar system exploration from reconnaissance-level or flyby missions of the outer planets to more detailed exploration missions. These exploration missions involve a wider range and a greater amount of scientific data that are much more difficult to gather than was the case for the earlier flyby missions. The range and amount of data collected by an exploration mission requires a power source to operate reliably over a long period of time. Gathering data for an outer space mission in the vicinity of Saturn where the Sun's intensity is only 1 percent of that experienced in Earth orbit requires a power source that can operate at vast distances from the Sun. These electrical power requirements must be fulfilled using a spacecraft design within the limited lift capacities of available launch vehicles.

Only a few combinations of launch vehicles, mission trajectories, and spacecraft electrical power sources can meet the requirements for the Cassini mission. The feasible launch vehicles evaluated include the most powerful U.S. launch vehicle, the Titan IV (solid rocket motor upgrade [SRMU])/Centaur and the Space Shuttle (i.e., Space Transportation System [STS]). If the new SRMU-equipped Titan IV could not be used, a Titan IV (SRM)/Centaur could be used. Mission trajectories include Earth- and non-Earth-Gravity-Assist trajectories to Saturn. Power system performance criteria require the use of the most reliable electrical power system capable of providing the large amounts of power needed over an extended period of time—the radioisotope thermoelectric generator (RTG). This EIS examines in detail the feasible components that combine to form the following mission alternatives:

- Proposed Action —NASA proposes to prepare for and implement the Cassini mission to collect scientific data from Saturn, its atmosphere, moons, rings, and magnetosphere. The spacecraft would be launched and inserted into a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn during the primary opportunity in October 1997 onboard a Titan IV (SRMU or SRM)/Centaur. A secondary launch opportunity exists in December 1997, with a backup opportunity in March 1999, both using a Venus-Earth-Earth-Gravity-

Assist (VEEGA) trajectory. The Proposed Action would enable the Cassini spacecraft to gather the full science return (i.e., data) desired to accomplish each of the mission science objectives. Achievement of the science objectives for the contingency launches would be essentially the same as for the primary launch opportunity but with some reduction in science return. In the event that a Titan IV (SRMU)/Centaur were unavailable, a Titan IV (SRM)/Centaur would be used with the same primary, secondary, and backup launch opportunities. The science objectives would be achieved but with reduced science return. The launch site for both the primary and contingency launch opportunities would be either Launch Complex 40 or 41 located at Cape Canaveral Air Station (CCAS) in Florida.

- 1999 Mission Alternative—For this mission alternative, preparations for and implementation of the Cassini mission to Saturn would involve dual manned Shuttle launches in 1999: one launch to predeploy an upper stage into Earth orbit and a second launch, separated by 21 to 51 days, to deliver the remaining upper stage(s) and the Cassini spacecraft into low Earth orbit. An on-orbit assembly of the upper stages with the spacecraft would occur, followed by upper stage ignition and insertion of the Cassini spacecraft in March 1999 into its 9.8-year VEEGA interplanetary trajectory. A backup launch opportunity, also a VEEGA, occurs in August 2000. This mission alternative, including both the primary and backup launch opportunities, would obtain less science return than the Titan IV (SRMU)/Centaur 1997 primary launch opportunity. The launch site for the primary and backup launch opportunities would be either Launch Pad 39A or 39B located at Kennedy Space Center (KSC) in Florida.

- 2001 Mission Alternative—This mission alternative consists of preparing for and implementing the Cassini mission to Saturn with a primary launch opportunity in March 2001. Launched from CCAS on a Titan IV (SRMU)/Centaur, the primary launch opportunity would place the spacecraft into a 10.3-year Venus-Venus-Venus-Gravity-Assist (VVVGA) trajectory to Saturn. There is no non-Earth-Gravity-Assist backup opportunity capable of meeting the science objectives that can be performed by a U.S. launch vehicle. However, a launch vehicle configuration has been identified that can perform an Earth-Gravity-Assist (EGA) trajectory. The Titan IV (SRMU)/Centaur could place the Cassini spacecraft into a VEEGA trajectory during a backup launch opportunity in May 2002. To perform the VVVGA trajectory, the Cassini spacecraft would require about 20 percent additional propellant and use a different spacecraft propulsion engine, a rhenium engine, to provide greater efficiency and higher performance. Even with the additional propellant and the high performance rhenium engine, limitations in the available propellant for spacecraft maneuvering at Saturn would restrict the acquisition of the desired amount of science return (JPL 1993i). However, the minimum acceptable level of science objectives for the mission could still be met.

- No-Action Alternative—Under the No-Action alternative, preparations for the launch would cease and the mission would not be implemented.

Figure 2-1 provides an overview of these alternatives. Sections 2.2, 2.3, 2.4, and 2.5 describe the alternatives in greater detail.

Section 2.6 summarizes the results of a complete evaluation of the launch vehicles, mission trajectories, and spacecraft electrical power systems, including components determined to be infeasible (JPL 1993a, JPL 1993f, JPL 1994a). Section 2.7 compares the mission alternatives evaluated, and Section 2.8 provides a brief overall summary.

2.2 DESCRIPTION OF THE PROPOSED ACTION

2.2.1 Mission Design

2.2.1.1 SRMU-Equipped Titan IV Configuration

The primary launch opportunity of the Cassini mission occurs within a 25-day launch period beginning October 6, 1997, and closing October 30, 1997 (JPL 1993a). Using the Titan IV (SRMU)/Centaur, described in Section 2.2.6, the spacecraft would be launched and injected into the 6.7-year VVEJGA interplanetary trajectory to Saturn, as shown in Figure 2-2.

After the spacecraft's launch and injection into interplanetary trajectory in October 1997, it would swing by the planet Venus for the first time in April 1998. Following a maneuver in December 1998, the spacecraft would be placed on a course for a second Venus swingby in June 1999. Because of the Earth's unique orientation relative to Venus during this time period, the spacecraft would fly on to Earth in slightly less than 2 months, where it would obtain its third planetary gravity-assist in August 1999. After flying past the Earth, the spacecraft would pass through the asteroid belt. The spacecraft would obtain a fourth and final gravity-assist at Jupiter in December 2000 before proceeding to Saturn. With these swingbys of Venus, Earth, and Jupiter, the spacecraft would gain sufficient velocity to reach Saturn.

For several months before arriving at Saturn in June 2004, the spacecraft would perform scientific observations of the planet prior to executing the Saturn Orbit Insertion (SOI) maneuver. This Saturn arrival date would provide the unique opportunity to have a distant flyby of Saturn's outer satellite Phoebe, 19 days before SOI. The SOI would place the spacecraft in a large elliptical orbit around Saturn. During the SOI, the spacecraft would be about 1.3 Saturn radii from the planet's center, its closest distance during the entire mission. This presents a unique opportunity to observe the inner regions of Saturn's ring system and magnetosphere; the 1.5-hour orbital insertion burn would be delayed from its optimal point to permit such observations (JPL 1993a).

Approximately three-quarters of the way around the SOI orbit and 3 weeks before Cassini's first flyby of Titan, the spacecraft would release the Huygens Probe on a trajectory for entry into Titan's atmosphere. Two days after release of the Probe, the Orbiter (i.e., the spacecraft without the Probe) would perform a deflection maneuver to be in position to receive scientific information gathered by the Probe during its estimated 2.5-hour parachute descent to Titan's surface. The data transmitted by the Probe would be stored on the Orbiter for later playback to Earth (JPL 1993c).

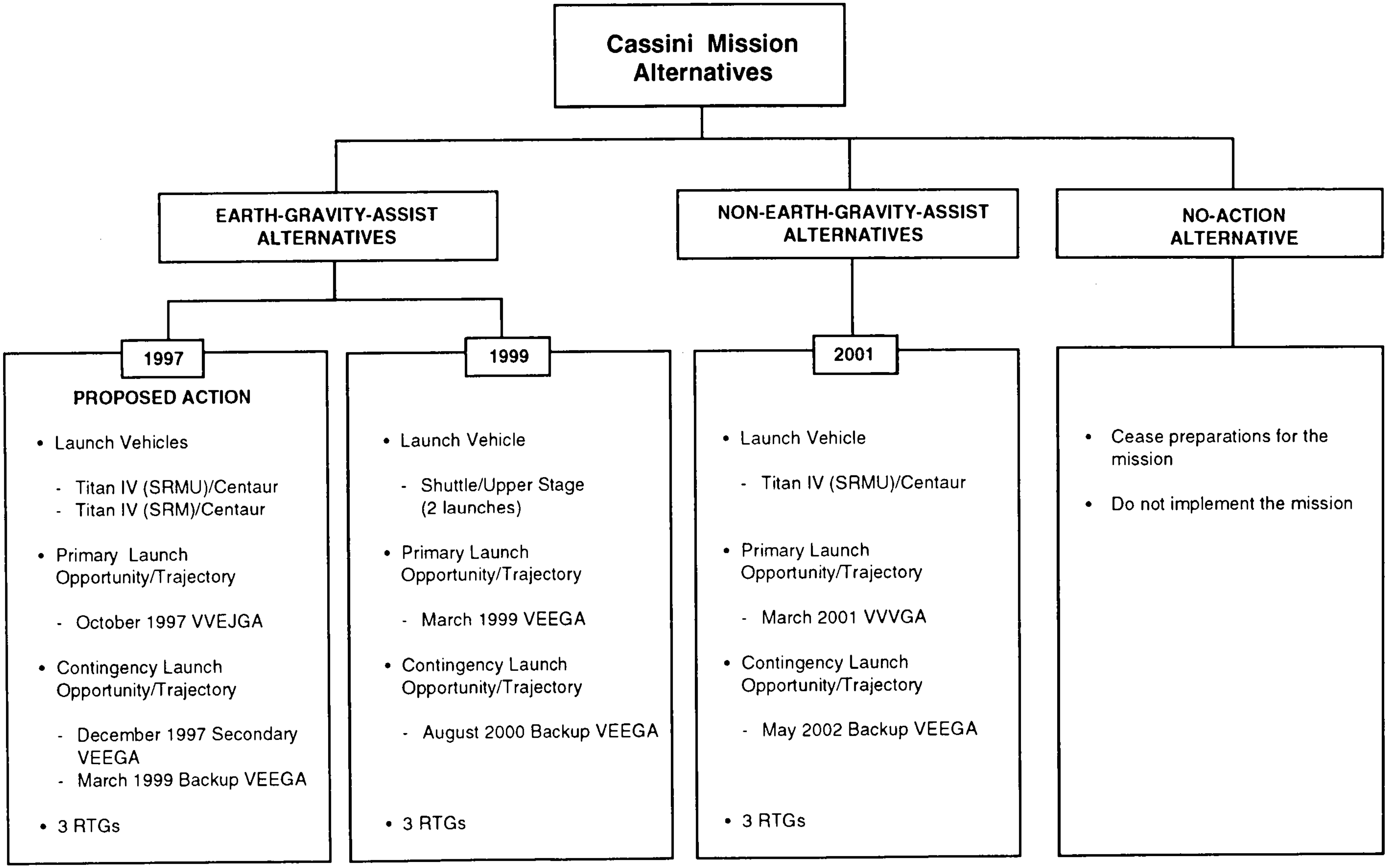
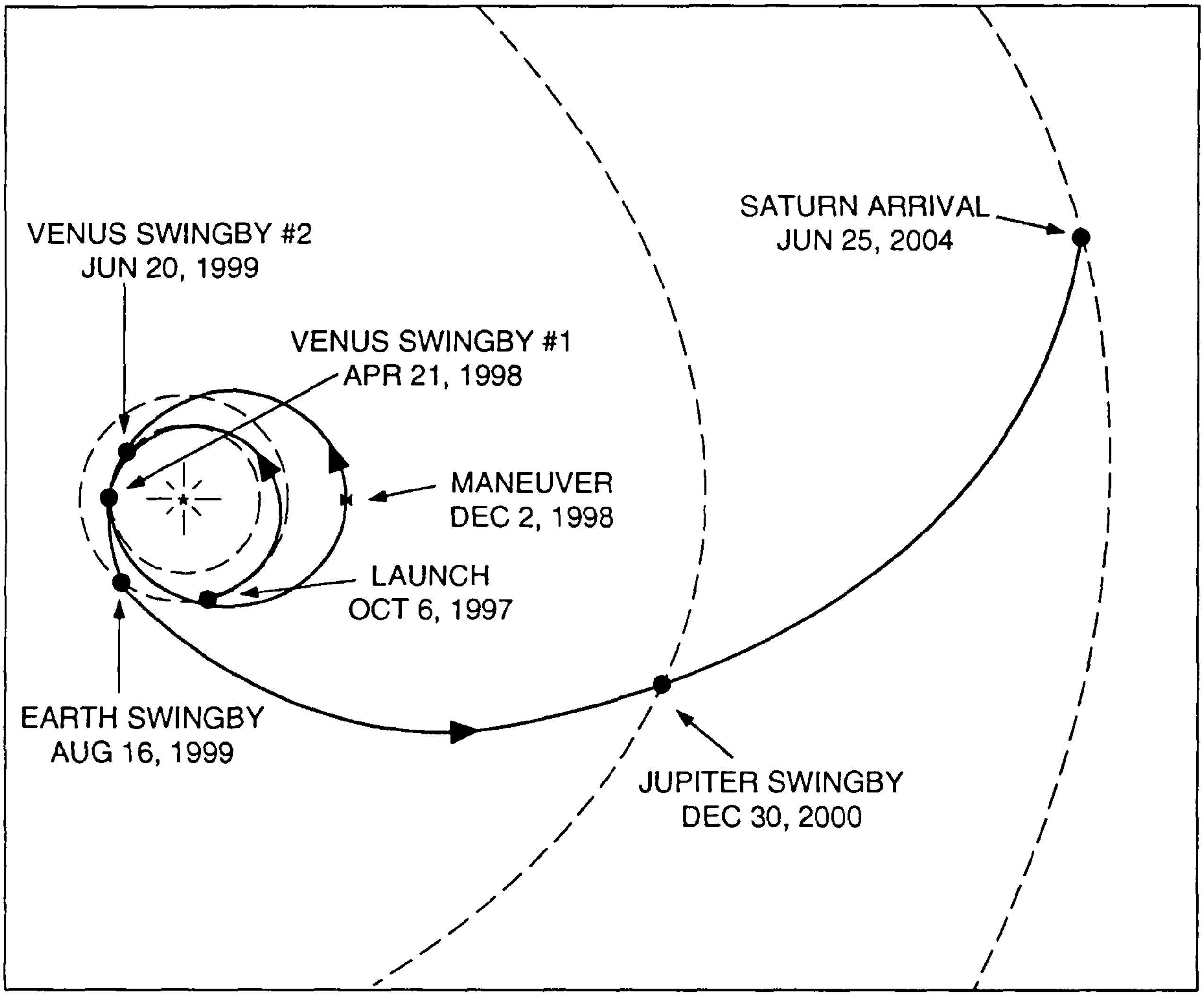


FIGURE 2-1. ALTERNATIVES EVALUATED FOR THE CASSINI MISSION



Source: JPL 1993a

FIGURE 2-2. CASSINI OCTOBER 1997 VVEJGA INTERPLANETARY TRAJECTORY

The spacecraft would then continue on its Saturn orbital tour, providing opportunities for ring imaging; magnetospheric coverage; and radio (Earth), solar, and stellar occultations of Saturn, Titan, and the ring system. A total of 35 close Titan flybys has been planned during the 4-year tour. The spacecraft would use repeated gravity-assist flybys of Titan and associated trajectory correction maneuvers to shape the trajectory. The spacecraft would also be targeted for 4 close flybys of selected icy satellites and would make 29 more distant satellite encounters. By the end of the 4-year tour, the orbital inclination would have been increased to approximately 80 degrees, allowing investigation from higher latitudes. In particular, the spacecraft would investigate the source of the unique Saturn Kilometric Radiation. Although the 10.7-year nominal mission would end in June 2008 (JPL 1993a), science data-gathering activities could continue, limited only by the remaining propellant and mission costs. The spacecraft would continue to orbit Saturn.

2.2.1.2 SRM-Equipped Titan IV Configuration

If the Titan IV SRMU were not available, the mission could be accomplished using the conventional Titan IV SRM configuration. The mission design in this case would be limited by the smaller mass injection capabilities of the SRMs. As currently designed (with the SRMUs), much of the mass that would be injected into the interplanetary trajectory would come from the propellant required for maneuvers during the mission. Reducing the propellant mass onboard the spacecraft would be required to allow a viable mission with this less capable launch configuration. The reduction in spacecraft propellant mass would require a reduction in maneuver activity by the spacecraft upon arrival at Saturn (JPL 1993c).

Specifically, the maneuver activity would be reduced in four major areas. First, the Saturn arrival date would be delayed by 5 months, from June (for the SRMU launch) to November 2004. The delay would decrease the propellant required by the SOI burn because the spacecraft's relative velocity at Saturn would be lower than that for the SRMU launch. Second, the initial orbit period would be increased, resulting in a further reduction of propellant required for SOI. Third, fewer Titan flybys would be planned to reduce the amount of fuel required to correct navigational errors in the trajectory. Fourth, the SOI burn would be centered optimally about the closest approach to Saturn, further reducing the SOI science return (JPL 1993c). The adjustments that would be made to compensate for the reduced injection capability and lower spacecraft bipropellant load necessitated by use of the SRMs are shown in Table 2-1.

TABLE 2-1. CASSINI MISSION CHARACTERISTICS FOR THE PROPOSED ACTION'S PRIMARY LAUNCH OPPORTUNITY USING EITHER A TITAN IV (SRMU)/CENTAUR OR TITAN IV (SRM)/CENTAUR

Mission Characteristics	SRMU	SRM
Launch Period	10/06/97 to 10/30/97	10/13/97 to 10/30/97
Bipropellant (kg [lb])	3,000 (6,614)	2,260 (4,982)
Saturn Arrival Date	06/25/2004	11/15/2004
SOI Burn Delay	Yes	No
Initial Orbit Period (days)	152	200
Titan Flybys	35	21

Source: JPL 1993c

2.2.2 Launch Opportunities

2.2.2.1 SRMU-Equipped Titan IV Configuration

Interplanetary missions can be launched only during specific opportunities (launch periods), depending on the relative positions of Earth and the target planet(s) and on the capabilities of the available launch vehicles. For the Proposed Action, the primary launch opportunity occurs during the 25-day period between October 6, 1997, and October 30, 1997. Problems with the launch vehicle or spacecraft or adverse weather conditions during this period could cause the loss of this primary launch opportunity. To recover from such unplanned events, NASA requires identification of contingency launch opportunities that would allow attainment of the same mission objectives (i.e., 4-year science tour and Probe delivery) as the primary launch opportunity. The mission planners have identified secondary and backup launch opportunities in December 1997 and March 1999, respectively, in case such conditions arise. Secondary launch opportunities, by definition, can occur less than 6 months after the primary launch opportunity; backup opportunities, however, are required to occur at least 6 months after the primary launch opportunity (JPL 1993c).

If a launch opportunity were missed, the spacecraft trajectories and mission operations would probably be altered and mission budgets augmented. Such a change would likely require modification of support facilities for communications, spacecraft tracking, and general operations. Revised launch plans would affect not only a delayed mission but also other missions that depend on the resources of these facilities. Because of the specialized nature of space exploration missions, such as Cassini, trained personnel and supporting facilities would generally be retained between launch opportunities, resulting in additional costs.

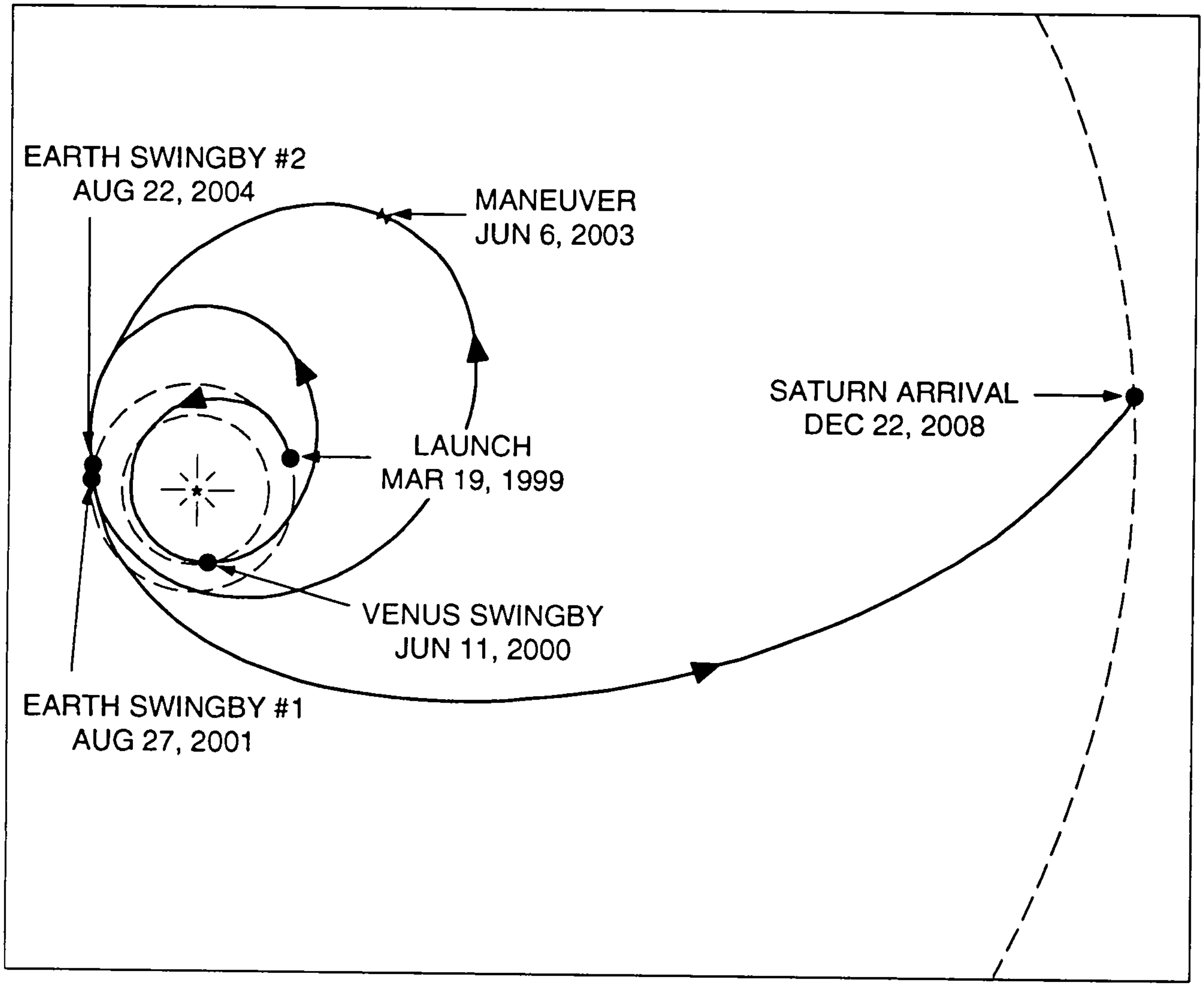
The secondary launch opportunity in December 1997, if utilized, would use an 8.8-year VEEGA trajectory. The interplanetary trajectory for the secondary launch opportunity would include a Venus swingby in June 1998, after which the spacecraft would proceed to Earth for 2 gravity-assists, during November 1999 and July 2002, respectively. The spacecraft would arrive at Saturn in October 2006. The launch opportunity would include a full 4-year tour of the Saturnian system and delivery of the Huygens Probe. The secondary launch opportunity would have a longer interplanetary cruise time and would return less ring science compared with the primary launch opportunity.

The March 1999 Titan IV (SRMU)/Centaur backup launch opportunity, illustrated in Figure 2-3, would use a 9.8-year VEEGA trajectory (JPL 1993a). This backup launch opportunity would have the same science objectives as the primary opportunity in October 1997, including the 4-year tour of Saturn's environment (JPL 1994a). The Huygens Probe experiments would be identical to those in the October 1997 launch. The interplanetary trajectory for the backup launch opportunity would include a Venus swingby in June 2000, after which the spacecraft would proceed to Earth for an additional gravity-assist in August 2001. This second assist would send the spacecraft on a broad sweeping arc through the asteroid belt. In August 2004, the spacecraft would arrive back at the Earth for a final gravity-assist and would arrive at Saturn in December 2008. The later arrival date would be less desirable than the arrival date for the October 1997 launch because there would be a 4-year delay in science return. In addition, the geometry of Saturn's rings would present less than optimum opportunities for both radio and optical science experiments. The 13.8-year nominal mission would end in December of 2012, about 4.5 years later than the primary launch opportunity.

Both the secondary and backup launch opportunities would have adequate allocations of propellant to meet the minimal science objectives. However, the longer flight times would result in lower electrical power output available from the RTGs during the science portion of the mission due to the natural decay of the radioisotopes. It would be during the last 4 years or the science portion of the mission that the electrical needs are greatest to power the science equipment and to perform data gathering activities. Therefore, fewer instruments could be operated at a given time or less engineering support given to some instruments (JPL 1993c). These mission constraints would reduce the science return from levels anticipated for the primary launch opportunity.

2.2.2.2 SRM-Equipped Titan IV Configuration

The launch opportunities for the Titan IV (SRM)/Centaur would be the same as those for the SRMU configuration. Because the SRM is a smaller booster with a lower lift capability, the amount of science return using the SRM-equipped Titan IV (for the same launch opportunities) would be less than that obtained with use of an SRMU-equipped Titan IV (JPL 1994a).



Source: JPL 1993f

FIGURE 2-3. CASSINI MARCH 1999 VEEGA INTERPLANETARY TRAJECTORY

2.2.3 Spacecraft Description

2.2.3.1 SRMU-Equipped Titan IV Configuration

The Cassini spacecraft, illustrated in Figure 2-4, is designed to be a three-axis stabilized probe-carrying orbiter for exploration of Saturn and its atmosphere, moons, rings, and magnetosphere. The Orbiter (i.e., the spacecraft without propellants or the Huygens Probe and its supporting equipment) would have a dry mass of 2,150 kg (4,740 lb), of which 335 kg (739 lb) are scientific instrumentation and 168 kg (370 lb) are the RTGs. The Huygens Probe and its supporting equipment would account for an additional mass of 352 kg (776 lb). The spacecraft launch vehicle adapter would add an additional 190 kg (419 lb). The spacecraft's most visible features would be the cylindrical shell structure. The main electronics and antennas would be mounted onto this structure. The primary bipropellant (hypergol fuels) tanks would be stacked within the shell. In addition, the main engines would be suspended from this structure. The RTGs would be supported by struts that extend from the base of the cylinder. The scientific instruments would be supported by a boom and two pallets or, in some cases, would be attached directly to the main structure (JPL 1993a). Less than 1 millicurie of minor radioactive sources (i.e., americium-241, barium-133, gadolidium-148, strontium-90, and rubidium-87) would be on the spacecraft, the Centaur, and the Probe, principally for instrument calibration.

The spacecraft would also contain communication, pyrotechnics, command and data, attitude and articulation control, propulsion, temperature control, and solid-state recorders subsystems.

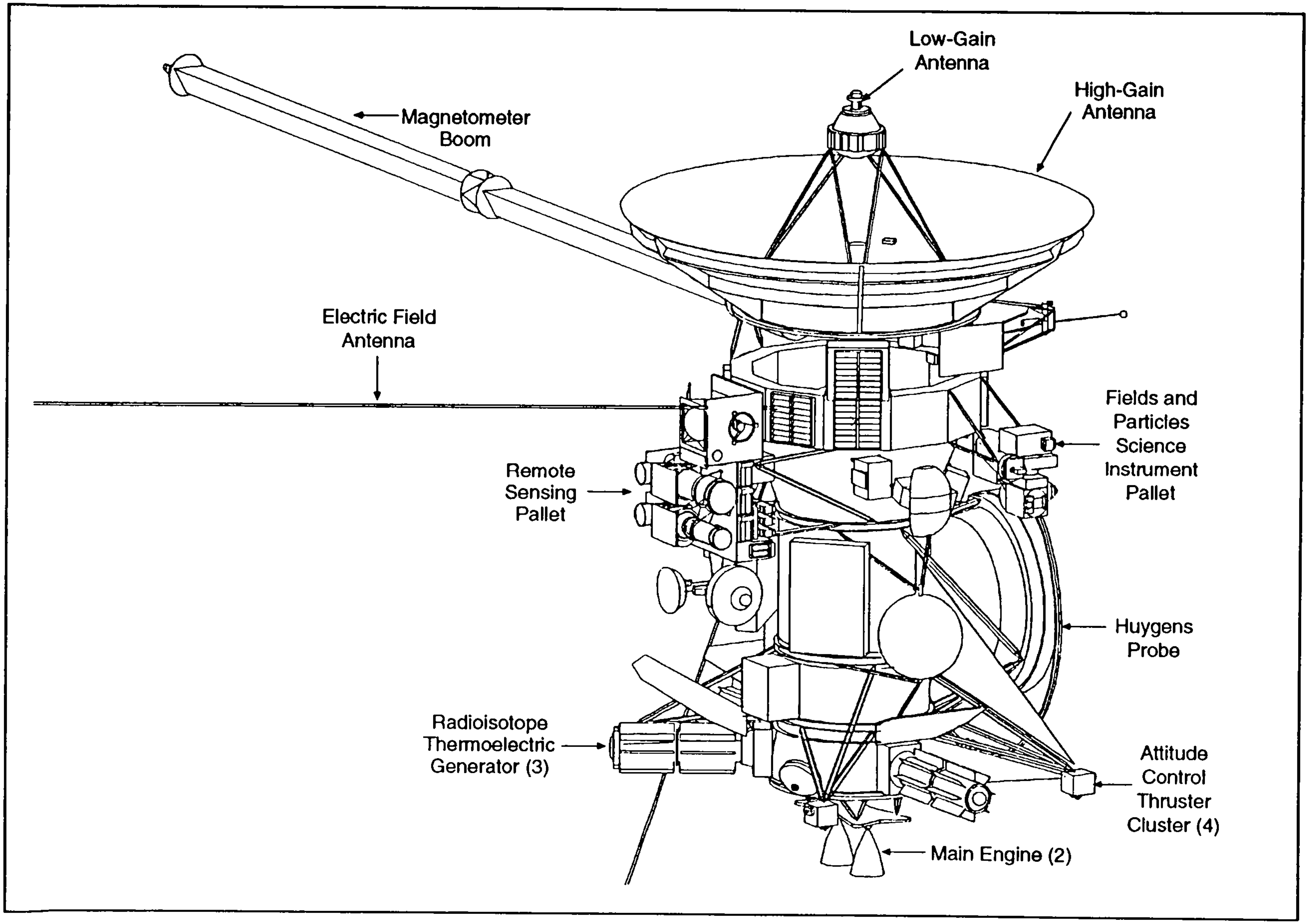
The components of the spacecraft relevant to any assessment of the potential for environmental impacts from the mission are the RTGs, the radioisotope heater units (RHUs), and the propellants. (RTGs and RHUs are discussed in Section 2.2.4.) For propellants, Cassini would carry up to 132 kg (291 lb) of hydrazine for small maneuvers and attitude and articulation control and about 3,000 kg (6,614 lb) of bipropellant (one tank each of monomethylhydrazine [MMH] and nitrogen tetroxide [NTO]) for larger maneuvers. The spacecraft (i.e., the Orbiter, the Probe and its supporting equipment, and the launch vehicle adapter), with propellants, would weigh 5,824 kg (12,840 lb) at launch (JPL 1993a).

2.2.3.2 SRM-Equipped Titan IV Configuration

If the Cassini spacecraft were to be launched using the Titan IV (SRM)/Centaur configuration, it would necessitate a reduction in the spacecraft bipropellant mass from 3,000 kg (6,614 lb) to 2,260 kg (4,982 lb) to compensate for the SRM's lower mass injection capabilities.

2.2.4 Spacecraft Electrical Power and Heating Sources

The Cassini spacecraft would use 3 RTGs as the source of electrical power for its engineering subsystems and science payload and a maximum of 157 RHUs to regulate temperatures of various subsystems on the spacecraft and the Probe (JPL 1994a). The



Source: JPL 1993a

FIGURE 2-4. DIAGRAM OF THE CASSINI SPACECRAFT

U.S. Department of Energy (DOE) would provide the RTGs and RHUs and would retain title to them at all times (DOE and NASA 1991).

2.2.4.1 Electrical Power System Performance Criteria

The Cassini spacecraft's 10.7-year mission (6.7-year VVEJGA trajectory plus 4-year Saturn tour) would impose stringent performance criteria for its systems and components. The electrical power requirement for the Cassini mission would be about 675 watts at end-of-mission (JPL 1994a). The mission would involve spacecraft-to-Sun distances of between 0.63 astronomical units (AU) and 9.3 AU (JPL 1994a) (an AU is the distance from the Earth to the Sun equal to 149,599,000 km [92,956,500 mi]). Therefore, the electrical power system must satisfy a variety of performance and implementability criteria, including the following:

- Operation during and after passage through intense radiation fields, such as those near the Earth and surrounding Jupiter
- Provision of sufficient power at distances of between 0.63 and 9.3 AU from the Sun
- Operation with a low mass-to-power ratio
- Provision of a long-term (12 years) source of electrical power with high reliability.

To fulfill these requirements, an indepth analysis of the available electrical power systems was performed to identify the most appropriate power source for the Cassini mission (JPL 1994a) (see Section 2.6.3). The use of RTGs was identified as the only feasible power system with the physical and operational characteristics compatible with achieving a high percentage of the science return from the Cassini mission. Previous performance and implementation criteria for other deep space missions have also identified RTGs as the only suitable power system, as was the case recently for both the Galileo and Ulysses missions (NASA 1989b, NASA 1990).

2.2.4.2 Radioisotope Thermoelectric Generators

The Cassini mission proposes to use three RTGs to provide electrical power to operate the spacecraft and its science instruments. An RTG power system uses an energy source and a conversion system. The decay heat from the radioactive energy source (plutonium dioxide) is directly converted into usable electrical energy by a thermoelectric converter.

RTGs were used on 23 previously flown U.S. space missions, including Voyager, Pioneer, Viking, all but the first of the manned Apollo flights, and the recent Galileo and Ulysses missions (Table 2-2). Heat source technology, pursued by DOE, has resulted in several models of an RTG power system, evolving from the Systems for Nuclear Auxiliary

TABLE 2-2. U.S. SPACECRAFT LAUNCHES INVOLVING NUCLEAR POWER SOURCES

Power Source (number of RTGs)	Spacecraft	Mission Type	Launch Date	Status	Power System Inventory of Pu at Launch (Curies)[a]
SNAP-3B7 (1)	TRANSIT 4A	Navigational	29 Jun 61	Currently in orbit	1,500 - 1,600
SNAP-3B8 (1)	TRANSIT 4B	Navigational	15 Nov 61	Currently in orbit	1,500 - 1,600
SNAP-9A (1)	TRANSIT 5BN-1	Navigational	28 Sep 63	Currently in orbit	17,000
SNAP-9A (1)	TRANSIT 5BN-2	Navigational	5 Dec 63	Currently in orbit	17,000
SNAP-9A (1)	TRANSIT 5BN-3	Navigational	21 Apr 64	Mission aborted; burned up on reentry as designed	17,000
SNAP-10A (reactor)	SNAPSHOT	Experimental	3 Apr 65	Successfully achieved orbit; after 43 days in orbit, was shut down	N/A
SNAP-19B2 (2)	NIMBUS-B-1	Meteorological	18 May 68	Mission aborted; heat source retrieved	34,400
SNAP-19B2 (2)	NIMBUS III	Meteorological	14 Apr 69	Currently in orbit	37,000
SNAP-27 (1)	APOLLO 12	Lunar	14 Nov 69	Station shut down	44,500
SNAP-27 (1)	APOLLO 13	Lunar	11 Apr 70	Mission aborted on way to moon; heat source fell in Pacific Ocean	44,500
SNAP-27 (1)	APOLLO 14	Lunar	31 Jan 71	Station shut down	44,500
SNAP-27 (1)	APOLLO 15	Lunar	26 Jul 71	Station shut down	44,500
SNAP-19 (4)	PIONEER 10	Planetary	2 Mar 72	Successfully operated to Jupiter and beyond	80,000
SNAP-27 (1)	APOLLO 16	Lunar	16 Apr 72	Station shut down	44,500
TRANSIT-RTG (1)	"TRANSIT" (TRIAD-01-1X)	Navigational	2 Sep 72	Currently in orbit	24,000
SNAP-27 (1)	APOLLO 17	Lunar	7 Dec 72	Station shut down	44,500
SNAP-19 (4)	PIONEER 11	Planetary	5 Apr 73	Successfully operated to Jupiter and Saturn and beyond	80,000
SNAP-19 (2)	VIKING 1	Mars	20 Aug 75	Lander shut down	~40,980
SNAP-19 (2)	VIKING 2	Mars	9 Sep 75	Lander shut down	~40,980
MHW-RTG (4) (2 each spacecraft)	LES 8/9	Communications	14 Mar 76	Currently in orbit	318,800
MHW-RTG (3)	VOYAGER 2	Planetary	20 Aug 77	Successfully operated to Neptune and beyond	240,000
MHW-RTG (3)	VOYAGER 1	Planetary	5 Sep 77	Successfully operated to Saturn and beyond	240,000
GPHS-RTG (2)	GALILEO	Planetary	18 Oct 89	Successfully operating on flight to Jupiter	264,400
GPHS-RTG (1)	ULYSSES	Planetary	6 Oct 90	Successfully operating on flight to the polar regions of the Sun	132,500

Source: updated from NASA 1990

[a] 1 Curie is equal to 3.7×10^{10} becquerel (Bq).

Power (SNAP)-RTG, to the Multi-Hundred Watt (MHW)-RTG, and, most recently, to the currently used General Purpose Heat Source (GPHS)-RTG. The GPHS technology is the culmination of almost 25 years of design evolution.

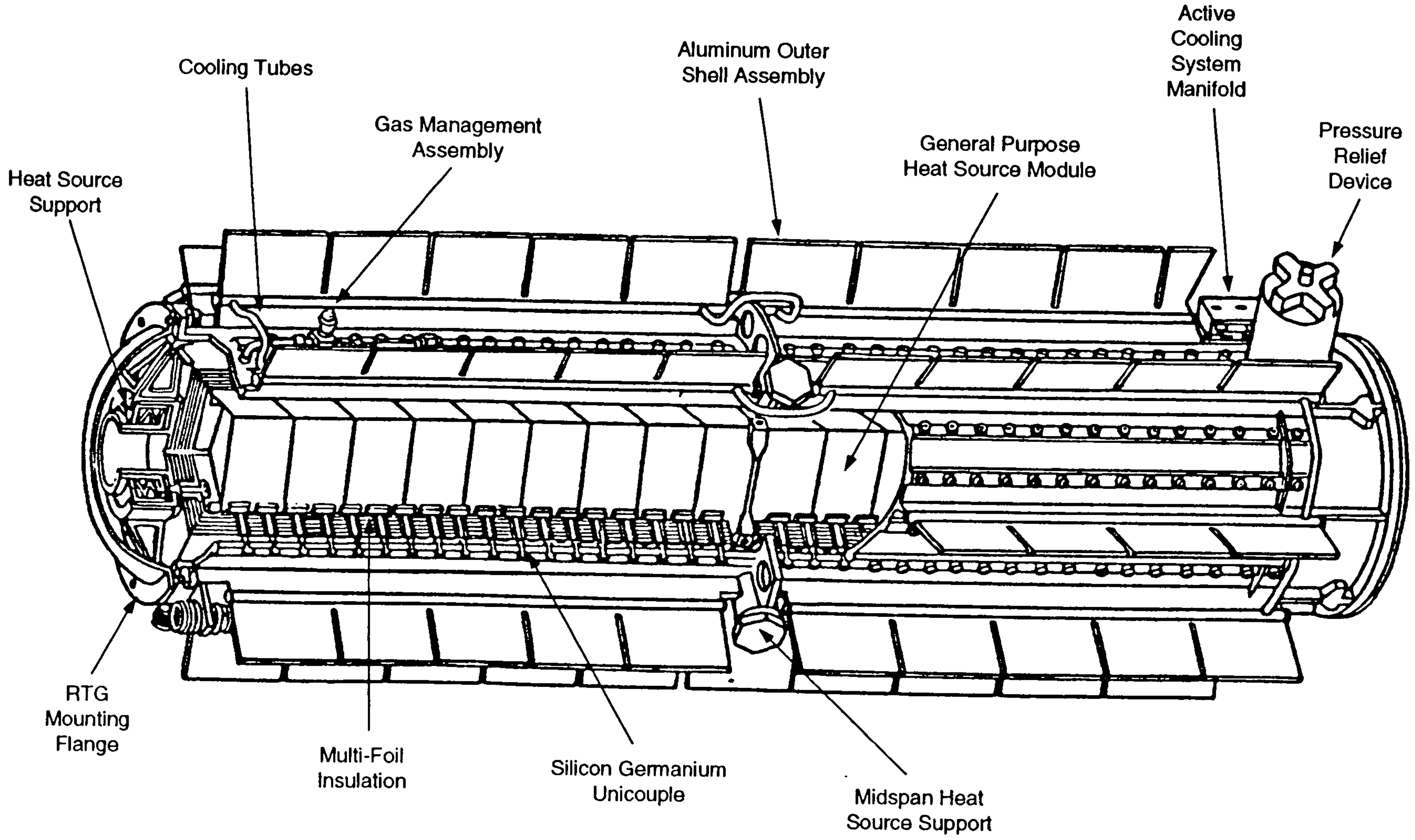
A GPHS-RTG assembly, commonly referred to as an RTG, weighs 56 kg (123.5 lb), is approximately 114 cm (44.9 in.) long and 42 cm (16.5 in.) in diameter, and contains 10.8 kg (23.8 lb) of plutonium dioxide fuel (DOE 1990a). Under space operational conditions, each RTG is designed to provide 285 watts of electrical power from 4,264 watts of heat (rating at launch). An RTG consists of two major functional components: the thermoelectric converter and the GPHS, as shown in Figure 2-5.

The thermoelectric converter consists of the aluminum outer shell assembly, the axial and midspan heat source supports, the thermoelectric elements, the multi-foil insulation packet, and the gas management system. The thermoelectric converter contains 572 silicon germanium (SiGe) thermoelectric couples (unicouples), which convert decay heat from the fuel directly into electricity. The unicouples are surrounded by multifoil insulation to reduce thermal losses. Each unicouple assembly is attached to an aluminum outer case (radiator) by sealing screws inserted through the case wall (DOE 1990a). The converter provides the support structure for the thermoelectrics, as well as for the GPHS modules.

The radioisotope energy source for the RTG is a stacked column of 18 individual GPHS modules, each having the dimensions of approximately 9.32 x 9.72 x 5.31 cm (3.67 x 3.83 x 2.09 in.) and a mass of about 1.45 kg (3.2 lb). The GPHS modules supply the thermal energy to the thermoelectric converter. Each GPHS module, illustrated in Figure 2-6, consists of a graphite aeroshell, two carbon-bonded carbon fiber (CBCF) insulator sleeves, two graphite impact shells (GISs), and four fueled clads. The graphite (carbon-carbon composite) aeroshell has a nominal operating temperature in space of 1,060°C (1,940°F) at the aeroshell surface (DOE 1990b) and serves as the module's primary heat shield to protect the internal components from direct exposure to a reentry's thermal and aerodynamic environment. The two GISs contained in the GPHS module provide the primary resistance to impact or mechanical loads. Each GIS assembly (i.e., the GIS and two fueled clads) is thermally insulated from the aeroshell by a low thermal-conducting CBCF insulator sleeve. Each fueled clad, separated by a graphite floating membrane, consists of one fuel pellet of ceramic (or solid) plutonium (mainly Pu-238)[1] dioxide encased in an iridium shell. The iridium shell protects and immobilizes the fuel. The iridium alloy is compatible (i.e., does not chemically react) with the plutonium dioxide fuel material to temperatures of more than 1,500°C (2,732°F), resists oxidation in air to 1,000°C (1,832°F), and melts at 2,425°C (4,497°F). Each clad also contains a vent designed to release the helium generated by the alpha particle decay of the fuel.

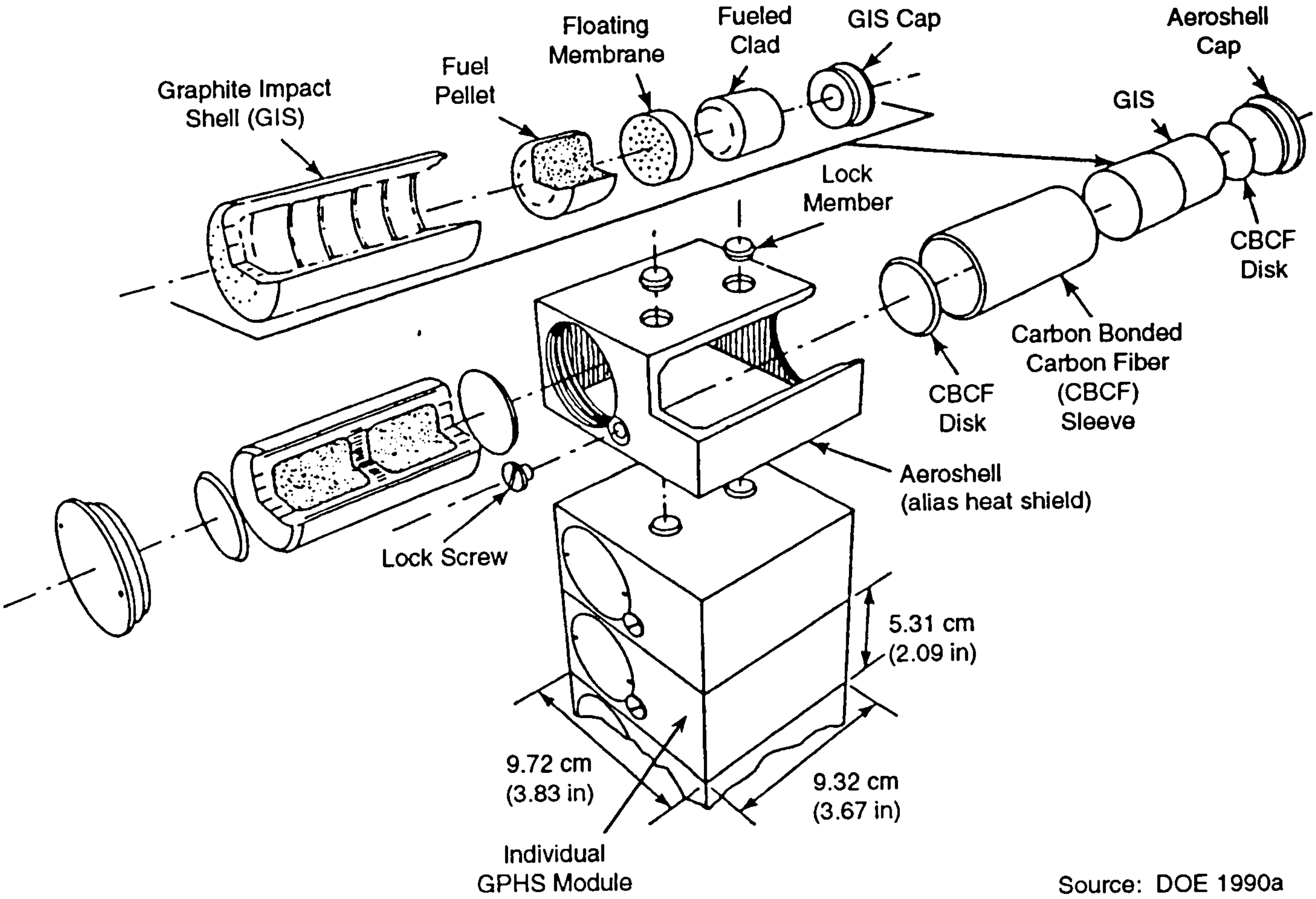
---

[1] Plutonium, atomic number 94, can exist in a number of radioactive isotopic forms, ranging from Pu-232 to Pu-246. Isotopes of an element have different atomic weights (e.g., 238, 239) but have the same or very similar chemical characteristics. The isotope Pu-238 forms the basis for the fuel in an RTG, whereas Pu-239 is the weapons-grade isotope. Pu-238 comes from the neutron bombardment of neptunium-237 and decays with an 87.75 year half-life to form naturally occurring uranium-234. Pu-239 comes from neutron capture by naturally occurring uranium-238.



Source: DOE 1990a

FIGURE 2-5. DIAGRAM OF GPHS-RTG ASSEMBLY



Source: DOE 1990a

FIGURE 2-6. DIAGRAM OF GENERAL PURPOSE HEAT SOURCE MODULE

Table 2-3 provides representative characteristics and the isotopic composition of the 10.8 kg (23.8 lb) of plutonium dioxide fuel that would be used in one RTG for the Cassini mission. Plutonium dioxide has a density of 9.6 g/cm^3 (600 lb/ft^3), melts at 2,400°C (4,352°F) and boils at 3,870°C (6,998°F) (DOE 1990b).

As noted in Table 2-3, each ceramic pellet of plutonium dioxide fuel at launch (October 1997) for the Cassini mission would contain, by weight, approximately 71 percent Pu-238 and 13 percent Pu-239 (Fairchild Space 1993). Pu-238, with a half-life of 87.75 years, contributes most of the thermal energy to the heat source, with smaller contributions coming from Pu-239 (half-life of 24,131 years). Henceforth, the term plutonium dioxide refers to a mixture of the oxides of several plutonium isotopes, with Pu-238 as the dominant isotope.

Safety Considerations

DOE has designed the GPHS to assure that the plutonium dioxide fuel is contained or immobilized to the maximum extent practical during all mission phases, including ground handling, transportation, launch, and unplanned events, such as atmospheric reentry from Earth orbit, Earth impact, and post-impact situations. The design features for the GPHS-RTG assembly incorporate many safety-related considerations. The graphitic (carbon-carbon composite) materials (i.e., the aeroshell, CBCFs, and GISs) contained in the GPHS modules perform several safety functions. As stated previously, the primary function of the aeroshell is to protect the fueled clads against the hostile environment of atmospheric heating. The GISs protect the fueled clads from ground or debris impact in the event of an accident. Each GIS also serves as a redundant heat shield in the event of a GPHS failure. In addition, the GIS also acts as a redundant reentry aeroshell. The graphitic material used for the aeroshell and impact shell is called fine weave pierced fabric (FWPF[1]). FWPF is a carbon-carbon composite material woven with high-strength graphite fibers in three perpendicular directions. Upon impregnation and graphitization, this material has outstanding high temperature strength capabilities required to accommodate heat shield mechanical and thermal stresses that occur during reentry. This material, used primarily by the U.S. Air Force (USAF) for missile nose cones (nosetips), is one of the best available for reentry applications (DOE 1988a).

The GPHS modules survive water impact. Given the additional protection of the iridium and the low solubility of the plutonium dioxide in fresh and sea water, the GPHSs will resist significant fuel release for virtually unlimited periods when submerged (DOE 1990a). (See Appendix C for further details.)

Because the GPHS is designed of small modular units, reentry heating and terminal velocity are lower than for previous heat sources, such as those used on the Pioneer and Voyager outer planet missions, due to a lower ballistic coefficient. A modular heat source tends to minimize the amount of fuel that could be released in a given accident.

---

[1] FWPF is a trademark of AVCO Corporation.

TABLE 2-3. REPRESENTATIVE CHARACTERISTICS AND ISOTOPIC COMPOSITION OF CASSINI RTG FUEL

Fuel Component	Weight Percent at Launch	Half-Life (years)	Specific Activity (Bequerels/gram [curies/gram] of plutonium)	Total Bequerels (curies)/RTG[a] at Launch
Pu-236	0.0000010	2.851	2.0×10^{13} (531.3)	2.2×10^{9} (0.06)
Pu-238	70.810	87.75	6.3×10^{11} (17.12)	4.84×10^{15} (130,925.20)
Pu-239	12.859	24,131	2.3×10^{9} (0.0620)	3.2×10^{12} (86.11)
Pu-240	1.787	6,569	8.4×10^{9} (0.2267)	1.6×10^{12} (43.75)
Pu-241	0.168	14.4	3.8×10^{12} (103.0)	6.9×10^{13} (1,864.30)
Pu-242	0.111	375,800	1.5×10^{8} (0.00393)	1.8×10^{9} (0.05)
Other[b] Oxygen	2.413 11.852	NA[c]	NA	NA
Total	100.000	NA	NA	4.9×10^{15} (132,920)

Source: Fairchild Space 1993

a. Based on computation of isotopic composition by Fairchild Space for the launch date (October 1997). The radioisotopic fuel for each Cassini RTG is a mixture of plutonium dioxide (PuO_2) containing 70 percent (plus or minus 1 percent) Pu-238 and totaling 10.8 kg (23.8 lb). Three RTGs are planned for Cassini.

b. Small amounts of long-lived actinides and stable impurities.

c. Not applicable.

Considerable testing has been performed to determine the response of the RTG, the GPHS module, and the bare fueled clads to the environments that could result from a potential launch accident. The following list summarizes the relevant safety testing and the RTG's estimated response to the associated accident environments (see additional details available in DOE 1989b, DOE 1990a):

- Explosions—Fueled clads contained in GPHS modules and intact RTG assemblies survive overpressures of 15.25 megaPascals (MPa) (2,210 pounds per square inch [psi]) without any release of fuel. (For an intact RTG, the threshold for removal of the graphite aeroshell has been estimated to occur at overpressures around 3.45 MPa [500 psi] [DOE 1989b]).

- Fire—Fueled clads contained in the GIS and bare fueled clads (without GIS protection) survive solid propellant fires with temperatures estimated to be about 2,360°C (4,280°F) without fuel release. The major components of the GPHS (graphite, iridium, and the plutonium dioxide) have individual melting points that are greater than the flame temperatures for solid and liquid propellant fires. Although the graphite eutectic temperature is around 2,269°C (4,165°F), solid and liquid propellant fire tests have not indicated eutectic melting of the iridium (DOE 1989b).

- Fragments—Small fragment tests with 18-g (0.64-oz) aluminum bullets at velocities of about 555 m/s (1,820 ft/s) can cause a breach when striking a bare fueled clad; 3.25-g (0.11-oz) titanium bullets at velocities of 423 m/s (1387 ft/s) can cause a bare fueled clad to breach. Tests using 142 cm (56 in.) square steel plates that are 1.27 cm (0.5 in.) thick indicate that an RTG can survive face-on fragment impacts at velocities up to 212 m/s (695 ft/s) with no release of fuel; edge-on fragment impacts on an RTG at 95 m/s (312 ft/s) will rupture only the leading fueled clads of the GPHS module impacted, resulting in a fuel release (DOE 1989b, Martin Marietta Astro Space 1993).

- Reentry From Earth Orbit—GPHS modules survive atmospheric reentry ablation and thermal stress with acceptable design margins up to the Earth escape velocity of 11.1 km/s (36,420 ft/s) (DOE 1989b).

- Earth Impact—A series of tests were performed that simulated the conditions that might be expected during reentry of GPHS modules from Earth orbit. These tests impacted GPHS modules at velocities in excess of their terminal velocity (50.3 m/s [165 ft/s]) onto hard surfaces, including steel, concrete, and granite. Releases from a GPHS module after impacting a hard surface at a velocity 10 percent higher than terminal velocity ranged from 0 g to 0.22 g (0 oz to 0.008 oz) for the tests simulating orbital decay reentry conditions (DOE 1990a). Releases from GPHS modules from Earth orbital decay reentry are not expected for impacts onto water, sand, or normal soils.

  Impact tests were performed with bare fueled clads. The tests concentrated mainly on a velocity range centered on the terminal velocity of the fueled clads, which is about 73.8 m/s (242 ft/s). Bare clads did not fail on soft targets, such as sand, at impact velocities to 250 m/s (820 ft/s), and the failure thresholds were established for impacts on steel and concrete at 53 and 58 m/s (174 ft/s and 190 ft/s), respectively (DOE 1990a).

Overall, DOE has spent more than 12 years in the engineering, fabrication, safety testing, and evaluation of the GPHS, building on the experience gained from previous heat source development programs and an information base that has grown since the 1950s. Test results have demonstrated that the present design exceeds the stringent safety standards achieved by earlier heat source designs. In addition, DOE has considered and continues to consider ways to improve the safety of the current RTGs, including alternative materials and RTG designs in the event there were to be a potential need in future outer space missions. The RTG technology also has a proven record of reliability in space applications and is the only power system available that satisfies all of the performance criteria associated with the Cassini mission. DOE will perform additional safety analyses for the Cassini mission and document the results in a Final Safety Analysis Report (FSAR).

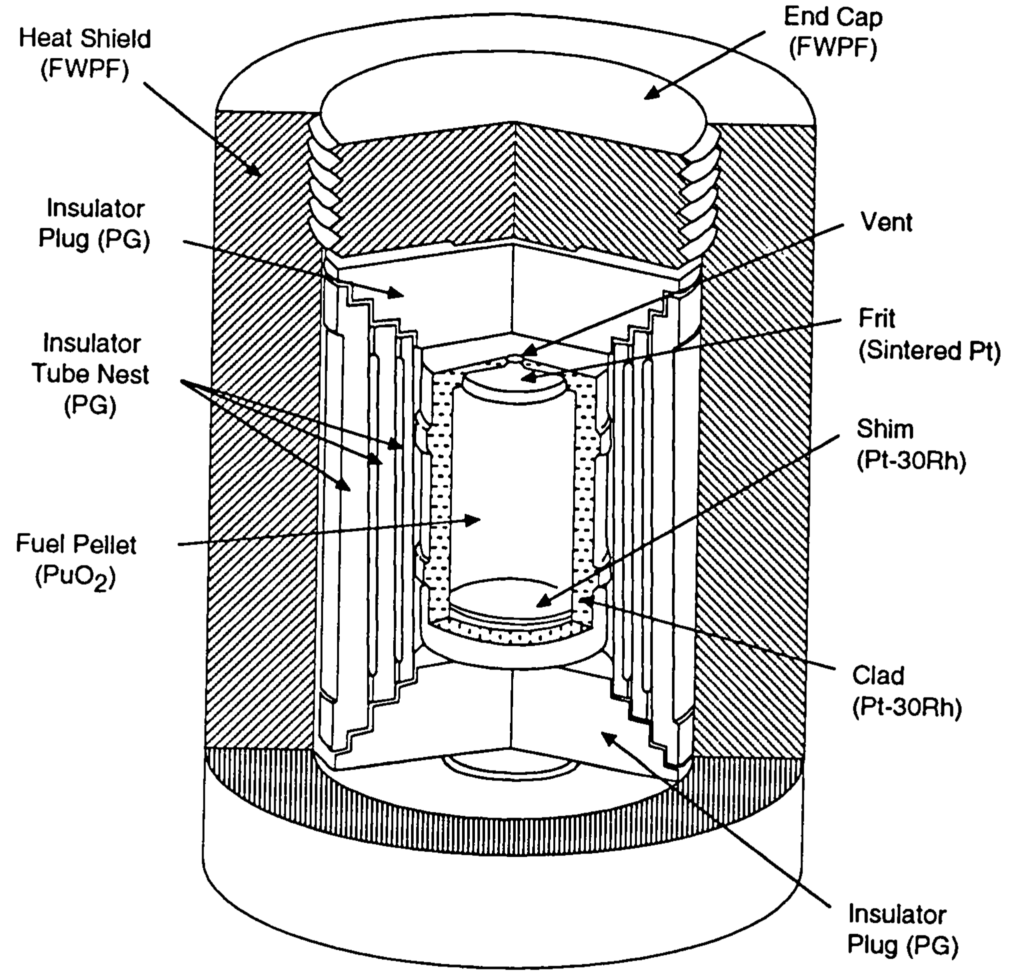
2.2.4.3 Lightweight Radioisotope Heater Units

The Cassini spacecraft and the Huygens Probe would use a maximum of 157 lightweight RHUs to regulate temperatures on the spacecraft and on the Probe (JPL 1993a). Each RHU provides about 1 watt of heat derived from the radioactive decay of 2.7 g (0.006 lb) of mostly plutonium (Pu-238) dioxide, contained in a platinum-30 rhodium (Pt-30Rh) alloy clad. Similar to the GPHS modules, the RHU design provides a high temperature capability by using the FWPF heat shield and a series of concentric pyrolytic graphite (PG) sleeves and end plugs to thermally insulate the fueled clad. The RHUs are protected from ground or debris impact partially by the heat shield, but principally by the Pt-30Rh clad material. Each RHU would contribute approximately 1.3 x 10^{12} Becquerel (Bq) (36 curies [Ci]) to the total radioactive inventory on Cassini. The exterior dimensions are 2.6 cm (1.03 in.) diameter by 3.2 cm (1.26 in.) long, each with a weight of about 40 g (0.09 lb). Figure 2-7 shows a cutaway view of an RHU.

The RHUs are designed to be lightweight units capable of containing the plutonium dioxide fuel in both normal operations and accidents (DOE 1988a). The integrity and durability of RHUs are well documented (DOE 1988a). DOE will perform additional safety analyses for the Cassini mission and document the results in a Final Safety Analysis Report (FSAR).

2.2.5 Spacecraft Propulsion Module Subsystem

The propulsive power for the Cassini spacecraft would be provided by two redundant bipropellant 490-N (110 lb of thrust) main engines for trajectory and orbit changes and 16 monopropellant thrusters rated at 0.6-N (0.13 lb of thrust) for attitude control and very small orbit changes (JPL 1993c). The bipropellant engines use NTO and MMH. The monopropellant thrusters burn hydrazine. Pressures in both the bipropellant and monopropellant elements are maintained using helium gas (JPL 1993a).



PG = Pyrolytic Graphite

Source: DOE 1988a

FIGURE 2-7. THE PRINCIPAL FEATURES OF THE RADIOISOTOPE HEATER UNIT

2.2.6 Launch Vehicle (Titan IV [SRMU or SRM]/Centaur) Configuration

The Titan family of unmanned, expendable launch vehicles has a launch history spanning more than 30 years of operations involving more than 320 Titan vehicles of all models. Titans have successfully carried astronauts into space 10 times and have successfully launched RTG-powered spacecraft into space 5 times. The Titan IV/Centaur with the newly developed SRMUs is proposed for this mission to Saturn, but if the SRMUs were not available, the mission would use the conventional SRMs. The SRMUs will be the most capable strap-on U.S. boosters when flight certified.

The Titan IV/Centaur comprises four basic components: core vehicle, the strap-on booster (SRM or SRMU), payload fairing (PLF), and Centaur (upper stage). The Titan IV (SRMU)/Centaur configuration is shown in Figure 2-8.

2.2.6.1 Core Vehicle

The core vehicle, which provides thrust, consists of two stages with their associated airframes, structures, avionics, mechanical systems, and liquid propulsion system. Stage 1 contains two bipropellant liquid rocket engines. The oxidizer is 101,176 kg (223,053 lb) of NTO and the fuel is 53,240 kg (117,373 lb) of Aerozine-50 (i.e., a 50-50 blend of unsymmetrical dimethylhydrazine and hydrazine). Stage 2 contains a single bipropellant engine virtually identical to the two used in Stage 1. The Stage 2 propellants comprise 22,239 kg (49,028 lb) of NTO and 12,436 kg (27,416 lb) of Aerozine-50 (Martin Marietta 1992).

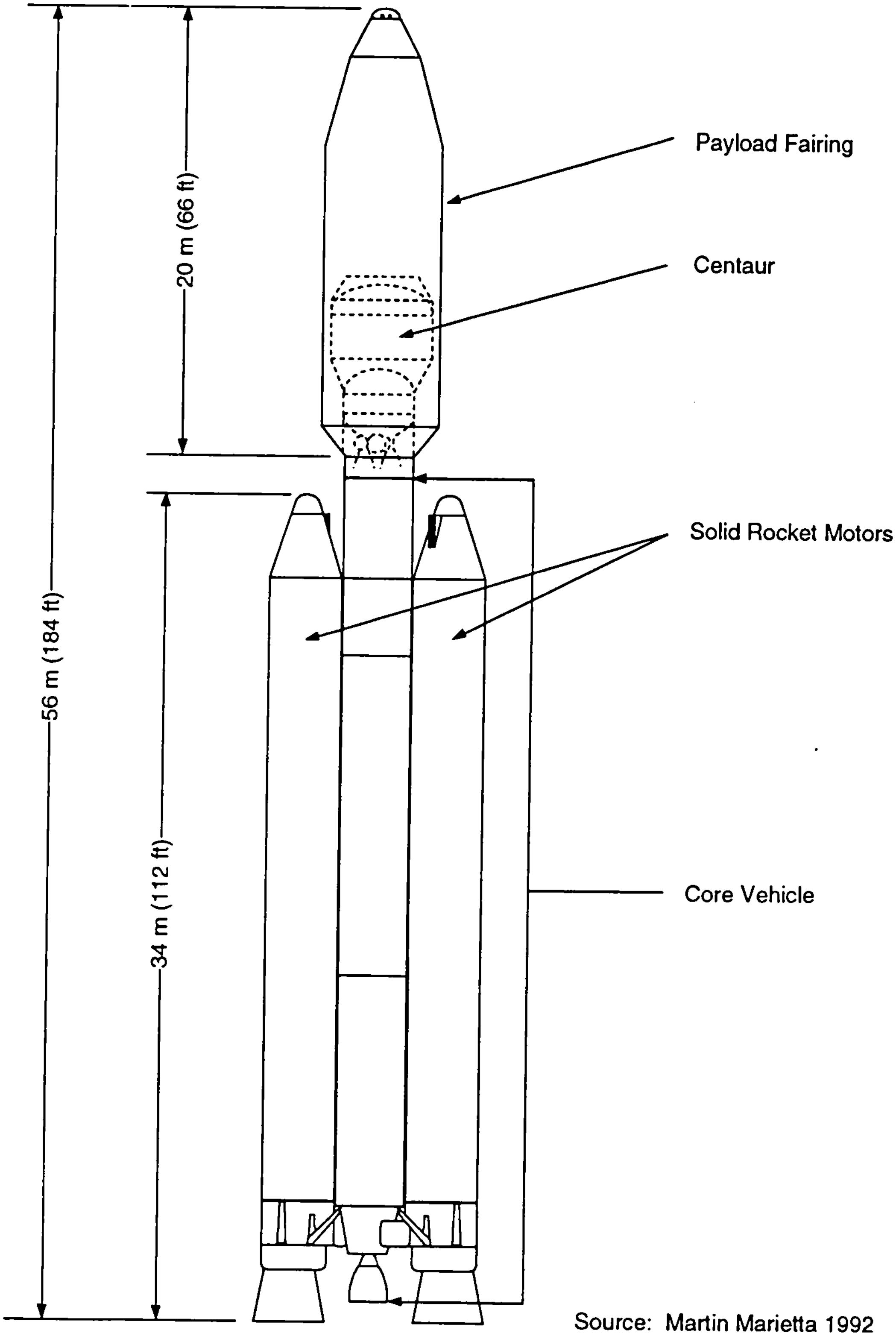
2.2.6.2 Strap-on Boosters

Two SRMUs (or SRMs), strapped onto the sides of the core vehicle, would provide the initial boost for the launch vehicle at liftoff. The SRMUs are three-segment, graphite-composite-cased motors representing a significant performance gain over the conventional SRM. The SRMU has passed all of its qualification tests and is awaiting final flight certification. Each SRMU weighs 351,220 kg (772,685 lb), of which 313,102 kg (688,824 lb) are propellant. The propellant is a U.S. Department of Defense (DOD) Hazard Class 1.3 solid propellant consisting of 69 percent ammonium perchlorate (oxidizer) and 19 percent nonspherical aluminum (fuel) with 8.84 percent hydroxyl terminated polybutadiene (HTPB) binder. The remaining 3.16 percent includes bonding and curing agents (Martin Marietta 1992).

The conventional SRM booster consists of a steel seven-segment propellant case plus forward and aft closures. Each SRM weighs 302,512 kg (694,470 lb), of which 257,440 kg (591,000 lb) is propellant consisting of 67.8 percent ammonium perchlorate and 16 percent aluminum with 10.2 percent polybutadiene acrylonitrile (PBAN) binder. The remainder consists of catalyst, resins, and stabilizers (Martin Marietta 1989).

2.2.6.3 Payload Fairing

The PLF, mounted on top of the core vehicle, encases the Centaur (upper stage) and spacecraft, thereby providing aerodynamic and thermal protection for these elements



Source: Martin Marietta 1992

FIGURE 2-8. DIAGRAM OF THE TITAN IV (SRMU OR SRM) / CENTAUR LAUNCH VEHICLE during ascent (Figure 2-9). The payload fairing is an all metal structure composed primarily of aluminum and pieced together as three segments. Between approximately 240 and 246 seconds after liftoff, the fairing segments would uncouple and would be jettisoned from the rest of the launch vehicle into the ocean (Martin Marietta 1992).

2.2.6.4 Centaur

The Centaur (upper stage) is designed to be compatible with the Titan IV booster. It uses two liquid hydrogen (LH_2)/liquid oxygen (LO_2) combustion engines with multiple restart capability. The Cassini mission would require two burns of the Centaur engine. The first burn would supplement the Titan IV in lifting the spacecraft/Centaur stack into the proper low altitude Earth parking orbit. The second burn would boost the spacecraft to the velocity needed to escape the Earth and would inject it into the proper trajectory toward the first gravity-assist swingby of Venus. The LH_2 and LO_2 are contained in two large tanks that account for the bulk of the Centaur's internal volume. Forward and aft adapters are mounted to these tanks. The forward adapter provides mounting supports for avionics packages and the spacecraft's mechanical and electrical interfaces with the Centaur, and the aft adapter provides the structural interface between the Centaur and the Titan IV (Martin Marietta 1992). Figure 2-10 illustrates the Centaur (upper stage) configuration.

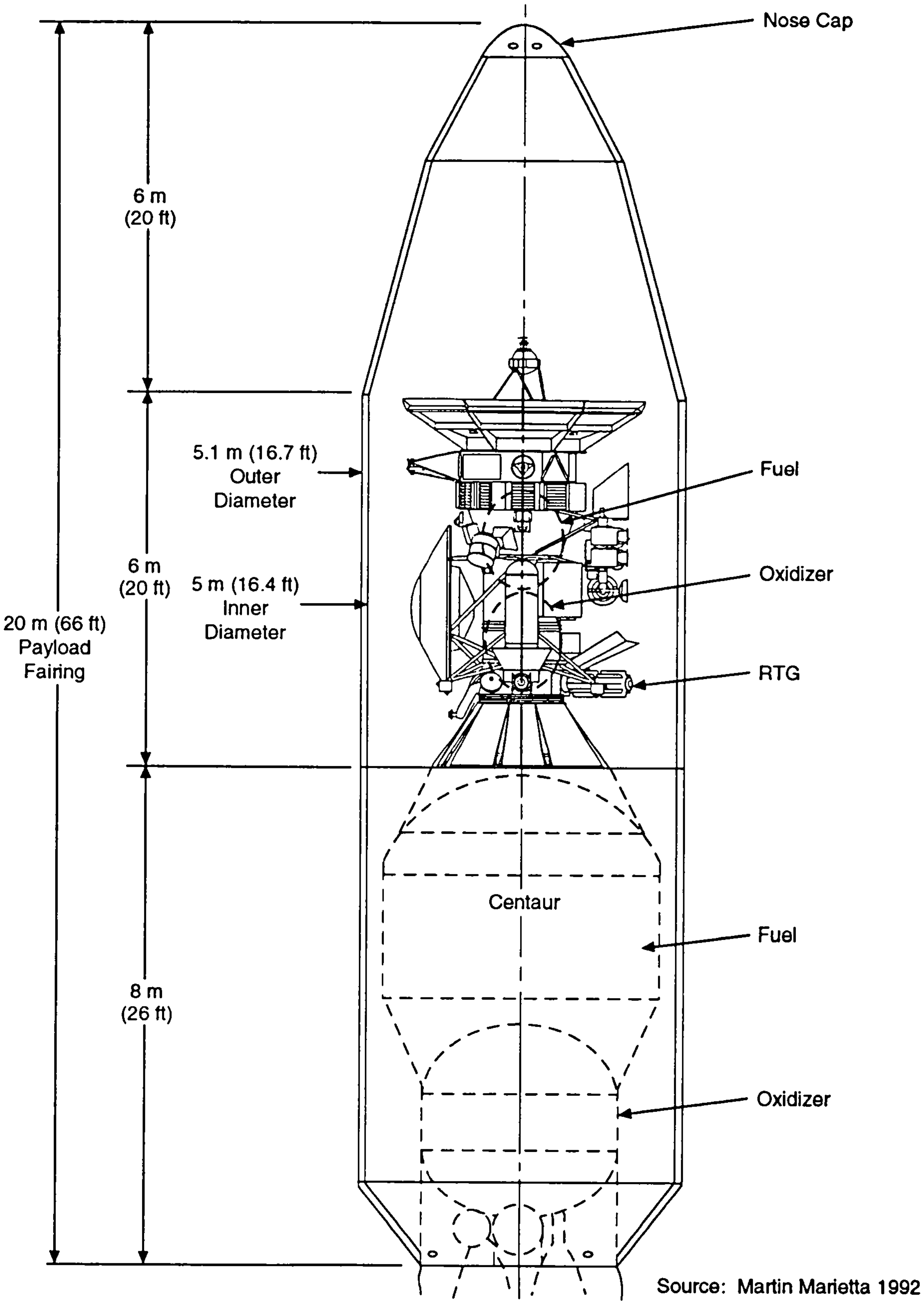
2.2.7 Cassini Mission Timeline

The nominal Cassini mission timeline is subject to slight modifications as the design of the Cassini mission is further refined. As shown below for the Titan IV (SRMU)/Centaur, the mission is divided into phases that primarily serve as the basis for potential launch accident scenario definitions and environmental analyses. For example, Phase 0 starts with fueling of the Titan IV core vehicle 4 days before launch (T - 4 days) and ends with ignition of the SRMUs at T minus zero seconds (T - 0 s). Where necessary, the phases are divided further to separate specific events that show changes in the fundamental characteristics of the accident environments to which the RTG could be subjected (Martin Marietta 1992). These phases are essentially identical for all the launch opportunities associated with the Titan IV (SRMU)/Centaur. The phases and typical timeframes are summarized below (Martin Marietta 1992):

- Phase 0 (T - 4 days to T - 0 s)—Phase 0 identifies the time following the installation of the RTGs when the fueling of the Titan IV core vehicle begins and continues to the instant of SRMU ignition.

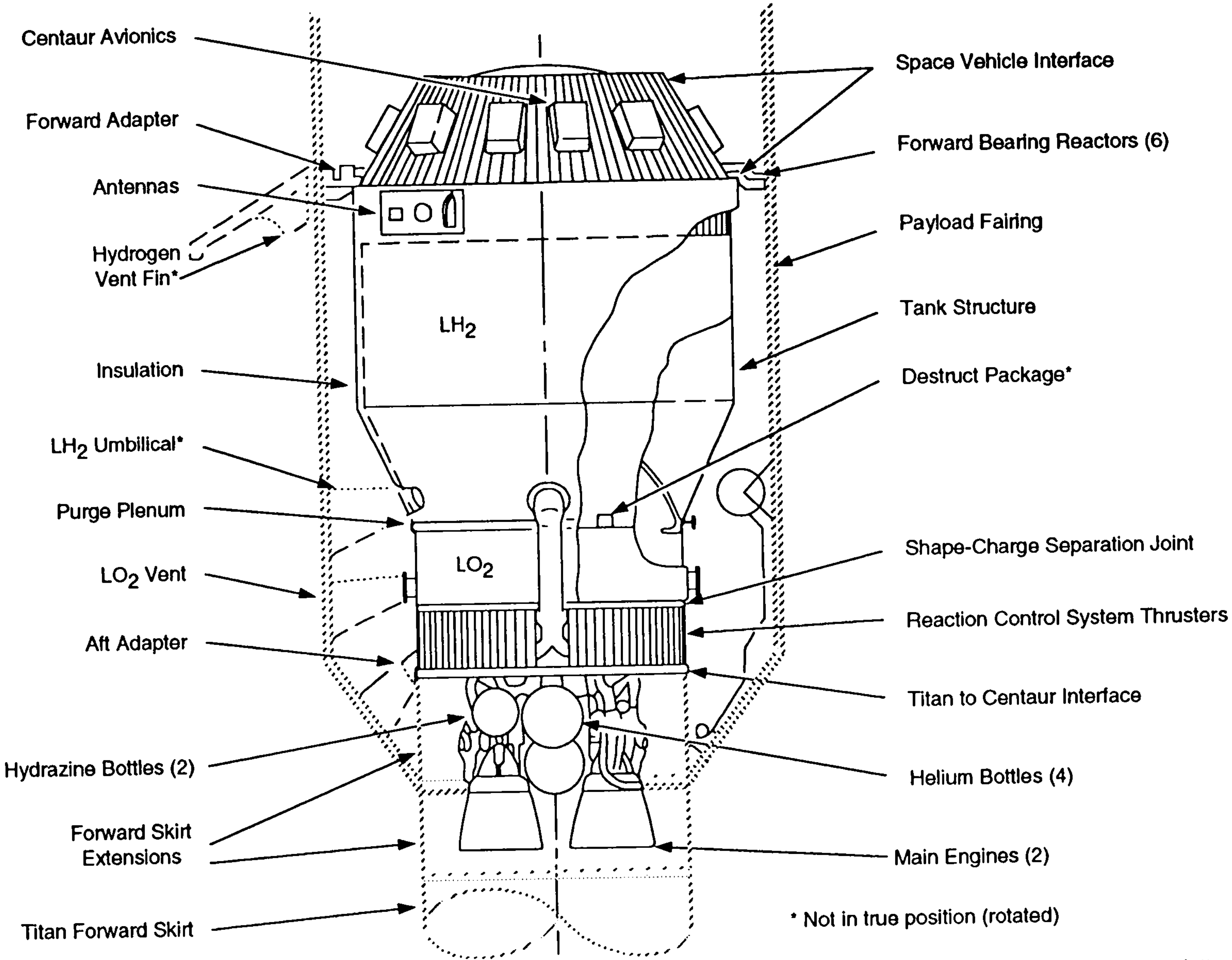
- Phase 1 (T - 0 s to T + 11 s)—Phase 1 covers the time period from the instant of SRMU ignition at a mission elapsed time (MET) of zero and continues to the time when the launch vehicle is high enough to provide launch site clearance in the event of an accident.

- Phase 2 (T + 11 s to T + 23 s)—This phase begins at the instant launch site clearance is achieved and continues to the point where the vehicle's instantaneous impact point (IIP—the point of vehicle impact given the termination of thrust, neglecting aerodynamic effects) would clear the Florida



Source: Martin Marietta 1992

FIGURE 2-9. THE CENTAUR AND SPACECRAFT IN THE PAYLOAD FAIRING



* Not in true position (rotated)

Source: Martin Marietta 1992

FIGURE 2-10. DIAGRAM OF CENTAUR CONFIGURATION coast (i.e., land clear). During this phase, the vehicle would impact land in the event of an accident.

- Phase 3 (T + 23 s to T + 56 s)—Phase 3 begins at the instant of land clear and ends when the vehicle reaches an altitude of 10,000 m (32,808 ft). At this altitude, the potential environmental impacts from an accident resulting in a plutonium dioxide release become global due to high altitude winds.

- Phase 4 (T + 56 s to T + 246 s)—Phase 4 identifies the period from 10,000 m (32,808 ft) altitude and continues to when the jettison of the PLF is completed. Stage I of the liquid-fueled core vehicle main engines are ignited at T + 135 s, and the SRMUs are jettisoned at T + 146 s.

- Phase 5 (T + 246 s to T + 688 s)—Phase 5 covers the period from the completion of PLF jettison to the time when the flight termination system(s) is shut down, becoming inoperable for the remainder of the mission. The FTS shut down occurs 2 seconds after the end of the first Centaur main engine burn. The vehicle's IIP would pass over the African continent between approximately T+664 s and T+672 s.

- Phase 6 (T + 688 s to T + 5,576 s)—Phase 6 begins at the time when the flight termination system(s) is shut down and ends when the second Centaur main engine burn is completed.

- Interplanetary Cruise Phase (5,576 s to end of the mission)—This phase involves the time between Earth escape and completion of the mission. Depending on the trajectory (i.e., VVEJGA, VEEGA, or VVVGA), a combination of planetary gravity assists will occur, resulting in SOI, delivery of the Huygens Probe, and ultimately, the data acquisition from the 4-year science tour of Saturn and its environment.

For a launch with the Titan IV (SRM)/Centaur configuration, the mission timeline would typically be as follows (Martin Marietta 1989):

- Phase 0 (T - 4 days to T - 0)—Phase 0 identifies the time period between when the liquid propellants are loaded and the RTGs installed to the instant of SRM ignition.

- Phase 1 (T - 0 to T + 5 s)—This phase covers the time period from the instant of SRM ignition through lift-off and continues to the time when the launch vehicle is high enough to clear the launch tower.

- Phase 2 (T + 5 s to T + 23 s)—This phase covers the time period from launch tower clearance to the time when the IIP would clear the Florida coast (i.e., land clear).

- Phase 3 (T + 23 s to T + 250 s)—Phase 3 identifies the time period from land clear to the time of jettison of the payload fairing.

- Phase 4 (T + 250 s to T + 543 s)—Phase 4 covers the period when the PLF is jettisoned to the separation of the upper stage from the core vehicle.

- Phase 5 (T + 543 s to payload separation)—This phase covers the period between the separation of the upper stage to the injection of the spacecraft.

- Interplanetary Cruise Phase (payload separation to end of mission)—Phase 6 covers the interplanetary trajectory between the Earth and Saturn.

2.2.8 Range Safety Considerations

2.2.8.1 General

Range Safety encompasses all activities from the design concept through test, checkout, assembly, and launch of space vehicles to orbit insertion from any range facility. The goal of the Range Safety program is to protect the general public, foreign and domestic, as well as their property, from harm or damage resulting from the debris or impact of hazardous components during a space flight. The launch and flight of space vehicles should present no greater risk to the general public than that imposed by the overflight of conventional aircraft. Although risk can never be completely eliminated, Range Safety attempts to minimize the risks while not unduly restricting the probability of mission success.

2.2.8.2 Flight Termination System

All space vehicles launched from the Eastern Range, which includes KSC and CCAS, must carry an approved Flight Termination System (FTS) that allows the Flight Control Officer to terminate powered flight if the vehicle violates established flight safety criteria.

The Flight Termination System (FTS), which includes a Titan IV launch vehicle system and a Centaur system, provides ground personnel with the capability to shut down any thrusting liquid stage only (core engines or Centaur) or to shut down any thrusting liquid stage and then destruct the Titan IV SRMUs and all liquid stage tanks. This element of the FTS is called the command shutdown and destruct system (CSDS).

Additionally, the FTS will automatically destruct a stage that separates from the portion of the vehicle carrying the command receivers and antennas. This element, originally called the inadvertent separation and destruct system (ISDS), is currently referred to as the automatic destruct system (ADS). The ADS is activated when a wire, strategically placed to sense a specific critical structural failure, is broken. Upon activation of an automatic destruct, Range Safety can, at their discretion, command destruct the Centaur and the remaining Titan IV elements, which were not destructed automatically or broken up due to collateral damage. (It should be noted that the location of the sensing wires that detect structural failure is subject to review based on Range Safety and nuclear safety issues.)

As of publication of the DEIS, the necessity for and design issues involving a Space Vehicle Destruct System (SVDS) for the Cassini spacecraft were under review.

Subsequent analyses and testing involving the spacecraft's hypergol fuels indicated that the launch vehicle configuration for the Proposed Action would not require an SVDS. Therefore, the Cassini spacecraft would not include an SVDS.

2.2.8.3 Electromagnetic Hazard Conditions

Techniques to respond to concerns for potential electromagnetic hazards have been incorporated into launch vehicle designs and launch procedures. The following potential electromagnetic hazard conditions exist for aerospace launch vehicles and payloads:

- Lightning
- Powerful electromagnetic transmitters (e.g., radars, radio transmitters), also referred to as the electromagnetic environment
- Charging effects (i.e., triboelectric charging effects and resultant electrostatic discharges [ESD]).

NASA and the USAF are concerned with these conditions with respect to the design of the launch vehicle, as well as with ordnance (explosives and explosive detonators/fuses), fuels, exposed skins of the vehicle, and critical electronic systems that must have highly reliable operations. These special concerns are well-known and they include the following:

- Effects of electromagnetic radiation on ordnance and fuels
- Electrostatic discharges
- Electromagnetic interference.

A large body of technical literature exists on these subjects and has been used by NASA and the USAF in designing safeguards. To better understand these hazards, the following paragraphs briefly describe these conditions and hazards.

Lightning

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

The conditions in which lightning is likely to occur can be monitored by measuring the local electric fields around the vehicle. Large electric fields indicate the presence of large amounts of electrical charge present in the overhead clouds. Because lightning results from an electrical discharge built up in these clouds, these fields indicate the likelihood of lightning activity in the area. The USAF monitors electrical fields within a 322 km (200 mi) radius of CCAS/KSC during launch times. Operations at the launch pad will neither commence nor continue if an electrical storm is within 8 km (5 mi).

The USAF also employs rigorous design specifications (e.g., Military Standard [MIL-STD]-1818, Electromagnetic Effects Requirements for Systems, dated 8 May 1992) to mitigate the potential effects of lightning strikes and will have strict meteorological criteria for launch of the Titan IV (SRMU or SRM)/Centaur to avoid subjecting the vehicle and its payload to unacceptable environments. In addition to visibility, ambient temperature, and surface wind speed and direction, severe weather restrictions address the maximum weather-induced, ground-level, and flight path electrical fields acceptable for launch (1 kv/m). These restrictions are strictly enforced.

Electromagnetic Environment

The electromagnetic radiation in the environment has, in recent years, become stronger and more prevalent primarily because of the increased number of radar systems and other radio transmitters worldwide.

Controlling the response and interaction of the Titan IV (SRMU or SRM)/Centaur and payload systems to the electromagnetic environment is achieved through two means: control of the radiated power of transmitters in the immediate vicinity of the vehicle and use of proven and effective electrical system design techniques. These techniques include using electromagnetic shields, controlling any naturally occurring electromagnetic leaks in the shields, using proper electrical bonding and grounding, filtering out and/or suppressing undesired effects in the electrical system, and using special signal computer software that recognizes and removes the effects. The techniques are designed to comply with MIL-STD-1818 and in MIL-STD-461, Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference, and MIL-STD-462, Electromagnetic Interference, Measurement of Characteristics.

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

All payload manufacturers are required to conduct EMC testing of their unintentional radiated and conducted emissions. NASA reviews test data according to strict specifications. When a piece of equipment, system, or subsystem is determined to have an inadequate Electromagnetic Interference Safety Margin, appropriate action is taken (e.g., redesign, substitution, or additional protection). Therefore, the concerns for payload to payload, payload to Titan IV (SRMU or SRM)/Centaur, and Titan IV (SRMU or SRM)/Centaur to payload radiated emissions are thoroughly addressed and resolved before flight readiness is attained.

Many well-known techniques are available to achieve EMC. The procedures used to achieve this operational compatibility are prescribed in Military Specification 6051, Electromagnetic Compatibility Requirements System, updated February 28, 1988, and supporting procedures. All avionics equipment on the Titan IV (SRMU or SRM)/Centaur has been EMC qualified per NASA, USAF, and contractor specifications. All EMC reports are presented and reviewed during a series of payload integration reviews involving all contractor and government parties. Problems are resolved during these reviews. In addition, all payload and the Titan IV (SRMU or SRM)/Centaur EMC requirements are constantly reviewed and updated whenever new information becomes available.

Charging Effects

Electrical charging effects can be associated with picking up an electrical charge that can suddenly discharge when a metallic object is touched. The effect results from rubbing or touching and parting two dissimilar materials together.

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

Techniques to mitigate the effects of ESD are well-known and generally depend on proper bonding and grounding of the external and internal vehicle assemblies and parts. This prevents large differential charges from building up between surfaces and arc discharging. Most vehicle charge resides on external and payload bay surfaces. The USAF uses Class S bonding, as prescribed by MIL-STD-1818, to prevent the effects of electrostatic discharging.

Ordnance and Fuels

Ordnance and fuels represent special concerns. Electrostatic and electrodynamic energy can potentially trigger fuel ignition of special ordnance (i.e., electroexplosive devices), which can lead to undesired ordnance ignition and possibly equipment separations. Due to the fuel containment design, substantial amounts of energy from the radio frequency environment or electrostatic discharge are needed to trigger the liquid and solid fuels.

Techniques used to protect such ordnance and fuels from lightning, the electromagnetic environment, and discharges are well-known and used in many aircraft and missile systems. These techniques, used by the USAF, are prescribed in MIL-STD-1576, Electroexplosives Subsystem Safety Requirements and Test Methods for Space Systems, which establishes general requirements for the design, development, and testing of electroexplosive subsystems to preclude hazards from ignition and failure to fire. This standard applies to all space vehicle systems (e.g., launch vehicles, upper stages, payloads, and related systems). Special designs of fuel tanks and fuel delivery subsystems are used to prevent ordnance ignition.

On the Cassini spacecraft, for example, there would be two types of such electroexplosive devices: NASA standard initiators (NSIs) and bellows actuators. NSIs would be used to actuate pinpullers, propulsion valves, release nuts, rod cutters, and the Huygens Probe parachute deployment device. An NSI and detonator combination would be used to activate the detonating cord used in the Linear Separation Assembly. The bellows actuators would be used to deploy science instrument covers. Both electroexplosive devices are designed to specifications that require an inability to "fire" when 1 watt or 1 ampere is applied to the device. These devices would be controlled by redundant firing circuits that are inhibited during launch by a series of relays located on the Centaur, the spacecraft, and the Huygens Probe. The inhibit logic and circuitry are designed to comply with the Range Safety Requirements document 45th Space Wing Regulation 127-1 and MIL-STD-1576. The combination of these devices provides a very large margin compared to the energy available from external sources.

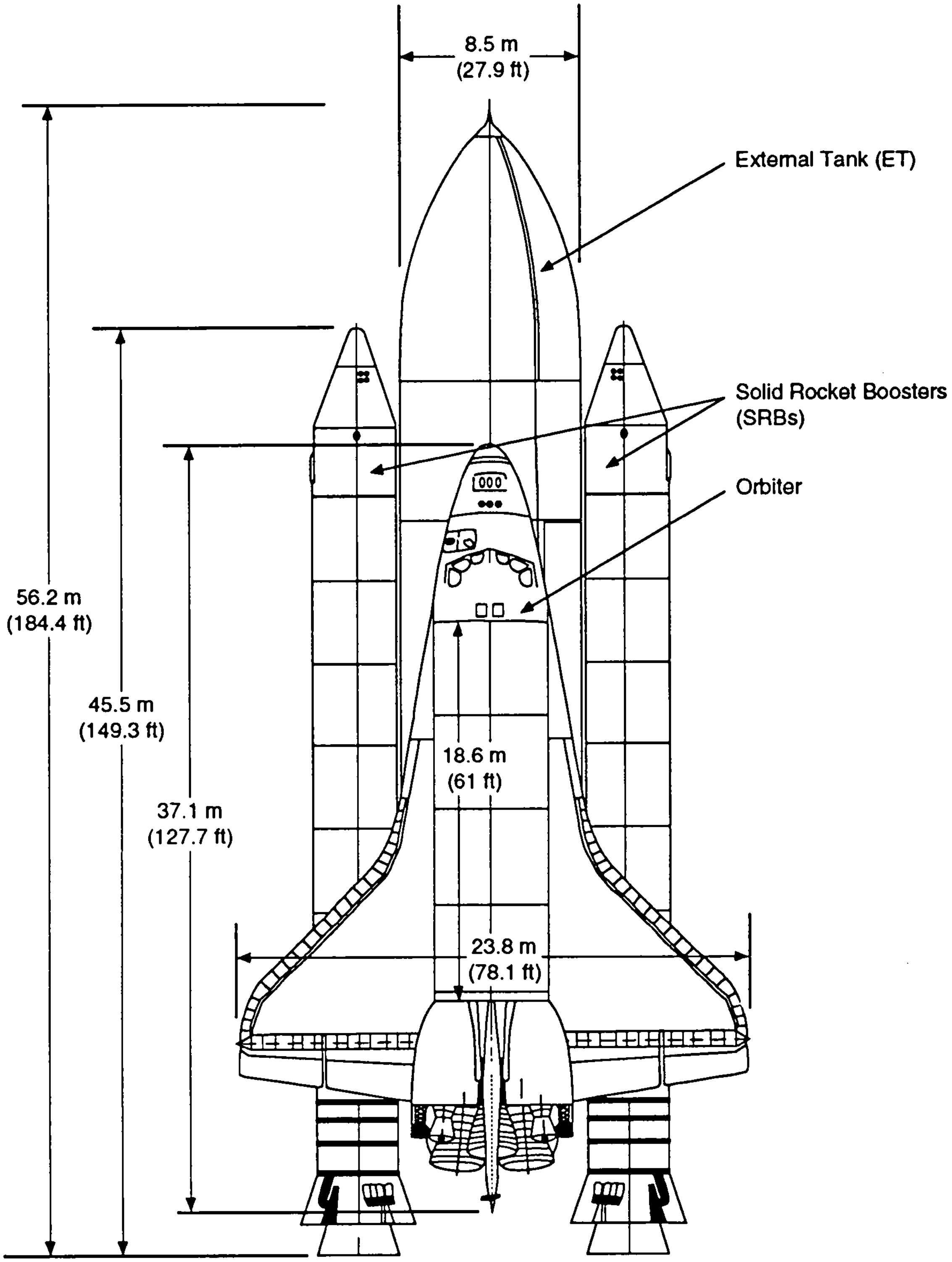
Electromagnetic interference is also a design consideration with respect to the pyrotechnic devices (detonators) on the launch vehicle. These devices and the firing circuits are designed to perform to MIL-STD-1512, Electro-Explosive Systems, Electrically Initiated, Design Requirements, and Test Methods. All spacecraft and upper stages that fly on the launch vehicle undergo an intensive review of their susceptibility to electromagnetic radiation in accordance with strict NASA and USAF specifications. Hazard reports must be prepared and closed out for devices that do not meet the specifications.

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

2.3 DESCRIPTION OF THE 1999 MISSION ALTERNATIVE

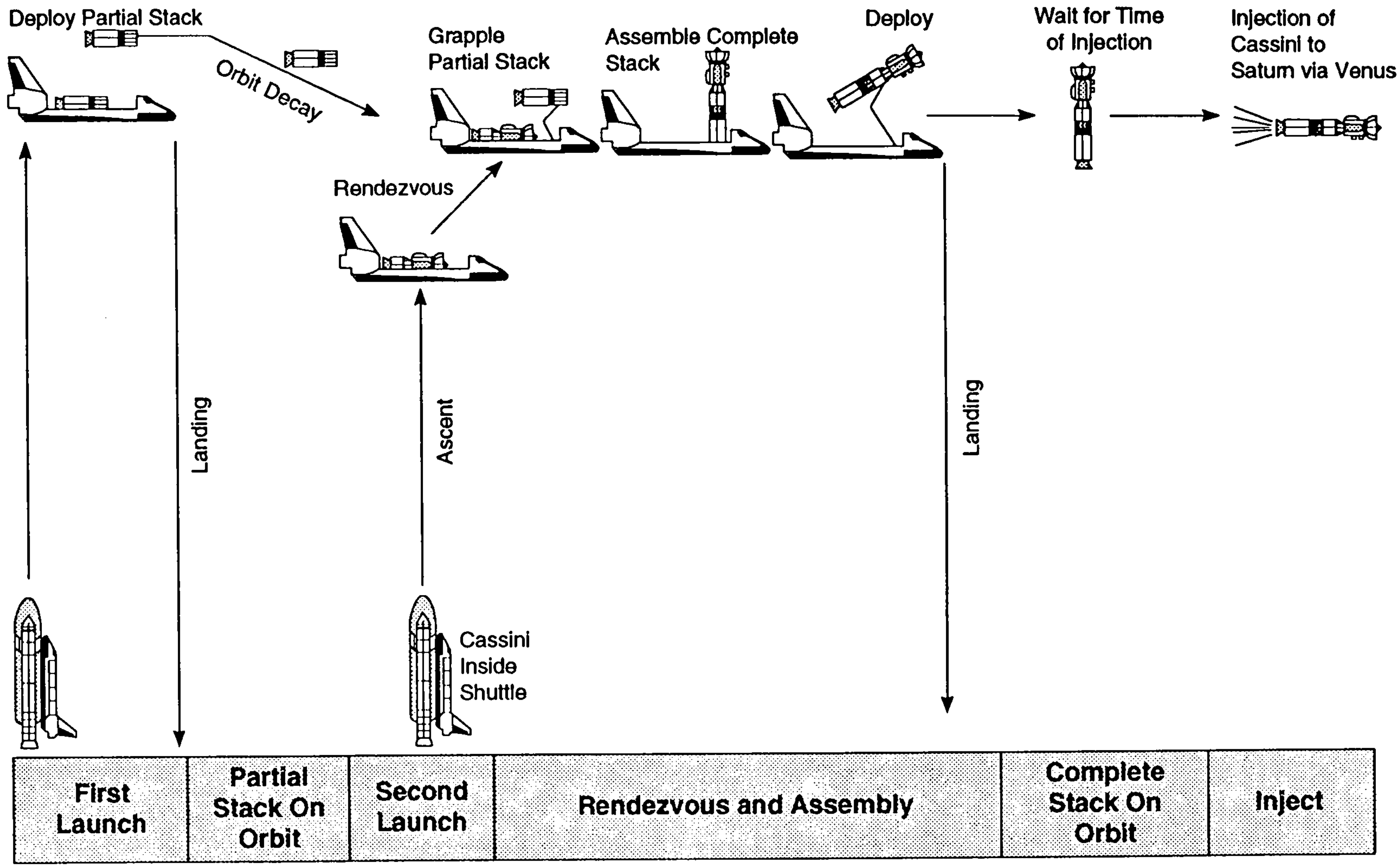
2.3.1 Mission Design

For the 1999 mission alternative, the Cassini spacecraft with the Huygens Probe and three RTGs would be launched to Saturn by the Space Shuttle from Launch Pad 39A or 39B located at Kennedy Space Center. Figure 2-11 illustrates the Shuttle. This mission alternative would require two Shuttle launches separated by at least 21 days but no more than 51 days. The first Shuttle launch would place an upper stage into low Earth orbit and the second launch would deliver the remaining upper stage(s) and the Cassini spacecraft including the RTGs. The upper stages with the spacecraft would be assembled on-orbit by astronauts. The spacecraft would then be injected into its interplanetary trajectory to Saturn by the upper stages. The spacecraft would travel on a VEEGA trajectory, which would be similar to the trajectory identified for the Titan IV March 1999 backup launch opportunity for the Proposed Action (see Figure 2-3). The backup launch opportunity for this mission alternative would occur in August 2000, using a VEEGA trajectory. Figure 2-12 illustrates the dual Shuttle launch and on-orbit assembly of the upper stages with the spacecraft. The dual Shuttle launch would provide full maneuvering capability (similar to the Titan IV [SRMU]/Centaur), but because of requirements of the Huygens



Source: JPL 1994a

FIGURE 2-11. DIAGRAM OF THE SHUTTLE (STS) LAUNCH VEHICLE



Source: JPL 1994a

FIGURE 2-12. EXAMPLE OF A DUAL SHUTTLE LAUNCH AND SPACECRAFT/UPPER STAGE ASSEMBLY ON ORBIT

Probe temperature control during the extended Earth orbital phase, the probe coast time would have to be reduced. The reduced coast time would result in a larger required orbiter deflection maneuver, which in turn would result in fewer Titan encounters. Therefore, launching of the spacecraft via the dual Shuttle in March 1999 or August 2000 would provide less science return than that expected from launching the spacecraft with the Titan IV (SRMU)/Centaur on the same launch opportunities (JPL 1994a).

Mission Contingencies

The Shuttle has intact abort capabilities to safely return the Shuttle crew and cargo to a suitable landing site in the event that specific failures (e.g., engine loss, electrical/auxiliary power failure) occur during the early phases of launch. There are three U.S. abort landing sites (i.e., Kennedy Space Center, Edwards Air Force Base, and White Sands Space Harbor). For every Shuttle mission, foreign abort sites are also identified in cooperation with host governments and would have to be identified if this mission were implemented.

2.3.2 Launch Opportunities

As stated previously, interplanetary missions can only be launched during specific opportunities. The primary launch opportunity for the dual Shuttle launches occurs in March 1999. A backup launch opportunity has been identified in August 2000, using a VEEGA trajectory.

As illustrated in Figure 2-12, launches would occur prior to the insertion date of March 1999 or August 2000, depending on the launch opportunity. Two Shuttle launches would be required with on-orbit mating of the upper stages with the spacecraft.

2.3.3 Spacecraft Description

The spacecraft would be essentially identical to the one described in Section 2.2.3.

2.3.4 Spacecraft Electrical Power and Heating Systems

The spacecraft electrical power and heating systems would be identical to those described in Section 2.2.4 for the Proposed Action. There may be a reduction in the number of RHUs for the Huygens Probe.

2.3.5 Spacecraft Propulsion Module Subsystem

The propulsion module subsystem would be as described in Section 2.2.5 for the Proposed Action.

2.3.6 Launch Vehicle (Dual Shuttle) Configuration

The Shuttle (see Figure 2-11) consists of an orbiter, a piloted (manned) reusable vehicle, which is mounted on a non-reusable (expendable) External Tank (ET) and two recoverable and reusable Solid Rocket Boosters (SRBs) (NASA 1988a).

Propulsion for the orbiter is provided by three engine systems: three Space Shuttle Main Engines (SSMEs), two SRBs, and an Orbital Maneuvering System (OMS). The SSMEs and the SRBs together provide thrust for lift-off and for the first 2 minutes or so of ascent. After the SRBs burn out, the SSMEs thrust the orbiter on, almost to orbit. After the SSMEs are shut down, the OMS provides thrust for attaining orbit, maneuvering while in orbit, and decelerating out of orbit (NASA 1988a).

The reusable SSMEs burn for about 8 minutes, and the nozzles are gimbaled for steering. The fuel is liquid hydrogen and the oxidizer is liquid oxygen, both stored in the ET (NASA 1988a).

The SRBs burn in parallel with the SSMEs to provide the initial ascent thrust. Each SRB (steel cased) weighs approximately 586,500 kg (1.293 million lbs), providing 12.76 million N (2.9 million lbs) of thrust at sea level. The nozzles on the SRBs are also gimbaled for steering. The propellant for the SRBs is a composite-type solid propellant formulated of polybutadiene acrylonitrile (PBAN) terpolymer binder, ammonium perchlorate, and aluminum powder (NASA 1988a).

The OMS includes two engines with gimbaled nozzles for steering. The fuel is MMH and the oxidizer NTO.

2.3.7 Mission Timeline

For a launch with the Space Shuttle, a typical mission timeline would be as follows (NASA 1988a):

- Phase 0 Prelaunch/Launch (T - 8 hr to T - 6.6 s)—This phase begins with the initiation of loading the liquid hydrogen (LH_2) and liquid oxygen (LO_2) into the Shuttle's ET at T - 8 hr and ends at SSME ignition at T - 6.6 s.

- Phase 1 Launch and Ascent (T - 6.6 s to T + 128 s)—This phase begins with SSME ignition at T - 6.6 s to SRB ignition at T - 0 and ends with SRB burnout and separation at T + 128 s. At T + 2 s, the vehicle would have sufficient velocity and attitude control to avoid striking the launch tower if the left SRB were to fail and lose thrust. The vehicle would clear the tower at T + 7 s. During this period, the telemetry and visual cues may be insufficient to permit use of the Flight Termination System (FTS). After T + 10 s, however, the FTS would be available. In the event of an accident, the IIP of vehicle debris would pass from land to the ocean at about T + 17 s and would be in deep water by T + 30 s, assuming a normal trajectory. After T + 30 s and before SRB burnout and separation at T + 128 s, the Shuttle would pass through the period of maximum dynamic pressure and SSME throttling. At T + 57 s, the Shuttle would reach an altitude where the results of an accidental fuel release would no longer threaten KSC or the local Florida region.

- Phase 2 Second Stage (T + 128 s to T + 532 s)—This phase begins with SRB separation at T + 128 s and ends with MECO at T + 532 s. Normally, the IIP for Africa landfall would occur at about T + 500 s and would reach the Indian Ocean at about T + 505.5 s.

- Phase 3 On Orbit (T + 532 s to T + 24,000 s)—This phase begins at T + 532 s and ends approximately T + 6 hr, just prior to the deployment of the spacecraft and the upper stage from the Shuttle's cargo bay. An OMS burn would be required at the beginning of this phase.

- Phase 4 Payload Deploy (T + 24,000 s to Earth Escape)—This phase begins with the deployment of the spacecraft and upper stage from the cargo bay.

- Interplanetary Cruise (Earth Escape to end of mission)—This phase covers the interplanetary cruise between Earth and Saturn.

The 1999 mission alternative would have some differences in the Shuttle mission timeline due to the on-orbit mating of the upper stages and the spacecraft by astronaut extra-vehicular activity.

2.3.8 Range Safety Considerations

2.3.8.1 General

Range safety encompasses all activities relevant to launch vehicles at KSC. See Section 2.2.8.1 for details.

2.3.8.2 Flight Termination System

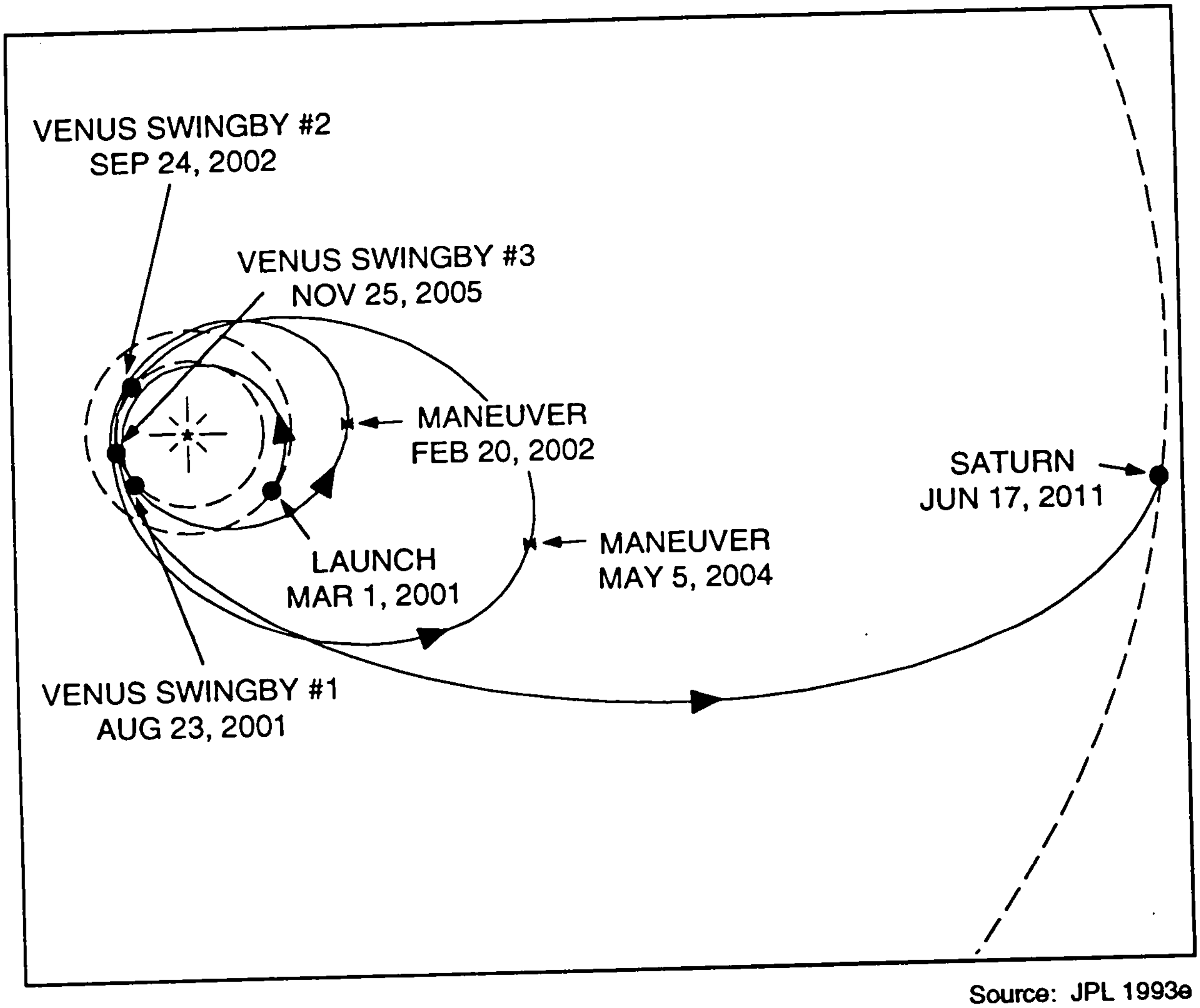
The FTS on the Shuttle, when activated from a ground signal, would destroy the two SRBs and the ET. The onboard systems for the two SRBs and one ET would be connected so that if either SRB received a destruct command all three would receive it. The system for each of these would be redundant to assure reliability (NASA 1988a).

2.3.8.3 Electromagnetic Hazard Conditions

The discussion in Section 2.2.8.3 also applies to the 1999 mission alternative.

2.4 DESCRIPTION OF THE 2001 MISSION ALTERNATIVE

The 2001 mission alternative would be similar to the Proposed Action in that it would include the Cassini spacecraft with the Huygens Probe and the three-RTG electrical power system, as described in Sections 2.2.3 through 2.2.5. This mission alternative, however, would insert the Cassini spacecraft into a non-Earth-Gravity-Assist trajectory. The launch vehicle would be the Titan IV (SRMU)/Centaur and would have a similar mission timeline as described in Section 2.2.7. Neither the Titan IV (SRM)/Centaur nor the dual Shuttle launch would be capable of launching and injecting the Cassini spacecraft into this trajectory. This mission alternative would have a primary launch opportunity during the first 2.5 weeks of March 2001 from CCAS and would use a 10.3-yr Venus-Venus-Venus-Gravity-Assist (VVVGA) trajectory, as depicted in Figure 2-13. The first Venus swingby would occur in August 2001, the second in September 2002, and the third in November 2005, arriving at Saturn in June 2011 for the 4-year tour of the Saturnian system (JPL 1994a).



Source: JPL 1993e

FIGURE 2-13. CASSINI MARCH 2001 VVVGA INTERPLANETARY TRAJECTORY

To accommodate the amount of maneuvering associated with the VVVGA trajectory, the Cassini spacecraft would have to be fitted with larger propellant tanks than used in the Proposed Action, to hold about 20 percent more propellant (increase of about 600 kg [1,323 lb]). In addition, a different spacecraft propulsion engine would have to be used—a rhenium engine. The rhenium engine, currently not space-qualified, is a higher performance engine than the currently designed engine for the spacecraft. A rhenium engine is a spacecraft main engine with a rocket chamber fabricated from rhenium and an internal oxidation-resistant iridium coating. It can perform at 2,200°C (4,000°F) which enables it to run without the need for cooling the rocket chamber. A version of this engine has been in development for NASA missions. Another version of the engine is being developed for commercial spacecraft. To make a rhenium engine available for this mission alternative, NASA would have to invest additional funds to complete engine development and make it flight ready. Only a high performance rhenium engine would have the potential capability to perform all the interplanetary maneuvers necessary to use the VVVGA trajectory and still leave enough propellant for maneuvers in orbit around Saturn. Even with the larger tanks, the amount of propellant available for spacecraft maneuvering upon reaching Saturn would be limited. The number of Titan flybys would have to be reduced from 35 (the Proposed Action) to 21, the SOI burn delay would have to be eliminated, and the initial orbit period would have to be increased significantly. This would reduce the amount of science return obtained from the Titan flybys and from close-in observation of Saturn's rings just prior to orbit insertion (JPL 1994a).

The Titan IV (SRMU)/Centaur would not have any launch mass margin to perform the VVVGA trajectory. Therefore, any increase in spacecraft mass would probably exceed the launch vehicle lift capability. The spacecraft would also be older at the time of arrival at Saturn compared with the Proposed Action's primary launch opportunity. The longer cruise time would also decrease the RTG electrical power output for the science experiments. The longer cruise time increases the probability of spacecraft failure and, therefore, loss of science.

There is no non-Earth-Gravity-Assist backup launch opportunity using the Titan IV (SRMU)/Centaur launch vehicle. A May 2002 VEEGA trajectory exists as a backup to the March 2001 VVVGA. This VEEGA trajectory would have characteristics similar to the December 1997 or March 1999 VEEGA trajectory for the Proposed Action's contingency launch opportunities.

A delay of the Cassini mission until the 2001 mission alternative would disrupt and could possibly strain the international partnerships formed to develop the Cassini Orbiter, Huygens Probe, and other space-related projects.

2.5 DESCRIPTION OF THE NO-ACTION ALTERNATIVE

The No-Action alternative would cancel the Cassini mission to Saturn. No further preparations would be made for the mission and the mission would not be implemented. None of the mission-specific science objectives would be realized. Some tangible benefits discussed in Section 1.4 (e.g., technological advances, such as a solid state data recorder and gyros) from the development of and planning for the Cassini mission have already been realized. Any future benefits directly attributed to the mission would be forfeited. Cancellation of the mission could seriously disrupt and strain the international partnerships NASA has formed to develop space-related projects.

2.6 EVALUATION OF LAUNCH VEHICLES, MISSION TRAJECTORIES, AND SPACECRAFT POWER SYSTEMS

In addition to the basic engineering design of the spacecraft, the other key components associated with the mission are the launch vehicle, the interplanetary trajectory, and the power system for the spacecraft's electrical requirements. These must function together to satisfy the requirements of the mission. Each of the key components were evaluated in developing the Proposed Action and alternatives addressed in this EIS.

The key components (see Figure 2-14) were evaluated in terms of 1) technical feasibility, 2) ability to satisfy the science objectives for the mission, and 3) potential for reducing the possible environmental impacts associated with the mission design for the Proposed Action. A component must provide the performance and operating characteristics required by all other components of the spacecraft and launch vehicle without imposing new requirements (JPL 1994a). The components must, of necessity, be compatible with all the other components for a particular mission. To be considered technically feasible, a component must have been tested for space-flight applications or must be in the development stages on a timetable consistent with the Cassini mission schedule. The requirement for the mission components to satisfy the science objectives is essential because the mission must provide useful information in a timely manner. The mission components were also evaluated with respect to relative environmental impacts.

2.6.1 Launch Vehicles

Performance (lift capabilities) and availability are the overriding considerations in the selection of a launch vehicle for a planetary mission because the launch vehicle must be able to reliably place the spacecraft into the proper trajectory. If the launch vehicle does not have adequate lift capacity (including sufficient margins), then it does not merit further evaluation (JPL 1994a). Performance is derived from an integrated launch vehicle consisting of the booster and an upper stage. The booster operates from the ground to insert the upper stage and payload into a desired parking orbit. The upper stage then injects the payload from the parking orbit into the desired interplanetary trajectory. In certain cases, the booster alone cannot place a fully loaded upper stage and payload (such as with the Cassini spacecraft) into parking orbit. Therefore, a portion of the propellant for the upper stage is used to insert the payload into the parking orbit. For instance, the Titan IV (SRMU)/Centaur for the Proposed Action would require that about 20 percent of the Centaur (upper stage) propellant be used to place the Centaur and the Cassini spacecraft into a low Earth parking orbit.

It is generally not possible to arbitrarily mix and match boosters and upper stages to create a launch vehicle configuration to deliver the payload to the desired trajectory. Upper stages are usually designed for use with certain boosters. Thus, boosters and upper stages must be compatible in both performance and integration. In addition, the size of the PLF (on expendable launch vehicles) or the cargo bay (on the Shuttle) is considered in

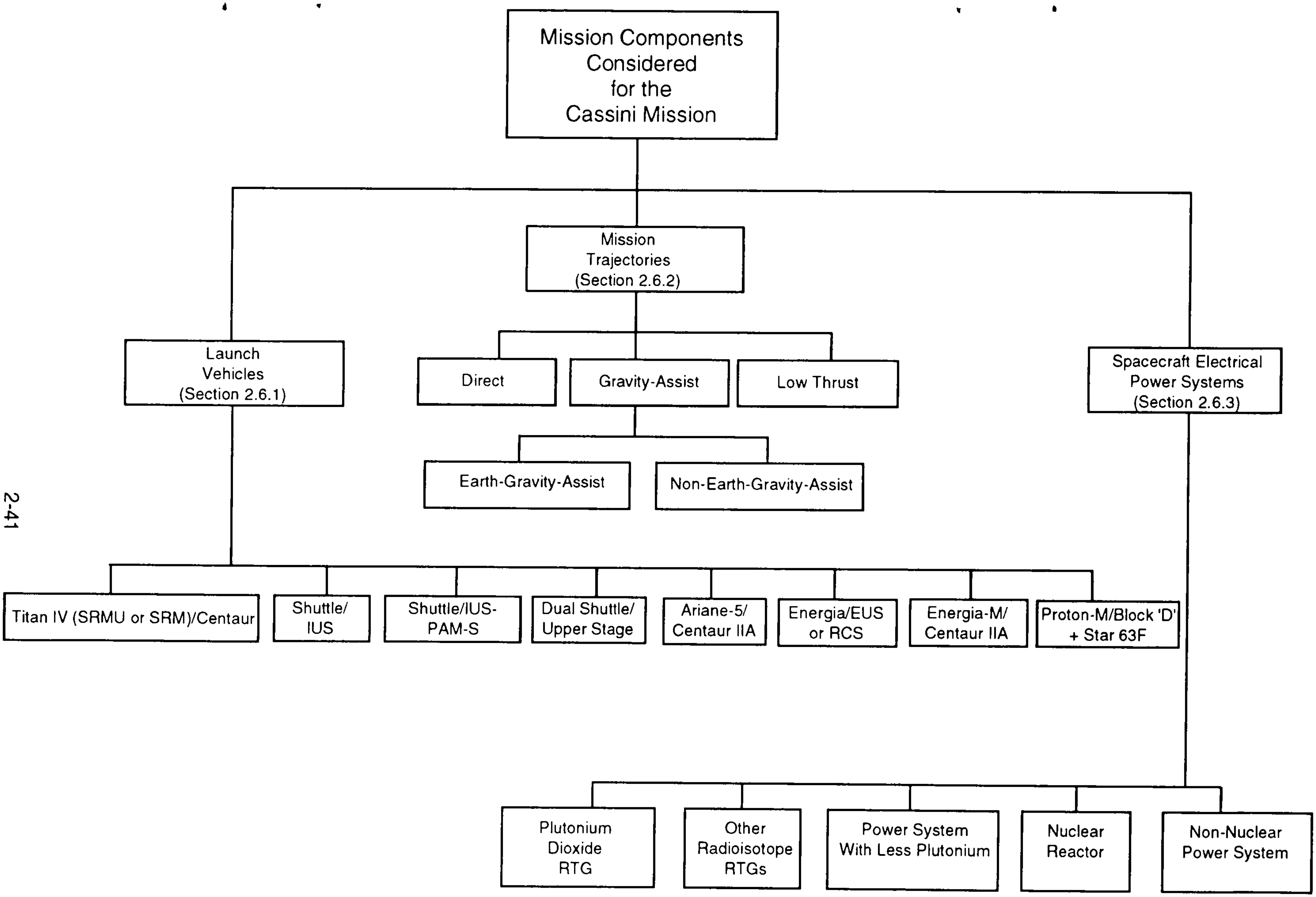


FIGURE 2-14. MISSION COMPONENTS CONSIDERED FOR THE CASSINI MISSION

the configuration of the launch vehicle. For example, the Titan IV (SRMU) can use a variety of PLF sizes, from 17.1 m to 26.2 m (56 ft to 86 ft) long (Martin Marietta 1992); the cargo bay on the Shuttle is 18.3 m (60 ft) long by 4.6 m (15 ft) in diameter (NASA 1988a). The volume available in the PLF or cargo bay for the spacecraft would depend on the size of the upper stage.

In its assessment of launch vehicles, JPL considered as technically feasible those systems that are technically mature and space qualified, and as potentially feasible, those launch vehicles that are under development on a timetable that if met, would be consistent with the schedule for the Cassini mission. Only those systems that would provide the required performance and operating characteristics without imposing any new requirements upon the mission or other mission components were considered in detail by JPL. This narrowed the launch vehicles for the Cassini mission to the U.S. and foreign launch vehicles discussed in Sections 2.6.1.1 and 2.6.1.2, respectively. Table 2-4 provides a summary comparison of the U.S. launch vehicles (JPL 1994a). The mission trajectories are discussed in Section 2.6.2 of this EIS.

2.6.1.1 U.S. Launch Vehicles

Two U.S. launch vehicles (Titan IV and Shuttle) are space-qualified, available and, in certain configurations have the lift capability to place the spacecraft into a low-Earth orbit (LEO) from which it could then be injected into a feasible trajectory to Saturn. The following configurations were evaluated for the Cassini mission:

- Titan IV (SRMU or SRM)/Centaur (for the Proposed Action)
- Shuttle (i.e., Space Transportation System [STS])/Inertial Upper Stage (IUS)
- Shuttle/IUS-Payload Assist Module Special (PAM-S)
- Shuttle/Unspecified Upper Stage(s)

The Titan IV (SRMU or SRM)/Centaur is described in Section 2.2.6 of this EIS. The Titan IV (SRMU) is the most capable U.S. expendable heavy lift vehicle with the capacity of placing 22,680 kg (50,000 lb) into LEO. The existing Titan IV (SRM), successfully flown in ten out of eleven missions (as of March 3, 1995), has an LEO capability of about 18,140 kg (40,000 lb). While either vehicle would be capable of launching the Cassini spacecraft during the launch opportunities of the Proposed Action, the science return for the SRM configuration would be less than that of the SRMU configuration.

The Shuttle, discussed in Section 2.3.6 and in several NASA NEPA documents, including the Galileo and Ulysses EISs (NASA 1989b, NASA 1990), has similar lift capabilities as the Titan IV (SRMU). It has been launched 68 times with 1 failure. The Shuttle, a piloted reusable vehicle, is mounted on a non-reusable ET containing liquid hydrogen and oxygen propellants and two SRBs. The Shuttle has three main rocket engines and a cargo bay 18.3 m (60 ft) long and 4.6 m (15 ft) in diameter (NASA 1978). Crew safety guidelines prohibit the use of the powerful Centaur upper stage in the Shuttle. For interplanetary missions, less energetic solid-propellant fueled upper stages, also

TABLE 2-4. SUMMARY OF POTENTIAL U.S. LAUNCH VEHICLES

Qualifying Launch Opportunities	Titan IV (SRMU) with Centaur	Titan IV (SRM) with Centaur	Single Shuttle with IUS/PAM-S	Dual Shuttle Launch with Upper Stage Assembly On-Orbit
October 1997 VVEJGA	X	X	–	See footnote a
December 1997 VEEGA	X	X	–	See footnote a
March 1999 VEEGA	X	X	–	X
August 2000 VEEGA	X	X	–	X
March 2001 VVVGA	X	–	–	–
March 2002 VVVGA	–	–	–	–
May 2002 VEEGA[b]	X	–	–	X
1997, 1998, 1999 JGA	–	–	–	–
Science Return for Equivalent Launch Opportunities[c]	Would return best science	Would return less than Titan IV (SRMU)/ Centaur	Not applicable	Would return less than the Titan IV (SRMU)/Centaur
Launch Vehicle Considerations	• Spacecraft needs rhenium engine for non-EGA opportunity • No non-EGA backup opportunities for March 2001	• Less performance than Titan IV (SRMU) with Centaur configuration • No non-EGA opportunities	• Not technically feasible	• Requires development of new upper stage • Assembly on-orbit increases technical complexity • No non-EGA opportunities

Source: adapted from JPL 1994a

NOTE: X Launch vehicle has sufficient capability to perform the mission with this trajectory.
– Launch vehicle does not have sufficient capability to perform the mission with this trajectory.

a. There is not enough time to develop and implement the integration design for the spacecraft, launch vehicle, and upper stage without incurring unacceptable development, integration, and schedule risk.

b. If the primary launch opportunity in March 2001 were missed, there would not be enough time to reconfigure the mission for a dual Shuttle backup launch opportunity.

c. Amount of science return expected compared to using a Titan IV (SRMU)/Centaur for the same launch opportunity.

compatible with the Titan IV vehicle, are typically used in the Shuttle. For example, the IUS was used for the Magellan and Galileo missions (in May 1989 and in October 1989, respectively), and the IUS/PAM-S was used for the Ulysses mission in 1990. For the Cassini mission, neither of these upper stages, when coupled with the Titan IV (SRMU or SRM) or the Shuttle, would be capable of placing the spacecraft into a feasible trajectory to Saturn. Therefore, launch vehicle configurations using either of these two upper stages were not considered further. Launch of the Cassini spacecraft using the Shuttle would require two Shuttle launches (separated by at least 21 days, but no more than 51 days) to place the spacecraft and upper stages into LEO, where the final on-orbit mating (of the spacecraft and upper stages) would be performed by astronauts. The upper stages would then inject Cassini into the VEEGA interplanetary trajectory. Though the dual Shuttle launch is technically feasible, there would be insufficient time to develop and implement the integration design for the spacecraft, launch vehicle, and upper stage without incurring unacceptable development, integration, and schedule risk for the 1997 launch opportunity (JPL 1994a). Thus, the dual Shuttle launch can be considered only for later launch opportunities, such as the March 1999 opportunity.

2.6.1.2 Foreign Launch Vehicles

Currently, the United States does not have any programs funded to develop a launch vehicle with a lift capability greater than the Titan IV (SRMU)/Centaur. However, the following foreign launch vehicles could potentially have similar capability to the Titan IV (SRMU)/Centaur (JPL 1994a):

- Ariane-5/Centaur IIA
- Energia/Energia Upper Stage (EUS) and/or the Retro and Correction Stage (RCS)
- Energia-M/Centaur IIA or Block 'DM' + Star 63F
- Proton-M/Block 'D' + Star 63F.

Though the above foreign vehicles are still in the development stage and/or have uncertain development schedules, their technical capability of launching the Cassini spacecraft can be potentially assessed. It should be noted that the use of a foreign launch vehicle raises special programmatic concerns. The following list summarizes some of these concerns:

- Substantial time would be required to analyze, develop, space-qualify and implement the integration design for the spacecraft, launch vehicle, and upper stage.
- The launch approval process for carrying a radioactive payload into space from foreign soil would require U.S. and foreign government involvement beyond the purview of this EIS.

- Transportation and security requirements specifically for the RTGs and RHUs would require U.S. and foreign government involvement and policy decisions that are beyond the purview of this EIS.

- Foreign relations and domestic/competitiveness policies are beyond the purview of this EIS (White House 1990).

- Difficulty would be associated with spacecraft and launch vehicle integration at unfamiliar overseas launch facilities.

Table 2-5 summarizes the foreign launch vehicles that JPL addressed in detail (JPL 1994a). The table identifies interplanetary trajectories and launch opportunities that can potentially be enabled by the launch vehicles (see Section 2.6.2). The table also identifies the amount of science return expected by using these launch vehicles compared with using a Titan IV (SRMU)/Centaur. Additional limitations associated with the use of these launch vehicles have also been presented in the table.

Ariane-5

The European Ariane-5, an expendable launch vehicle being developed to replace the operational Ariane-4 series by 1999, is proposed to have its first commercial flight in 1996. The Ariane-5 would be launched from Kourou in French Guiana. It would be a two-stage core vehicle with two strap-on boosters. The planned fairing size would be 4.6 m (15.1 ft) diameter and 12 m (39.4 ft) long. The capability of the Ariane-5 would be comparable to the Titan IV (SRMU) at 20,865 kg (46,000 lb) to LEO (JPL 1994a). Currently, there are no plans to develop any upper stages for this vehicle. However, the Ariane-4 H10 cryogenic third stage or Centaur IIA could potentially be modified to inject planetary payloads. (The Centaur IIA is the version of the Centaur cryogenic upper stage which is currently used by the U.S. Atlas II family of launch vehicles). Use of the Ariane-5/Centaur IIA to launch the spacecraft would involve technical complexities with substantial analysis, integration and qualification of the upper stage to the spacecraft. In addition, major launch pad and operational modifications would have to be implemented for the Centaur IIA, the spacecraft, and the necessary interfaces. The payload fairing would also be too small for the currently designed spacecraft. Regardless of the current developmental status and potential of the Ariane-5 with the Centaur IIA, it would not enable any new interplanetary trajectories beyond those identified for the Proposed Action using the Titan IV (SRMU)/Centaur. Therefore, these complexities, the lack of any new trajectories and the programmatic concerns eliminate the Ariane-5 from further consideration for this mission.

Energia

The Russian Energia, the most powerful launch vehicle built in the last decade, has not flown since November 1988. It has had a brief flight history consisting of two test flights, with an upper stage failure during one of these test flights. The Energia was designed to be able to place approximately 93,070 kg (205,000 lb) of payload into a 200 km (125 mi) sub-orbital trajectory (JPL 1994a). Payloads can then be boosted into Earth orbit either by using their own propulsion systems or by an upper stage. The Energia

TABLE 2-5. SUMMARY OF POTENTIAL FOREIGN LAUNCH VEHICLES

Qualifying Launch Opportunities	Ariane-5 with Centaur IIA	Energia with EUS/RCS	Energia-M with Centaur IIA	Proton-M with Block 'D' + Star 63F	Split Mission Proton-M with Block 'D' + Star 63F
October 1997 VVEJGA	See footnote a	See footnote a	See footnote a	See footnote a	See footnote a
December 1997 VEEGA	See footnote a	See footnote a	See footnote a	See footnote a	See footnote a
March 1999 VEEGA	X	X	X	X	X
August 2000 VEEGA	X	X	X	X	X
March 2001 VVVGA	X	X	X	–	–
March 2002 VVVGA	X	X	X	X	X
May 2002 VEEGA	X	X	X	–	–
1997, 1998, 1999 JGA	–	X	–	–	–
Science Return for Equivalent Launch Opportunities[b]	Would return full science; for non-EGAs, meets minimum requirement	Would return full science; for non-EGAs, meets minimum requirement	Would return full science; for non-EGAs, meets minimum requirement	Would return less science	Would return full science
Launch Vehicle Considerations[c]	• Needs development of new upper stage configuration • PLF is too small for the Cassini spacecraft • Spacecraft needs rhenium engine for non-EGA opportunities; would need idealized rhenium engine performance for March 2002	• Development of upper stages is uncertain • Lack of information available with respect to the booster and upper stages to assess technical feasibility	• Needs development of new upper stage configuration • 2002 VVVGA opportunity has a cruise duration of 12 years • March 2002 VVVGA requires a substantially larger bipropellant tank	• Needs development of new upper stage configuration • PLF is too small for the Cassini spacecraft • No flight termination system	• Needs development of new upper stage configuration • PLF is too small for the Cassini spacecraft • Would use a total of 5 RTGs • Twice the number of gravity-assists • Increased mission risk because requires two successful launches and two successful Saturn orbit insertions for full science return

Source: JPL 1994a

NOTE: X Launch vehicle has sufficient capability to perform the mission with this trajectory.
– Launch vehicle does not have sufficient capability to perform the mission with this trajectory.

a. Even if this launch configuration was determined to be available and technical feasible, there would be insufficient time to develop and implement the integration design for the spacecraft, launch vehicle and upper stage without incurring unacceptable development, integration and schedule risk.

b. Amount of science return expected compared to using a Titan IV (SRMU)/Centaur for the same launch opportunity.

c. Transportation and security requirements for the RTGs and RHUs would require both U.S. and foreign government involvement and policy decisions that are beyond the purview of this EIS.

consists of a cryogenic core stage with four to eight strap-on boosters. A 6.7 by 42.1 m (22 by 138 ft) cargo container is side-mounted to carry the upper stage and payload. Depending on the booster and upper stage configuration, the Energia could potentially enable Jupiter-Gravity-Assist (JGA) and direct trajectories for Cassini. Russia is reportedly developing two upper stages for the Energia. These are the Retro and Correction Stage (RCS) (also known as Block to Transfer and Correction [BTK]), and the Energia Upper Stage (EUS) (JPL 1994a). Operational and flight schedules for these upper stages are uncertain at this time. The availability of the Energia has not been established and the future of this launch vehicle is uncertain. Due to insufficient information on the status of development and performance of the Energia core vehicle, an accurate evaluation of the Energia's technical performance (e.g., the operation and payload integration details and accident analysis) for the Cassini mission cannot be made. The Energia is eliminated from further consideration for the Cassini mission due to the lack of adequate technical data on its performance and due to the programmatic concerns.

The Energia-M is designed to be a smaller version of the Energia discussed above. It would use two of the Energia's strap-on boosters. Also, the core engine would be a scaled down version of the Energia's. Its payload fairing would be 5.1 m (16.7 ft) in diameter and 21.5 m (70.5 ft) long, in line with the core. The Energia-M would place a 30,845 kg (68,000 lb) payload in near low Earth orbit (sub-orbital) (JPL 1994a). The Centaur IIA (upper stage) could potentially be used with the Energia-M for the Cassini mission. However, major launch pad (i.e., Baikonur Cosmodrome in Kazakhstan) and operational modifications would be necessary to implement and launch such a configuration. The Energia-M has only undergone a full scale model launch pad compatibility evaluation at Baikonur. The Centaur IIA and the Cassini spacecraft would fit the Energia-M's 21.5 m (70.5 ft) long PLF. The less energetic (compared to the Centaur IIA) Block 'DM'+ Star 63F upper stage could also be used. However, the Energia-M configuration would not enable any new interplanetary trajectories different from those identified for the Proposed Action using the Titan IV (SRMU)/Centaur. The actual development of the Energia-M has not begun; therefore, future availability is highly uncertain. Thus, for these reasons and the programmatic concerns, the Energia-M is eliminated from further consideration for the Cassini mission.

Proton

When available, the Russian Proton-M, a modernized version of the Proton D-1-e which has flown over 200 missions, is expected to have the capability of placing about 23,700 kg (52,250 lb) in LEO. Two versions of the Proton upper stage, i.e., the Block 'DM' and the Block 'D' are available. Each is a single engine, liquid-fueled, three-axis stabilized, inertially guided, restartable stage. The 'D' version is lighter and more energetic than the 'DM' version. In order for the Proton-M with the 'D' version upper stage to be potentially feasible for the Cassini mission, an additional upper stage (e.g., a Star 63F) and a larger payload fairing would be required. This configuration (i.e, Proton-M/Block 'D'+ Star 63F) could provide a performance comparable to the Titan IV (SRM)/Centaur and it would not be capable of enabling any new interplanetary trajectories different from those identified for the Titan IV (SRMU)/Centaur. Because of these technical issues, its unavailability, and the programmatic concerns associated with foreign launch vehicles, the Proton-M is eliminated from further consideration for the Cassini mission.

The Proton-M with Block 'D' + Star 63F could also enable a split mission. In this configuration, two smaller spacecraft would be launched to Saturn, with only one spacecraft carrying the Huygens Probe to Titan. This approach would require the use of a total of five RTGs. Due to technical complexities and programmatic concerns, the Proton-M with Block 'D' + Star 63F is eliminated from further consideration for the Cassini mission.

2.6.1.3 Summary of Launch Vehicles

Due to the technical complexities, the lack of adequate technical data, and the programmatic concerns associated with the use of foreign launch vehicles, they are eliminated from further consideration for the Cassini mission. For a 1997 launch, the U.S. Titan IV (SRMU)/Centaur is the only feasible launch vehicle to accomplish all of the planned science objectives with a full science return. If the Titan IV (SRMU)/Centaur were not available, then the less powerful U.S. Titan IV (SRM)/Centaur would be used to implement the mission. Using the Titan IV (SRM)/Centaur would necessitate a reduction in the mass of the propellant on the spacecraft. This action would limit the amount of maneuvers at Saturn and would therefore result in a reduced science return when compared with a launch on the Titan IV (SRMU)/Centaur. In addition, an opportunity to implement the mission exists in 1999 using the Shuttle. Using the Shuttle, however, would require two launches, separated by a minimum of 21 but no more than 51 days. The science return in this case would be less than that for the 1997 Titan IV (SRMU)/Centaur launch.

2.6.2 Mission Trajectories

Trajectories for interplanetary missions are either ballistic or nonballistic. In a ballistic trajectory, the spacecraft's flight path is shaped only by the gravitational influences of the Sun and planets. A nonballistic trajectory includes, in addition to the gravitational influences, velocity changes produced by the spacecraft's chemical propulsion system. All planetary missions flown to date have used nonballistic trajectories. These trajectories, therefore, consist of two or more ballistic trajectory arcs connected by spacecraft maneuvers. Both ballistic trajectories and nonballistic trajectories can be classified as either direct trajectories (see Section 2.6.2.1) or gravity-assist trajectories (see Section 2.6.2.2). Another class of nonballistic trajectories, low-thrust trajectories, can be used by spacecraft with a low-thrust propulsion system (see Section 2.6.2.3) (JPL 1994a).

2.6.2.1 Direct Trajectory

A direct trajectory typically uses chemical propulsion, does not use planetary gravity-assist swingbys, and can be either ballistic or nonballistic. This trajectory shortens flight time, lowers operational costs, and reduces mission complexity. It also reduces the likelihood of accidental reentry into the Earth's atmosphere. Opportunities to use a given direct trajectory repeat whenever the same relative planetary alignment (phasing) occurs. Currently, none of the available U.S. launch vehicles has the lift capability necessary to launch the Cassini spacecraft into a direct trajectory (JPL 1994a). A U.S. vehicle is not being developed with this capability; therefore, this type of trajectory is infeasible at this time.

2.6.2.2 Gravity-Assist Trajectory

A gravity-assist trajectory depends on chemical propulsion and uses one or more swingbys of planets to significantly reduce requirements for either the mission's launch injection energy, arrival velocity, or flight time. Several past missions have used gravity-assist swingbys. Pioneer 11, launched in 1973, used a Jupiter-Gravity-Assist to allow a flyby of Saturn. Mariner 10, also launched in 1973, used a Venus-Gravity-Assist to swing by Mercury. Voyagers 1 and 2 (launched in 1977) each used a gravity-assist swingby of Jupiter to reach Saturn. Voyager 2 also used a gravity-assist at Saturn to go to Uranus and then a gravity-assist of Uranus to continue to Neptune. The Galileo spacecraft used swingbys of Venus in 1990 and Earth in both 1990 and 1992, which will enable the spacecraft to encounter Jupiter in 1995 (JPL 1994a).

The Proposed Action would use a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) involving an Earth-Gravity-Assist swingby. Gravity-assist swingbys of Earth represent a very effective means of increasing the mass that can be delivered to an outer planet, such as Saturn. Trajectories using combinations of Venus and Earth-gravity-assist swingbys, such as Venus-Earth-Gravity-Assist (VEGA), Venus-Venus-Earth-Gravity-Assist (VVEGA), and Venus-Earth-Earth-Gravity-Assist (VEEGA), have an important advantage since their launch energy requirements are low. The addition of a Jupiter-Gravity-Assist after the final Earth or Venus swingby, such as Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) or Venus-Venus-Venus-Jupiter-Gravity-Assist (VVVJGA), makes it possible to deliver a spacecraft to an outer planet beyond Jupiter with a shorter flight time and/or with lower post-launch propellant requirements (JPL 1994a).

Gravity-assist trajectories that use planets other than the Earth result in a lower level of potential environmental impacts because they eliminate the possibility of an Earth-targeted swingby reentry accident and any associated environmental impacts. For the Cassini mission, JPL performed detailed analyses of numerous trajectories that would not use Earth swingbys, including Jupiter-Gravity-Assist, Mars-Gravity-Assist, Mars-Venus-Gravity-Assist, Mars-Jupiter-Gravity-Assist, Venus-Gravity-Assist, and Venus-Jupiter-Gravity-Assist (JPL 1994a).

A Jupiter-Gravity-Assist (JGA) greatly reduces the required launch injection energy while retaining most of the advantages of a direct trajectory. Even with the reduced injection energy, however, a JGA with launch opportunities in 1997, 1998, and 1999 for Cassini would still require a launch vehicle with performance capabilities (lift and injection) that would exceed that of the Titan IV (SRMU)/Centaur.

The planet Mars was evaluated for a gravity-assist swingby for missions to outer solar system planets. Because of its relatively low mass (about one-tenth that of the Earth), however, Mars is not effective in increasing the energy of a spacecraft trajectory during a single swingby. A Mars swingby would be most useful if the spacecraft returned to Earth for a gravity-assist after the Mars swingby before heading to Saturn. The next launch opportunity using an Earth-Mars combination would be in 2011, which is outside the timeframe for the Cassini mission. Because the Earth is required, the Earth-Mars combination would not present any environmental advantage over any of the currently identified trajectories to Saturn. In addition, the combinations of Mars with either Venus or Jupiter do not provide any advantages (JPL 1994a).

JPL also identified non-Earth gravity-assist trajectories to Saturn using either Venus alone in a VVVGA or Venus combined with Jupiter for a Venus-Venus-Venus-Jupiter-Gravity-Assist (VVVJGA) (including the March 2002 opportunity noted in Table 2-4) (JPL 1994a). Several VVVGA opportunities to Saturn exist between 1996 and 2004 but only the 1996 and 2001 opportunities might be feasible using the Titan IV (SRMU)/Centaur. For the Venus-Jupiter combination, 1996 is the first opportunity and it becomes available again 17 to 20 years later. Of all these trajectories, three were found to be potentially feasible using the Titan IV (SRMU)/Centaur: 1) a VVVGA with a March 1996 launch date, 2) a VVVJGA with a March 1996 launch date, and 3) a VVVGA with a March 2001 launch date (JPL 1994a).

Preparations for launch are not feasible for either a 1996 VVVGA or a 1996 VVVJGA trajectory due to significant schedule and technical issues that would have to be addressed before launch. Accelerating development of the Cassini spacecraft and Huygens Probe for either of these 1996 launch opportunities, 1.5 years earlier than the Proposed Action, would require an accelerated equipment development schedule from NASA, the European Space Agency (ESA), and the Italian Space Agency (ASI). There would not be enough time to develop and implement the integration design for the spacecraft, launch vehicle, and upper stage without incurring unacceptable development, integration, and schedule risk, consequently increasing developmental risk and the risk of spacecraft component failures in flight.

The March 2001 VVVGA, however, would be a viable trajectory (see Section 2.4 for a detailed discussion). This trajectory would be technically feasible to implement with the Titan IV (SRMU)/Centaur. Without an EGA, it would eliminate the possibility of an inadvertent reentry during an Earth swingby, as well as any of the associated environmental impacts. However, this trajectory would not rule out the possibility of a long-term inadvertent reentry (see Section 4.1.5.3).

2.6.2.3 Low-Thrust Trajectory

A low-thrust trajectory requires the use of low-thrust propulsion systems with thrust acceleration levels less than one ten-thousandth of the Earth's gravity with specific impulses that are 5 to 50 times higher than that of a chemical propulsion system. However, low-thrust trajectories require propulsion systems that are not available or require significant development. Low-thrust propulsion systems that have been studied over the last three decades for unmanned planetary missions include the Solar-Electric Propulsion (SEP), Solar-Thermal Propulsion (STP), Nuclear-Electric Propulsion (NEP), and Solar Sail. The SEP, the most mature and best understood system, uses large solar arrays to provide electrical power to a number of modular electric bombardment thrusters using xenon as a propellant. The STP concept uses large solar concentrators to heat hydrogen or some other working fluid, which is then discharged through a nozzle to produce thrust. The NEP combines a small nuclear reactor with a high-power thruster. Thrust for the Solar

Sail is produced by momentum transfer from sunlight falling on a large, flat, very lightweight membrane. These types of propulsion systems, except for NEP, can generally be operated only near the Sun (JPL 1994a) and, therefore, would not be feasible near Saturn, which is 9.3 AU from the Sun. Spacecraft for these solar-dependent low-thrust missions would need to be augmented by chemical propulsion systems for near-Saturn maneuvers, diminishing or eliminating any payload mass benefit from the otherwise low-thrust system. Moreover, none of these low-thrust technologies, including NEP, is in a state of development that allows commitment to a launch in the 1997 to 2001 timeframe consistent with the mission goals and objectives (JPL 1994a).

2.6.3 Spacecraft Electrical Power Systems

Electrical power generating systems comprise an energy source and an energy conversion subsystem. The available energy sources include the Sun, chemicals in fuel cells or batteries, and heat from either radioactive decay, nuclear fission (reactors), or the combustion of fuels. The energy conversion subsystem transforms energy into electricity using, for example, photovoltaic cells, thermoelectric couples, or dynamic conversion machinery. Only certain combinations of energy source and energy conversion subsystems are inherently compatible.

Other energy sources for the RTGs, if available for Cassini, that could potentially reduce or eliminate the environmental risks associated with the plutonium dioxide used in the RTGs were evaluated. Power systems based on such sources must also satisfy the electrical power system performance criteria discussed in Section 2.2.4.1. The other power systems considered for Cassini include those that: 1) replace the plutonium (mainly Pu-238) dioxide fuel in the RTGs with a less potentially hazardous radioisotope, 2) implement power system designs that require less plutonium dioxide fuel, 3) use a nuclear reactor, or 4) use a power system based on a non-nuclear energy source (JPL 1994a).

2.6.3.1 Other Radioisotope RTGs

The principal concern for using plutonium dioxide fuel in RTGs is the potential radiation health and environmental hazards created if the fuel is released into the environment following an accident. In principle, any radioisotope with a half-life long enough to provide sufficient power throughout the Cassini mission and with a high enough specific activity to provide the required power with a suitably small generator can be used. Two other radioisotopes identified for RTGs are the oxides of strontium-90 (Sr-90) and curium-244 (Cm-244) (JPL 1994a). An examination of their properties and production requirements indicates that neither oxide has a significant environmental advantage over plutonium dioxide. Sr-90 emits gamma radiation and Cm-244 emits both gamma and neutron radiation. Therefore, extensive shielding would be required during their production and handling, as well as when the oxide was onboard the spacecraft. Extensive development and safety testing would also be required. In addition, production facilities for sizeable quantities of these radioisotopes are not available. Therefore, Sr-90 and Cm-244 oxides cannot be considered feasible isotopic heat sources for the Cassini power system.

2.6.3.2 Power Systems Requiring Less Plutonium Dioxide

To provide comparable power levels with less plutonium, a more efficient conversion system would be required. The thermoelectric converter on the RTG has an efficiency of 6.8 percent (DOE 1987a). Other conversion technologies considered include static systems (thermionic, thermophotovoltaic, and alkali metal thermoelectric converter [AMTEC]) and dynamic systems (Rankine, Brayton, and Stirling cycles).

The GPHS has a maximum operating temperature of 1,100°C (2,012°F). Thermionic converters are high-temperature systems operating at temperatures above 1,327°C (2,420°F), which make them incompatible with the GPHS. Thermophotovoltaic converters operate at temperatures above 1,227°C (2,240°F), again making them incompatible with the GPHS. With appropriate filters and sufficient development time, however, thermophotovoltaic converters can operate at the limiting GPHS temperatures. The AMTEC is in its developmental phase and requires the resolution of issues regarding performance, degradation, spacecraft integration, launch, lifetime, and zero gravity effects before it can be considered for a spacecraft application. The dynamic conversion systems are not sufficiently developed for use in space at this time (JPL 1994a).

All of these power systems also exhibit serious technology maturity issues that could not be resolved in a timeframe consistent with the Cassini mission requirements and, therefore, are not feasible (JPL 1994a).

An additional approach evaluated for reducing the amount of plutonium dioxide fuel needed for the mission would be to reduce the number of RTGs to two and add batteries. This would be possible on some missions if the electrical power demand is intermittent and a secondary (rechargeable) battery could be added to supply power during peak demand periods and allowed to recharge during low demand times. For the Cassini mission, however, the highest and most continuous power demand would occur during the final years of the mission when the RTG power would be at its lowest output. Current power demand profiles would require partial or total spacecraft power shutdowns to recharge the batteries so that the spacecraft could restart itself again. Not only would this procedure result in the loss of science data, but it would entail extremely high-risk wake-ups from dormant modes that have not been demonstrated for such large numbers of cycles (JPL 1994a).

2.6.3.3 Nuclear Reactors

The environmental advantage of using a nuclear reactor is that it can be launched in a nonoperating mode when the inventory of radioactive fission byproducts is very small. A nuclear reactor of a size and operating lifetime suitable for Cassini, however, does not exist nor is it being developed in the United States (JPL 1994a). A number of technical problems remain to be solved even though nuclear reactors have been launched and operated in space since 1965. Some of the challenges to reactor development and implementation for deep space, long-duration missions, such as Cassini, involve control complexity and excessive mass required for shielding. Therefore, a nuclear reactor is not a feasible power source for the Cassini mission.

2.6.3.4 Non-Nuclear Power Systems

Energy sources other than the heat generated by radioisotopes are available. They include solar energy, fuels and chemicals, and power-beaming (microwave or laser) sources. The feasibility of using any of these non-nuclear power sources in spacecraft electrical power systems is addressed below.

Solar Energy

The use of solar energy for U.S. space applications was initiated in 1958 on the Vanguard I. Since then, solar energy has played a vital role in the U.S. space program by providing electrical power for most spacecraft operating between the orbits of Mercury and Mars (i.e., 0.38 and 1.52 AU [56.6 and 226.3 million km or 35.2 and 140.6 million mi, respectively]). For the Cassini mission, the greatest electrical power requirements would occur when the spacecraft is acquiring scientific data near Saturn, between 9.0 and 9.3 AU (1.34 and 1.38 billion km [840 and 865 million mi]) from the Sun. At these distances from the Sun, the intensity of sunlight is only about 1 percent of that at Earth, and temperatures are quite low.

Solar energy as the source of electrical power for deep-space probes would be desirable were it not for the large size and mass of the resulting power-generating system. Generating spacecraft electrical power from the sun has been and continues to be the subject of several evaluations and studies. A 1981 conceptual study of the system impacts of using a concentrated solar array (CSA) on the Galileo spacecraft, launched in 1989 to Jupiter and powered by two RTGs, concluded that such an effort could be performed but would require an "extensive development effort" and that "..the severe environmental constraints and the embryonic state of CSA development indicates that CSA will not displace the RTG on the Galileo mission" (Rockey et al. 1981). For the same mission, another evaluation of the feasibility of replacing the RTGs on the spacecraft with solar arrays also concluded that the most promising solar technology, the Advanced Photovoltaic Solar Array, would not be feasible due to insurmountable mass and schedule difficulties, and that a completely new solar-powered mission to Jupiter could probably not be launched until the late 1990's or later (JPL 1989). The NASA-JPL study also indicated that "no solar technology could demonstrate any viability for missions more distant than Jupiter." In general, the present level of development of the technology would necessitate the use of large, heavy arrays of solar cells. Although the large mass and dimensions would cause numerous technical problems, such as deploying the arrays, maneuvering the spacecraft, and operating the navigation, communication, and science systems, the resultant mass is the fundamental limitation. The added mass of the solar arrays necessary to power the systems on complex planetary exploration spacecraft, such as Cassini, pushes the total mass of the spacecraft, including its propellants and scientific instruments, above the launch capability of the current generation of U.S. launch vehicles for a launch trajectory to Saturn (JPL 1994a). To accomplish the Cassini mission's science objectives, the spacecraft's size and mass must be within the launch capabilities and capacities of the Titan IV (SRMU)/Centaur and the spacecraft must be sufficiently maneuverable when deployed to acquire the desired science data.

The Sun's energy is typically harnessed by two technologies: 1) a reflective or refractive surface (i.e., an optical lens) concentrator coupled with an appropriate conversion system, such as photovoltaic cells, to convert the Sun's energy into electricity and 2) photovoltaic (solar) cells on flat nonconcentrating arrays that directly convert the Sun's energy to electricity.

Concentrators have not been demonstrated in space, and a number of significant technical problems would have to be solved before a concentrator could be considered feasible for space missions, such as Cassini. The problems include how to regulate the concentrator's temperature for acceptable performance as the spacecraft traverses a Sun-to-spacecraft range from 0.63 AU to 9.3 AU; how to predict the behavior of the optics over the mission lifetime, because small changes in the concentrator condition (e.g., yellowing, aging, and sagging) can lead to significant power losses; and how to improve the alignment of the concentrator elements due to the dependence of the concentrator's power-generating ability on the Sun's incident angle. In addition, concentrator performance depends on clear, unobscured optics, and estimating the buildup of interstellar (and Saturnian) dust on the optics would be difficult. Moreover, vibration testing of any concentrator array would have to be performed to verify post-launch optical alignments and operating characteristics in zero gravity environments. The size of the concentrator arrays that would be needed for the exploration of the Saturnian system would not easily integrate into the Titan IV (SRMU)/Centaur and would not satisfy the launch mass constraints. Furthermore, it is not clear that concentrator arrays would provide any advantage over planar arrays for this mission (JPL 1994a).

For the nonconcentrating photovoltaic arrays, two solar cell technologies, one based on silicon (Si) and the other based on gallium arsenide layered on a germanium substrate (GaAs/Ge), have been considered for the Cassini mission. Silicon solar cells have been used for space power applications since the late 1950s, and improvements in cell performance continue to be made. The development of the GaAs cells began in the 1960s but it was not until the late 1970s that their efficiencies began to equal and then exceed those of silicon. GaAs cells now offer higher efficiency (18 percent) than Si cells (13.8 percent), better efficiency at elevated temperatures, and improved radiation resistance. GaAs-based cells are more brittle than Si cells, however, and have more than twice the mass of typical Si circuits. For scientific and commercial satellites in Earth orbit, Si cells have been the historically preferred technology based on flight experience and cost (JPL 1994a). However, it is expected that the use of GaAs cells in future missions will increase due to technological maturity, flight success, and continuing cost reduction.

The most promising solar array configuration is the Advanced Photovoltaic Solar Array (APSA). The APSA is a lightweight, deployable solar array that may be suitable for long-duration interplanetary missions. The APSA design is a flexible blanket array that uses thin solar cells (Si or GaAs) to minimize mass. Environmental tests of the APSA array (i.e., vibration, acoustics, and temperature cycling) and strength/stiffness tests have been completed. Tests have been conducted to verify the performance of various mechanisms and to demonstrate its mode of deployment; however, no flight testing has been undertaken or planned. An APSA of the size required for Cassini has not been fabricated or tested under the conditions similar to those anticipated for the Cassini mission (JPL 1994a).

The natural radiation environment to which the spacecraft would be exposed on a mission to Saturn will reduce the efficiency of solar cells relative to their performance at Earth. The Cassini mission includes a planned swingby of the planet Jupiter, where the intensity of the radiation is greater than that of the Van Allen belts, due primarily to the presence of a larger magnetic field around Jupiter than around the Earth. If solar cells are to be considered potentially feasible for missions like Cassini, therefore, they must either be adequately shielded from the radiation environment (new technologies that are more radiation resistant be developed) or their significantly lower efficiencies accepted and compensated for in the spacecraft design.

Solar cell performance, particularly for Si cells, is also affected by the combined effects of low (insolation) intensity and low temperature (LILT) in a complex and interactive relationship, the components of which are not completely understood. This interaction results in an anomalous reduction in power output from the cells. The phenomenon is so irregular and random that it is impossible to predict what the actual cell performance distribution would be for any group of cells (Stella and Crotty 1987). LILT effects have been estimated for distances up to 5 AU but there are almost no data to characterize the effects for greater distances. LILT effects at Saturn have been extrapolated from existing data. Unlike Si cells, the GaAs cells are not believed to be affected by LILT to any significant degree, although recent limited testing at JPL suggests that this may not be the case given conditions at Saturn (JPL 1994a).

In addition to environmentally induced cell performance degradation, other real engineering problems, including the size and inertia of the solar array structures and array/spacecraft integration issues, significantly limit the use of solar photovoltaic technologies for long-duration interplanetary space missions such as Cassini. Spacecraft integration issues include field-of-view (FOV) restrictions, extremely long spacecraft turn times, and the potential for interference from electromagnetic and ionizing radiation. FOV difficulties arise from the size of the arrays. The size is large enough to block out significant portions of what the instruments see and necessitates more frequent spacecraft turning. Difficulties are exacerbated by the extremely long turn times associated with using large arrays. The array size (further increasing the initial mass) adds to the spacecraft's inertia, making turning more difficult and propellant-intensive. Electromagnetic and electrostatic interference can also be generated by large arrays when the current in them fluctuates or a charge builds on nonconductive surfaces. This interference could reduce the performance of scientific and communication equipment. Solar-powered spacecraft also require battery-provided backup power during periods when the solar arrays are not illuminated (eclipsed) and during maneuvers that would require the arrays to be pointed away from the Sun.

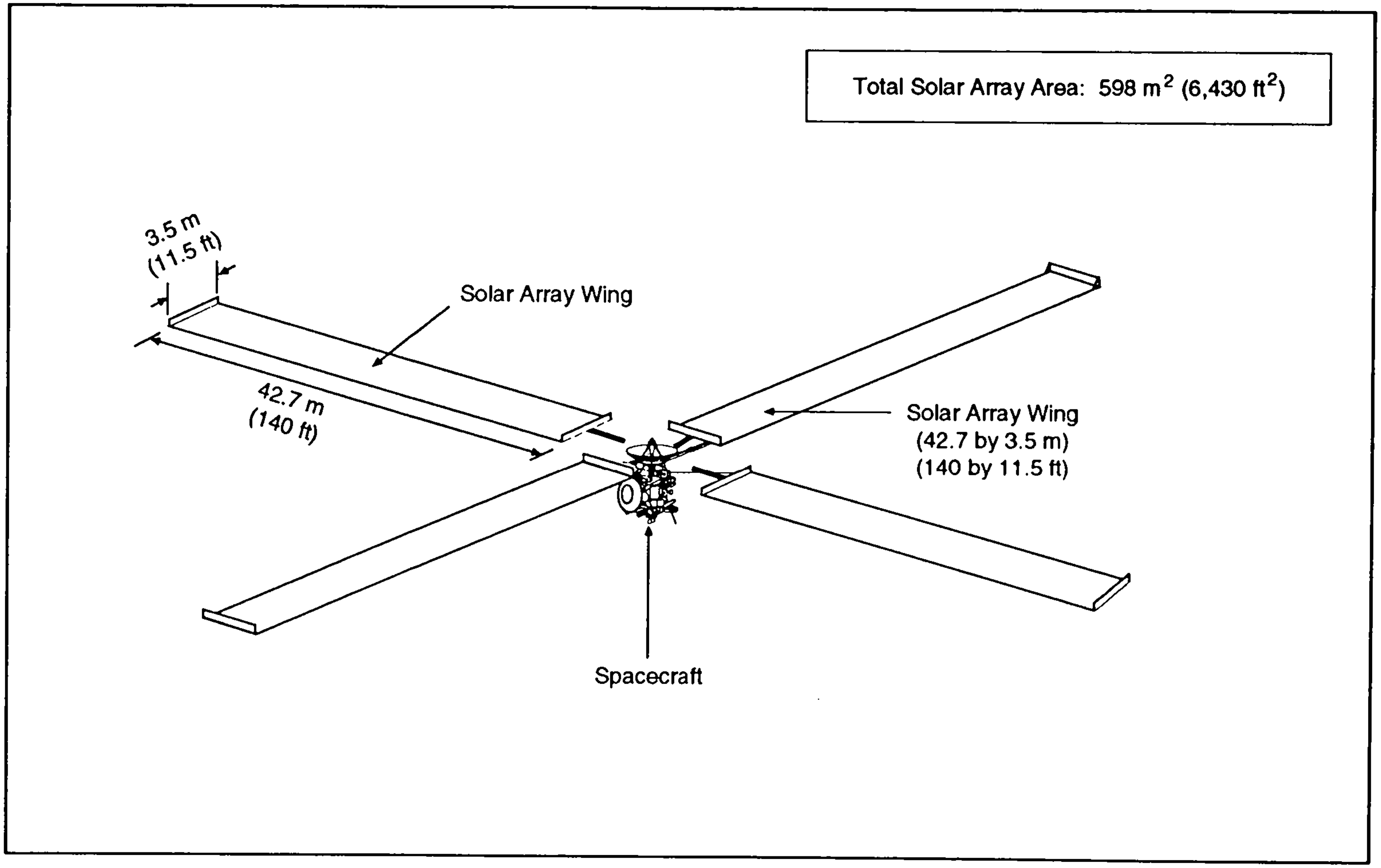
Despite the limiting factors discussed and assuming the use of GaAs APSA technology (for the Cassini mission, GaAs APSA is lighter than Si APSA for the same power output), JPL developed and evaluated several designs of solar-powered spacecraft to ascertain the array compatibility with Cassini's power and operational requirements (JPL 1994a). The designs sought to retain as much science as possible in accordance with the mission's science objectives. In keeping with this goal, two major all-solar designs (and several variants) were evaluated.

In one design, the science instruments were mounted on turntables and scan platforms so that the entire spacecraft would not have to turn to acquire data. The all-solar Cassini design would use four wings, as shown in Figure 2-15, each five times the size of a Hubble Space Telescope wing now operating in low Earth orbit. This design allows the continued acquisition of high-resolution observations during the long (hour to day) maneuvers necessary with large solar arrays. The deployment of such large, massive spacecraft appendages would add considerable risk of failure to the mission compared with using RTGs. In this case, the required solar array size was 598 m^2 (6,430 ft^2). The addition of this size array, in conjunction with the other modifications required to implement solar power, increased the spacecraft dry mass by 1,337 kg (2,948 lb). With the mass of the propellants, the Huygens Probe, and the launch adapter, the total spacecraft mass would increase to 7,228 kg (15,935 lb), far exceeding the launch capacity of the Titan IV (SRMU)/Centaur of 6,234 kg (13,743 lb) for a trajectory to Saturn (JPL 1994a).

Several variations of this design were further investigated in attempts to reduce the mass of the solar arrays. The variants included a combination of RTGs and solar arrays, concentrators to focus sunlight on the arrays, and solar propulsion technologies. All of these designs were very complex and involved increased cost, elevated spacecraft failure risk, and reduced science return. Each of these designs resulted in spacecraft too heavy to be launched in a trajectory to Saturn, given current launch systems.

In the second design, the science instruments were fixed to the body of the spacecraft (as currently designed for use with the RTGs) to reduce the overall mass and the electrical power needed. This design would require that the entire spacecraft be turned to aim the various instruments to acquire data. To further reduce the size of the arrays, the power available to the science instruments was reduced by 50 percent. Because of the large moment of inertia created by the large solar panels (397 m^2 [4,269 ft^2] and 585 kg [1,290 lb]) (JPL 1994a), the time required to turn and maneuver the spacecraft during its exploration of the Saturnian system would increase by a factor of between 4 and 18 compared with the compact RTG-powered spacecraft. The resulting impacts on the mission's science objectives would be serious and include increased times for image mosaics, inadequate turn rates for fields and particles instruments, reduced image resolution due to inadequate target motion compensation, loss of instrument observation time during turns for communicating with Earth, and insufficient turn rates to support radar observation of Titan's cloud-enshrouded surface. These effects on the quality and quantity of the science return raise significant issues about whether the data received would justify the expenditure and risk of this mission design.

This evaluation indicated that the second design would require arrays and other modifications that would increase the spacecraft dry mass by 876 kg (1,931 lb), resulting in a total spacecraft mass (including propellants, the Huygens Probe, and launch adaptor) of 6,293 kg (14,100 lb). This mass would exceed the Titan IV (SRMU)/Centaur launch capability by 59 kg (130 lb). The launch vehicle mass constraints could be satisfied only by disallowing the contingency propellant margins and reserves. Experience, however, has repeatedly demonstrated that the margins and reserves are required for mission success (JPL 1994a). Additionally, there are a number of technical problems associated with this design that would require additional mass to correct, which would further exacerbate the



Source: JPL 1994a

FIGURE 2-15. ALL-SOLAR (GaAs APSA) CONFIGURATION FOR THE CASSINI SPACECRAFT mass problem. While this design comes close to meeting the launch weight restrictions, the mission would fall short of the minimum science objectives that justify a mission to Saturn.

A wide range of mission opportunities and spacecraft configurations with varying levels of science return would fall between the two major spacecraft designs. The design analyses and evaluations showed that additional science data could only be obtained at the expense of spacecraft electric power subsystem mass.

In summary, an all-solar Cassini spacecraft is considered infeasible at this time because no U.S. launch vehicle exists to launch the mass of even the lightest solar configuration (the GaAs APSA) into the proper trajectory. The large arrays could also generate severe electromagnetic and electrostatic interference, which could adversely affect communications. If a heavy-lift booster and more energetic upper stages were available, severe limitations on spacecraft maneuverability, instrument FOV constraints, and programmatic risks would still make this configuration infeasible (JPL 1994a).

Fuels and Chemicals

Fuels and chemicals are effective means of storing energy that can be converted directly into electricity in a battery, combusted in a fuel cell, or combusted to generate heat to use with a number of energy conversion systems. These types of systems are common on spacecraft. In principle, these power sources would eliminate the concerns regarding a mission accident-related release of radioactive material into the environment. However, the mass requirements of a power system based on fuels and chemicals for an interplanetary mission, such as Cassini, would exceed the launch capacities of a Titan IV (SRMU or SRM)/Centaur. For example, assuming a hydrogen and oxygen power system (with the highest currently available energy-per-unit mass) and a 100 percent efficient conversion system, a mass for the fuel and oxidizer of more than 12,000 kg (26,455 lb) would be required. This is four to six times the allocated dry launch mass of the Cassini spacecraft. No launch vehicle is capable of launching such a large mass. Therefore, power systems based on fuels and chemicals are not feasible for the Cassini mission (JPL 1994a).

Power Beaming (Microwave and Laser) From Earth

Power beaming from Earth consists of generating and transmitting microwaves or laser beams from Earth to a spacecraft, receiving or collecting the energy onboard, and then converting the energy to electricity. The power requirements and the distance from Earth to the spacecraft are primary drivers for this type of system. It is not possible, however, to develop a laser beam power system to satisfy the 1997 Cassini launch date with the current technology and available development time. The ability to deliver a coherent, high-power laser light to such a small target, such as the Cassini spacecraft (out to 9.3 AU), represents a long-term space technology development effort and, therefore, is not available for the Cassini mission.

2.7 COMPARISON OF MISSION ALTERNATIVES, INCLUDING THE PROPOSED ACTION

This section provides a summary comparison of the Proposed Action, including the contingency launch opportunities, and the alternatives. The factors used for this comparison are separated into environmental impacts for both a normal launch and those involving an accident. Table 2-6 compares the environmental impacts from a normal launch for the Proposed Action and the other alternatives. The impacts of the SRM-equipped Titan IV for the Proposed Action are similar to those of the SRMU-equipped Titan IV unless noted. Mission-specific considerations are summarized for all of the alternatives in Section 2.8.

2.7.1 Environmental Impacts of the Proposed Action

2.7.1.1 Environmental Impacts of Preparing for Launch

Preparing for launch of the Cassini spacecraft involves many activities (e.g., launch vehicle processing; integration of the Huygens Probe, RHUs, and RTGs; and fueling of the spacecraft, the Titan IV launch vehicle, and the Centaur). These preparations would not adversely affect the CCAS/KSC regional area. Section 4.1.1 provides a more detailed discussion of the environmental impacts associated with launch preparations.

2.7.1.2 Environmental Impacts of a Normal Launch

Implementation of the primary launch opportunity in October 1997, secondary launch opportunity in December 1997, or the backup launch opportunity in March 1999 could result in limited short-term air quality, noise, water quality, and biological impacts in the immediate vicinity of the launch site. These impacts have been previously addressed in other NEPA documents (USAF 1986, USAF 1988a, USAF 1988b, USAF 1990, NASA 1994) and would be associated with the routine launch operations of the SRMU or SRM on the Titan IV booster. The potential environmental impacts resulting from a normal launch were determined not to have a substantial adverse effect on CCAS workers or the general population, either individually or cumulatively. Table 2-6 summarizes the environmental impacts of a normal launch, and Section 4.1.2 provides a more detailed discussion.

2.7.1.3 Environmental Impacts of Balance of Mission

The Cassini spacecraft, once injected into its interplanetary VVEJGA trajectory (or a VEEGA for the secondary or backup launch opportunities), would have no adverse impact on the human environment, given a normal trajectory. In addition, the delivery of the Huygens Probe to Titan and the Cassini Saturnian tour would not affect the Earth's environment. The Cassini program complies with NASA policy on planetary protection (JPL 1990).

TABLE 2-6. SUMMARY COMPARISON OF THE IMPACTS OF A NORMAL LAUNCH OF THE CASSINI MISSION

Environmental Impacts	Proposed Action	Alternative Actions		
	1997	1999	2001	
	Primary, Secondary, and Backup	Primary/Backup	Primary/Backup	No-Action
Land Use	No substantial adverse impacts on non-launch-related land uses.	Similar to Proposed Action.	Similar to Proposed Action.	No Effect.
Air Quality	High levels of SRMU exhaust products within the exhaust cloud as it leaves the flame trench; cloud would rise and begin to disperse near launch pad; greatest amount of wet HCl deposition within area of about 183 m (600 ft) of launch pad. Exhaust product concentrations expected to drop rapidly with buoyant rise and mixing/dispersal of exhaust cloud; HCl levels expected to decrease to 18.2 mg/m^3 (12 ppm) and Al_2O_3 particulates to about 25 μg/m^3 within about 5 km (3.1 mi) of launch site. No adverse air quality impacts expected in offsite areas. Not anticipated to adversely affect global climate. Temporary localized decrease in ozone along the flight path, with rapid recovery. Air impacts from SRM-equipped Titan IV similar to Titan IV (SRMU); impacts on troposphere similar; impacts on stratosphere somewhat less than from SRMUs.	Similar to Proposed Action. Greater magnitude of exhaust products due to larger size of the Shuttle solid rocket boosters (SRBs); greater deposition of HCl aerosols and droplets near launch pad due primarily to use of Shuttle main motors at liftoff (main motors emit large quantities of water). Exhaust cloud typically disperses within 14 km (9 mi) of the launch site. Heaviest deposition of HCl droplets and particulates within 1 km (0.6 mi) of launch pad, with substantial short-term air quality degradation within this area. About twice as much solid rocket exhaust products emitted to the stratosphere compared to SRM- or SRMU-equipped Titan IV. Short-term decrease in stratospheric ozone levels along flight path, with rapid recovery. Impacts would occur twice during a period of 21 to 51 days.	Similar to Proposed Action.	No Effect.
Noise and Sonic Boom	No sustained adverse impacts on work force or unprotected public.	Similar to Proposed Action. Twice the number of sonic booms occur over ocean; no adverse impacts expected.	Similar to Proposed Action.	No Effect.
Geology and Soils	Short-term acidification of the soils adjacent to the launch site. Increased surface concentration of aluminum in the soils. SRM-equipped Titan IV would have similar impacts to Titan IV (SRMU).	Similar to Proposed Action. Greatest impacts in a 1 to 15 ha (2.5 to 37 acre) area north of launch pad. Impacts would occur twice during a period of 21 to 51 days.	Similar to Proposed Action.	No Effect.
Hydrology and Water Quality	No substantial adverse long-term impacts. Short-term increase in the acidity of nearby waters. SRM-equipped Titan IV would have similar but slightly lower magnitude impacts compared to Titan IV (SRMU).	Similar to Proposed Action. Impacts would occur twice during a period of 21 to 51 days.	Similar to Proposed Action.	No Effect.

TABLE 2-6. SUMMARY COMPARISON OF THE IMPACTS OF A NORMAL LAUNCH OF THE CASSINI MISSION (Continued)

Environmental Impacts	Proposed Action	Alternative Actions		
	1997	1999	2001	
	Primary, Secondary, and Backup	Primary/Backup	Primary/Backup	No-Action
Biological Resources	No impact to floodplain. Some acidification of wetlands adjacent to launch site. High-risk zone for wildlife within about 183 m (600 ft) of launch pad; vegetation damage and wildlife mortality in a 20-m (66-ft) area near the flame trench exit. If exhaust cloud is pushed back over land, short-term acidification of nearby surface waters could cause mortality of aquatic biota. No long-term adverse effects expected. No substantial short-term or long-term impact to threatened or endangered species. SRM-equipped Titan IV would have similar but slightly lower magnitude impacts compared to Titan IV (SRMU).	Similar to Proposed Action. In addition, fish kills in nearby impoundments possible with each Shuttle launch due to acidification from exhaust cloud. Impacts would occur twice during a period of 21 to 51 days.	Similar to Proposed Action.	No Effect.
Socioeconomics	Potential short-term economic benefits from tourism.	Some economic benefits associated with tourists coming in region to observe Shuttle launch. Could get influx twice, about 21 to 51 days apart.	Similar to Proposed Action.	No Effect.
Historical/Archaeological Resources	No impact expected.	Similar to Proposed Action.	Similar to Proposed Action.	No Effect.
Radiation Exposures	Occupational doses from handling of RTGs and RHUs will be within regulatory requirements and strictly monitored. No substantial exposure to other workers or the general public.	Similar to Proposed Action.	Similar to Proposed Action.	No Effect.
Balance of Mission	No impact.	Similar to Proposed Action.	Similar to Proposed Action.	No Effect.

2.7.1.4 Environmental Impacts and Consequences of Mission Accidents

Possible Nonradiological Impacts of a Mission Accident

The nonradiological impacts of the possible Titan IV accidents were addressed in the Titan IV Environmental Assessments (USAF 1986, USAF 1988a, USAF 1990) and are fundamentally similar to the Space Shuttle nonradiological accident impacts addressed in the Shuttle Program EIS (NASA 1978), the Tier 1 Galileo and Ulysses missions EIS (NASA 1988b), and the Tier 2 EISs for Galileo (NASA 1989b) and Ulysses (NASA 1990) missions. These accidents include on-pad propellant spills, fires, and explosions. In addition, some accident scenarios could result in the inadvertent reentry of the Cassini spacecraft into the Earth's atmosphere from parking orbit or during an Earth swingby. Should either of these reentry scenarios occur, it is expected that the spacecraft would break up and the remaining liquid propellants onboard would burn and/or disperse in the atmosphere. The propellants would not reach the Earth in concentrations sufficient to affect ambient air quality. Section 4.1.4 provides a more detailed discussion of the potential nonradiological impacts of a mission accident.

Possible Radiological Impacts and Consequences of Mission Accidents

DOE has conducted safety testing and analyses to determine the response of the RTGs and RHUs to postulated accidents, and the consequences of accidents. DOE has designed the GPHS-RTG assembly to ensure that the fuel is contained to the maximum extent practical. RTG and RHU responses to a broad range of accident conditions and estimates of the radiological consequences, if any, of an accident can be predicted. The results of the current accident analyses (Martin Marietta Astro Space 1993, Halliburton NUS 1994a) used to support evaluations for this EIS are presented in Section 4.1.5. DOE will perform additional safety analyses for the Cassini mission and document the results in Final Safety Analysis Reports.

For the Proposed Action (October 1997 primary, December 1997 secondary and the March 1999 backup launch opportunities), analyses indicate that while the consequences of a release could range from small to substantial, the probability of an accident occurring that could release plutonium dioxide fuel is extremely small (see Section 4.1.5.3 of this EIS for more detail).

The regional and global areas of the environment, defined in Section 3, could be affected by a release of plutonium dioxide fuel. The regional area, including the six-county region surrounding CCAS and KSC, could be impacted by a Phase 1 accident. The global area (areas elsewhere around the world) could be potentially impacted by accidents identified in Phases 5, 6, or by an inadvertent reentry during an Earth swingby.

Although most potential accidents would result in the loss of the launch vehicle and/or Cassini spacecraft, most accidents would not result in a release of the plutonium dioxide fuel to the environment (Martin Marietta 1992, Martin Marietta Astro Space 1993). However, four specific accident scenarios were identified as representative of the categories of failures that could cause a release of plutonium dioxide fuel from the GPHS modules at ground level within the post-accident plume during mission launch Phases 1 through 6: 1) Command Shutdown and Destruct, 2) Titan IV (SRMU) Fail-to-Ignite, 3) Centaur Tank Failure/Collapse, and 4) Inadvertent Reentry From Earth Orbit (Martin Marietta Astro Space 1993). Accident scenarios leading to launch vehicle propellant explosions could subject the RTGs to accident environments, such as blast overpressures, solid or liquid propellant fires, and high-velocity fragments. In addition, two postulated accident scenarios associated with the interplanetary cruise portion of the VVEJGA and VEEGA trajectories have been defined. The short-term inadvertent reentry scenario involves the reentry of the spacecraft into the Earth's atmosphere during a planned Earth swingby. The long-term inadvertent reentry scenario involves a spacecraft failure that leaves it drifting in an Earth-crossing orbit around the Sun and potentially reentering the Earth's atmosphere a decade to millennia later. NASA is designing the Cassini mission and spacecraft to ensure, to the maximum extent practical, that an inadvertent reentry accident does not occur.

The potential for radiological impact to the affected area depends on the mission phase/scenario combination, the probability of the accident occurring with a fuel release, the amount of fuel released (i.e., source term), and the radiological consequences of the release. Radiological consequences can be expressed as the collective dose, health effects (i.e., excess latent cancer fatalities), individual dose, or land contamination. Health effects can be considered with or without de minimis. The concept of de minimis assumes that doses of less than 1×10^{-5} Sv/yr (1×10^{-3} rem/yr) do not result in any health effects and, therefore, are not included in the health effects calculations.

Although radiological consequences can be used to predict doses to an individual or exposed population, risk is another useful assessment. A health effects risk assessment was performed specifically for the Cassini mission to quantify the consequences that could result from a radiological accident (Halliburton NUS 1994a, Halliburton NUS 1994b). Risk is presented in Tables 2-7 and 2-8 as average individual risk and in Table 2-9 as health effects mission risk. The average individual risk due to a given accident scenario represents the probability that any given individual within the exposed population group would develop a latent cancer fatality as a result of that accident scenario. The health effects mission risk contribution of a given accident scenario is defined as a probability-weighted health effect as a direct result of that accident scenario. Table 2-7 identifies the impacts from the accident scenario that dominates the average individual risk of acquiring a health effect within the regional area, assuming that a radiological accident has occurred during a launch phase. Table 2-8 summarizes the radiological impacts for an inadvertent reentry during an Earth swingby.

Table 2-9 compares the health effects mission risk as a result of implementation of each of the alternatives. For clarity, the total health effects mission risk is separated into the risks associated with the launch, the Earth swingby(s) during the interplanetary trajectory, and the combined risks of the launch phases and swingby portion of the mission. Section 4.1.8 presents a detailed risk assessment. The health and environmental risks associated with plutonium (mainly Pu-238) dioxide are addressed in the Galileo and Ulysses EISs (NASA 1989b, NASA 1990) and in Appendix C of this EIS.

2.7.2 Environmental Impacts of the 1999 Mission Alternative

A Shuttle launch generally results in limited short-term air, water, and biological impacts in the immediate vicinity of the launch site. These impacts have been addressed in detail in other NEPA documents (NASA 1978, NASA 1986, NASA 1989b, NASA 1990)

TABLE 2-7. SUMMARY COMPARISON OF POTENTIAL RADIOLOGICAL IMPACTS ASSOCIATED WITH LAUNCH PHASE ACCIDENTS FOR ALL ALTERNATIVES[a,b]

Potential Radiological Impacts Associated with Launch Phase Accidents	Proposed Action	Alternative Actions		
	1997	1999	2001	No-Action
	Primary/Secondary/Backup[c]	Primary/Backup[d]	Primary/Backup	
CCAS/KSC Regional Area—Near Pad				
Source Term, Bq (Ci)	1.38×10^{11} (3.72×10^{0})	2.38×10^{12} (6.44×10^{1})	Same as Proposed Action	No Effect
Total Probability (likelihood)	9.1×10^{-4} (1 in 1,100)	1.0×10^{-5} (1 in 100,000)	Same as Proposed Action	No Effect
Health Effects[e]	3.36×10^{-4}	4.86×10^{-3}	Same as Proposed Action	No Effect
Land Contamination, km^2 (mi^2)[f]	1.86×10^{-1} (7.18×10^{-2})	3.84×10^{0} (1.48×10^{0})	Same as Proposed Action	No Effect
Average Individual Risk[e,g] (likelihood)	3.1×10^{-12} (1 in 323 billion)	5.0×10^{-13} (1 in 2 trillion)	Same as Proposed Action	No Effect
Global Area—Africa				
Source Term, Bq (Ci)	5.44×10^{10} (1.47×10^{0})	5.07×10^{10} (1.37×10^{0})	Same as Proposed Action	No Effect
Total Probability (likelihood)	4.6×10^{-4} (1 in 2,170)	5.8×10^{-5} (1 in 17,200)	Same as Proposed Action	No Effect
Health Effects[e]	1.51×10^{-4}	1.41×10^{-4}	Same as Proposed Action	No Effect
Land Contamination, km^2 (mi^2)[f]	2.17×10^{-2} (8.38×10^{-3})	2.02×10^{-2} (7.80×10^{-3})	Same as Proposed Action	No Effect
Average Individual Risk[e,g] (likelihood)	6.9×10^{-11} (1 in 14.5 billion)	8.2×10^{-12} (1 in 121 billion)	Same as Proposed Action	No Effect

Sources: Halliburton NUS 1994a, Halliburton NUS 1994b

a. The detailed consequence analyses are presented in Sections 4.1.6 and 4.2.6.
b. Radiological consequences are identified for the accident scenario that dominates the average individual risk of acquiring a health effect within the affected area.
c. If the Titan IV (SRM)/Centaur configuration is used, no substantial differences would be expected in the radiological consequences.
d. The second launch of each opportunity would have identical radiological consequences. Only the second launch carries the radioactive payload.
e. Estimated without de minimis. The de minimis dose level for the purpose of this EIS is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year. Health effects are estimated for the population near the launch area or impact area.
f. Land contamination is the estimated land area contaminated above the EPA screening level of 7.4×10^{3} Bq/m^2 (0.2 μCi/m^2). See Sections 4.1.6.2 and 4.2.6.1.
g. The average individual risk for a given accident scenario is: (Total Probability of the Scenario x Health Effects for the Scenario)/(Exposed Population at Risk). See Sections 4.1.8 and 4.2.8.

TABLE 2-7. SUMMARY COMPARISON OF POTENTIAL RADIOLOGICAL IMPACTS ASSOCIATED WITH LAUNCH PHASE ACCIDENTS FOR ALL ALTERNATIVES[a,b] (Continued)

Potential Radiological Impacts Associated with Launch Phase Accidents	Proposed Action	Alternative Actions		
	1997	1999	2001	No-Action
	Primary/Secondary/Backup[c]	Primary/Backup[d]	Primary/Backup	
Global Area—Unspecified Locations				
Source Term, Bq (Ci)	5.55×10^{10} (1.50×10^{0})	5.55×10^{10} (1.50×10^{0})	Same as Proposed Action	No Effect
Total Probability (likelihood)	4.4×10^{-4} (1 in 2,300)	1.9×10^{-3} (1 in 526)	Same as Proposed Action	No Effect
Health Effects[e]	6.90×10^{-4}	6.89×10^{-4}	Same as Proposed Action	No Effect
Land Contamination, km^2 (mi^2)[f]	2.22×10^{-2} (8.57×10^{-3})	2.22×10^{-2} (8.57×10^{-3})	Same as Proposed Action	No Effect
Average Individual Risk[e,g] (likelihood)	6.0×10^{-11} (1 in 16 billion)	2.6×10^{-10} (1 in 3.8 billion)	Same as Proposed Action	No Effect

Sources: Halliburton NUS 1994a, Halliburton NUS 1994b

a. The detailed consequence analyses are presented in Sections 4.1.6 and 4.2.6.

b. Radiological consequences are identified for the accident scenario that dominates the average individual risk of acquiring a health effect within the affected area.

c. If the Titan IV (SRM)/Centaur configuration is used, no substantial differences would be expected in the radiological consequences.

d. The second launch of each opportunity would have identical radiological consequences. Only the second launch carries the radioactive payload.

e. Estimated without de minimis. The de minimis dose level for the purpose of this EIS is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year. Health effects are estimated for the population near the launch area or impact area.

f. Land contamination is the estimated land area contaminated above the EPA screening level of 7.4×10^{3} Bq/m^2 (0.2 μCi/m^2). See Sections 4.1.6.2 and 4.2.6.1.

g. The average individual risk for a given accident scenario is: (Total Probability of the Scenario x Health Effects for the Scenario)/(Exposed Population at Risk). See Sections 4.1.8 and 4.2.8.

TABLE 2-8. SUMMARY COMPARISON OF THE POTENTIAL RADIOLOGICAL IMPACTS ASSOCIATED WITH THE SHORT-TERM INADVERTENT REENTRY ACCIDENT SCENARIO FOR ALL ALTERNATIVES[a,b,c]

	Proposed Action			Alternative Actions		
	1997			1999	2001	No-Action
Potential Radiological Impacts	Primary	Secondary/Backup[d]		Primary/Backup	Primary/Backup	
Reentry Case	VVEJGA	VEEGA E1	VEEGA E2	VEEGA	VVVGA/VEEGA	No Effect
Source Term, Bq (Ci)	5.40×10^{15} (1.46×10^5)	5.44×10^{15} (1.47×10^5)	5.29×10^{15} (1.43×10^5)	Same as secondary and backup of Proposed Action	Not applicable/same as secondary and backup of Proposed Action	No Effect
Total Probability (likelihood)	7.6×10^{-7} (1 in 1.3 million)	1.9×10^{-7} (1 in 5.3 million)	2.8×10^{-7} (1 in 3.6 million)	Same as secondary and backup of Proposed Action	Not applicable/same as secondary and backup of Proposed Action	No Effect
Health Effects without de minimis[e]	2.30×10^3	2.48×10^3	4.56×10^3	Same as secondary and backup of Proposed Action	Not applicable/same as secondary and backup of Proposed Action	No Effect
Land Contamination, km^2 (mi^2)[f]	2.04×10^3 (7.88×10^2)	2.00×10^3 (7.72×10^2)	4.13×10^3 (1.59×10^3)	Same as secondary and backup of Proposed Action	Not applicable/same as secondary and backup of Proposed Action	No Effect
Average Individual Risk without de minimis[e,g] (likelihood)	3.4×10^{-13} (1 in 2.9 trillion)	9.4×10^{-14} (1 in 11 trillion)	2.6×10^{-13} (1 in 3.8 trillion)	Same as secondary and backup of Proposed Action	Not applicable/same as secondary and backup of Proposed Action	No Effect

Source: Halliburton NUS 1994a, Halliburton NUS 1994b, JPL 1993f

a. The detailed consequence analyses are presented in Sections 4.1.6 and 4.2.6.

b. Radiological consequences and risk for the long-term inadvertent reentry case for all alternatives cannot be estimated and, therefore, are not included.

c. Expectation case or "expected" source terms are used.

d. The impacts were estimated for the backup launch opportunity only. The impacts of the secondary launch opportunity are assumed to be similar.

e. Health effects, or excess latent cancer fatalities, for the short-term inadvertent reentry accident are evaluated based on collective exposure of approximately 5 billion persons worldwide. Most of the persons exposed would receive an individual radiation dose of less than 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year (the de minimis dose level). If only those individuals worldwide receiving higher than de minimis dose level are considered, the estimated health effects would be approximately 10 (excess latent cancer fatalities) with the VVEJGA, and about 15 with either the VEEGA E1 or E2.

f. Land contamination is the estimated land area contaminated above the EPA screening level of 7.4×10^3 Bq/m^2 (0.2 μCi/m^2). See Sections 4.1.6.2 and 4.2.6.1.

g. The average individual risk for a given accident scenario is: (Total Probability of the Scenario x Health Effects for the Scenario)/(Exposed Population at Risk). See Sections 4.1.8 and 4.2.8.

TABLE 2-9. SUMMARY COMPARISON OF THE HEALTH EFFECTS MISSION RISK FOR ALL CASSINI MISSION ALTERNATIVES

Mission Phase	Health Effects Mission Risk					
	Proposed Action[a]		Alternative Actions			
	1997		1999	2001		
	Primary	Secondary/Backup	Primary/Backup	Primary	Backup	No-Action
• Launch Phases	8.4×10^{-7}	8.4×10^{-7}	2.1×10^{-6}	8.4×10^{-7}	8.4×10^{-7}	No Effect
• Short-Term Inadvertent Reentry	1.7×10^{-3}	1.8×10^{-3}	1.8×10^{-3}	No Short-Term Reentry	1.8×10^{-3}	No Effect
• Long-Term Inadvertent Reentry	b	b	b	b	b	b
• Total Mission (without long-term inadvertent reentry health effects mission risks)	1.7×10^{-3}	1.8×10^{-3}	1.8×10^{-3}	c	1.8×10^{-3}	No Effect

Sources: Halliburton NUS 1994a, Halliburton NUS 1994b

a. If the Titan IV (SRM)/Centaur configuration is used, no substantial differences would be expected in the mission risk.

b. It should be noted that all alternatives have the potential for interplanetary trajectory accidents that could result in a long-term inadvertent Earth reentry. The mean probability of a long-term reentry for each alternative has been estimated as very small (6.0×10^{-8} over the first 100-years for the 1997 primary VVEJGA mission; 4×10^{-7} for the longer backup 1997 and the 1999 VEEGA missions; and on the order of 10^{-7} for the 2001 VVVGA alternative). Since the timing of a long-term reentry cannot be predicted, it is not possible to estimate the world population or the extent of radioactive decay of the fuel for such a reentry, thus it would not be possible to estimate the resulting consequences (i.e., health effects and land contamination) and risks. It would be reasonable to assume, ignoring the uncertainties noted above, that the radiological releases, and in turn the consequences and risks would be on the same order of magnitude as those for a short-term reentry for an Earth-gravity-assist trajectory.

c. Following the assumptions in "b" above, and assuming the risk associated with long-term inadvertent reentry would be on the same order of magnitude as that for a short-term reentry, the long-term reentry then becomes the principal determinant of total mission risk for the 2001 VVVGA alternative. Thus, the total mission risk for this alternative is assumed to be on the same order of magnitude as noted for the other alternatives.

and are associated with the routine launch operations of the Shuttle. Since this mission alternative would involve two Shuttle launches during a period of 21 and 51 days, the associated launch impacts would occur twice.

2.7.2.1 Environmental Impacts of Preparing for Launch

Preparing for a Shuttle launch of the Cassini spacecraft would involve several activities, including the integration of the Huygens Probe, RTGs, and RHUs and fueling of the spacecraft, the Shuttle, and its external tank. These preparations would not adversely affect the CCAS/KSC regional area.

2.7.2.2 Environmental Impacts of a Normal Launch

The environmental impacts associated with a normal launch of the Shuttle, addressed in detail in several NEPA documents (NASA 1978, NASA 1986, NASA 1989b, NASA 1990) and the *KSC Environment Resources Document* (NASA 1994) are summarized in Table 2-6, given previously.

2.7.2.3 Environmental Impacts of Balance of Mission

The environmental impacts of balance of mission for the 1999 mission alternative would be similar to those of the Proposed Action. See Section 2.7.1.3.

2.7.2.4 Environmental Impacts and Consequences of Mission Accidents

Possible Nonradiological Impacts of a Mission Accident

The nonradiological impacts of the possible Space Shuttle accidents were addressed in the Shuttle Program EIS (NASA 1978), the Tier 1 Galileo and Ulysses missions EIS (NASA 1988b), and the Tier 2 EISs for Galileo (NASA 1989b) and Ulysses (NASA 1990) missions. These accidents include on-pad propellant spills, fires, and explosions. In addition, some accident scenarios could result in the inadvertent reentry of the Cassini spacecraft into the Earth's atmosphere from parking orbit or during an Earth swingby. Should either of these reentry scenarios occur, it is expected that the spacecraft would break up and the remaining liquid propellants onboard would burn and/or disperse in the atmosphere. The propellants would not reach the Earth in concentrations sufficient to affect ambient air quality. Section 4.2.4 provides a more detailed discussion of the potential nonradiological impacts to the environment from a mission accident.

Possible Radiological Impacts and Consequences of Mission Accidents

The results of the current accident analyses (Halliburton NUS 1994b, Martin Marietta Astro Space 1994b) used to support evaluations for this EIS are presented in Section 4.2.5. DOE will perform additional analyses for the Cassini mission, and will document the results in Final Safety Analysis Reports.

For the 1999 mission alternative, while the consequences of a release could range from small to substantial, analyses indicate that the likelihood of an accident occurring that could release plutonium dioxide fuel is extremely small. In the event of an accident, the regional and global areas of the environment, defined in Section 3, could be affected by a release of plutonium dioxide fuel. The regional area, including the six-county region surrounding CCAS/KSC, could be impacted by a Phase 1 accident. Indeterminate locations within the global area could be potentially impacted by accidents in the higher altitude portions of Phase 1 and Phases 2 through 4, as well as by an accident occurring as a result of an inadvertent reentry.

Although most potential accidents would result in the loss of the launch vehicle and/or Cassini spacecraft, most accidents would not result in a release of the plutonium dioxide fuel to the environment. However, several specific accident scenarios were identified from these previous analyses that could cause a release of plutonium dioxide fuel from the GPHS modules during Shuttle launch Phases 1 through 4. In addition, the two inadvertent reentry scenarios identified for the Proposed Action would also be associated with the 1999 mission alternative.

Using the same methodology as for the Titan IV (SRMU), the potential extent of radiological impact to the affected area was estimated for the 1999 mission alternative. Details of the radiological impacts are given in Section 4.2.5. Table 2-7, given previously, identifies the impacts that would dominate the average individual risk of acquiring a health effect within the affected area, assuming that a radiological accident had occurred during a launch phase. Table 2-8, also given previously, summarizes the radiological impacts for the short-term inadvertent reentry. As with the Proposed Action, a risk assessment was specifically conducted for the 1999 mission alternative to quantify the degree of consequence that could result from a radiological accident (Halliburton NUS 1994b, Martin Marietta Astro Space 1994b). Table 2-9, given previously, presents the health effects mission risk.

2.7.3 Environmental Impacts of the 2001 Mission Alternative

The impacts from preparation for and implementation of a normal launch of the Cassini spacecraft during the 2001 mission alternative on a VVVGA trajectory would be similar to those of the Proposed Action using the Titan IV (SRMU)/Centaur. The SRM-equipped Titan IV does not have the capability to insert the spacecraft into a VVVGA trajectory. The 2001 primary launch opportunity would essentially use identical components (i.e., Titan IV (SRMU)/Centaur and electrical power source) as those used for the Proposed Action, described in Section 4.1. The spacecraft would use larger propellant tanks, however, to accommodate the additional propellant required to complete the mission using the VVVGA trajectory and a specially designed rhenium engine for spacecraft propulsion. This alternative would require the spacecraft to execute three gravity-assist swingbys of the planet Venus.

Launch accident scenarios, environments, and radiological consequences for the primary opportunity would be similar to those for Phases 1 through 6 of the Proposed Action (see Sections 4.1.5 through 4.1.9). The accident environments created by a potential explosion of the additional propellant would be no more severe than those estimated for the representative accident scenarios discussed previously (JPL 1993b). In addition, the mission trajectory would not use the Earth for a gravity-assist, thereby eliminating the potential for an inadvertent short-term reentry. However, should the spacecraft become uncommandable anytime after injection into its interplanetary trajectory and before the SOI, the probability of a long-term reentry would exist. The long-term reentry conditions would be assumed to be similar to the short-term inadvertent reentry conditions described for the Proposed Action.

Because there is no non-Earth-Gravity-Assist backup launch opportunity for the 2001 non-EGA trajectory (i.e., VVVGA), the backup opportunity would employ a VEEGA trajectory. Tables 2-7 through 2-9, previously given, present the potential radiological impacts associated with launch phase accidents, potential radiological impacts associated with the short-term inadvertent reentry accident scenario (for the backup opportunity), and health effects mission risk, respectively.

As with all launch opportunities, a long-term inadvertent reentry could also result in health effects risks. These risks are not known but the probability is expected to be very low and the risks are expected to be similar to those for the short-term inadvertent reentry for the Proposed Action.

2.7.4 Environmental Impacts of the No-Action Alternative

The No-Action alternative would not cause any adverse health or environmental impacts.

2.7.5 Scope and Timing of Mission Science Return

The Proposed Action would accomplish NASA's scientific objectives for the Cassini mission's study of Saturn, its atmosphere, moons, rings, and magnetosphere. Launch of Cassini in October 1997 (the Proposed Action primary launch opportunity) would result in the earliest collection of these scientific data at a most optimum time (in 2004) because the spacecraft would arrive at Saturn when the rings would have a scientifically favorable tilt toward the Sun and the Earth. The secondary launch opportunity would afford a similar science profile but would be limited by poorer ring geometry. The science return would be delayed 2 years compared with the primary launch. The 1999 backup launch opportunity would accomplish essentially the same science objectives, with some reduction of ring science. The backup launch opportunity would delay the science return by 4 years.

The 1999 mission alternative using the dual Shuttle launches would be able to obtain similar levels of science objectives and science return as either the secondary or backup launch opportunities of the Proposed Action.

The 2001 mission alternative would result in a later arrival date at Saturn, when Saturn's rings would be seen nearly edge-on from Earth and with lower solar illumination, thereby limiting the use of radio and optical science experiments during the Saturnian tour. The number of Titan flybys would have to be reduced significantly from 35 to 21, and the SOI burn delay would have to be eliminated, substantially decreasing the close-in ring science. Therefore, the overall science return would be reduced from the return of the Proposed Action. In addition, the spacecraft would be older at the onset of the science phase, increasing the probability of spacecraft failure due to aged components. Limitations with propellant and electrical power margins would reduce the science return associated with this alternative compared with the Proposed Action.

The No-Action alternative would not yield any of the anticipated science data on Saturn and its environment, thereby effectively preventing NASA, ESA, and ASI from achieving their solar system exploration objectives. Although new technological advances (e.g., solid-state recorders, an innovative solid-state power switch, and gyros) have been made during the development of Cassini, the scientific investigations of the American and international scientists who have contributed to the development of the Cassini spacecraft and its experiments would be terminated. In addition, this alternative would terminate the international agreements to develop Cassini, disrupt and strain the relationships for other space-related projects, and hinder the future formation of other international science and engineering teams. Cassini's U.S.-European partnership is an example of an undertaking whose scope and cost would not likely be borne by any single nation, but is made possible through the shared investment and participation. Failure to undertake the mission would discourage other similar international partnerships for large peaceful efforts.

2.7.6 Launch Schedules and Availability of Launch Vehicle

Consistent with planning for the Proposed Action, the Cassini mission would be scheduled for flight to Saturn and its environs using the Titan IV (SRMU or SRM)/Centaur in October 1997 from Launch Complex 40 or 41 at CCAS. If NASA could not launch Cassini in October of 1997, the contingency launch opportunities (secondary in December 1997 and the backup in March 1999) would then be considered. Depending on the nature of the delay, launch facility schedules, mission budgets, and the cooperation of the foreign partners, the Cassini mission would then be rescheduled and launched on either the secondary or backup opportunities on the Titan IV (SRMU or SRM)/Centaur. Similarly, schedules would be developed, if necessary, for the 1999 and 2001 mission alternatives.

2.7.7 Availability of Facility and Personnel

To implement the Proposed Action, NASA anticipates that all required NASA, ESA, and ASI scientific and engineering facilities and personnel (including contractors and subcontractors) would be available to support the mission's launch in October 1997 from CCAS. NASA's Deep Space Network is preparing to meet the tracking and data relay requirements of the mission.

The 1999 mission alternative on the Shuttle would require retaining the program personnel and facilities for approximately 2 years, as well as securing new personnel and launch services for the Shuttle. Moreover, the delay of this mission could disrupt and possibly strain the international partnerships formed to develop the Cassini Orbiter, the Huygens Probe, and other space-related projects.

A launch of the 2001 mission alternative would require retaining the program personnel and facilities for approximately 4 years. Some of the mission's expert personnel could be lost during this period. Moreover, the delay of this mission would disrupt and possibly strain the international partnerships.

The selection of the No-Action alternative would terminate the existing U.S. and foreign engineering and scientific services, and important expertise could be irretrievably lost.

2.8 SUMMARY

This section summarizes the mission-specific considerations for the Proposed Action and alternatives. Table 2-10 provides a summary comparison of these considerations.

TABLE 2-10. SUMMARY COMPARISON OF THE MISSION-SPECIFIC CONSIDERATIONS FOR THE CASSINI MISSION ALTERNATIVES

Considerations for Comparison	Proposed Action		
	Primary[a]	Secondary[a]	Backup[a]
Launch Vehicle	Titan IV (SRMU or SRM)/Centaur	Titan IV (SRMU or SRM)/Centaur	Titan IV (SRMU or SRM)/Centaur
Trajectory	VVEJGA	VEEGA	VEEGA
Launch Opportunity	October 1997	December 1997	March 1999
Cruise Time to Saturn	6.7 Years	8.8 Years	9.8 Years
Mission Margins			
• Power	Adequate	Slightly Reduced	Slightly Reduced
• Propellant	Adequate	Adequate	Adequate
Timing of Science Return			
• Saturn Arrival Date	June 2004	October 2006	December 2008
• End of Saturnian Tour	2008	2010	2012
Completion of Science Return	Full Return	Reduced Science Return	Reduced Science Return
Continuity of Support			
• Facilities Available	Firm Commitment	Firm Commitment	Firm Commitment
• Mission Personnel	Firm Commitment	Firm Commitment	Firm Commitment
International Agreements	Cooperative	Cooperative	Possibly Disrupted

Source: JPL 1994a

[a] Should the Titan IV (SRM) be needed, differences exist in cruise time and Saturn arrival date. The science return would be less than the Titan IV (SRMU)/Centaur primary launch opportunity.

TABLE 2-10. SUMMARY COMPARISON OF THE MISSION-SPECIFIC CONSIDERATIONS FOR THE CASSINI MISSION ALTERNATIVES (Continued)

Considerations for Comparison	Alternative Actions				
	1999 Dual Shuttle		2001 Non-EGA		No-Action
	Primary	Backup	Primary	Backup	
Launch Vehicle	STS/Upper Stage(s)	STS/Upper Stage(s)	Titan IV (SRMU)/Centaur	Titan IV (SRMU)/Centaur	Not Applicable
Trajectory	VEEGA	VEEGA	VVVGA	VEEGA	Not Applicable
Launch Opportunity	March 1999	August 2000	March 2001	May 2002	Not Applicable
Cruise Time to Saturn	9.8 Years	9.4 Years	10.3 Years	11.4 Years	Not Applicable
Mission Margins					
• Power	Slightly Reduced	Slightly Reduced	Slightly Reduced	Slightly Reduced	Not Applicable
• Propellant	Adequate	Adequate	Marginal	Marginal	
Timing of Science Return					
• Saturn Arrival Date	December 2008	January 2010	June 2011	September 2013	Not Applicable
• End of Saturnian Tour	2012	2014	2015	2017	
Completion of Science Return	Reduced Science Return	Reduced Science Return	Reduced Science Return	Reduced Science Return	No Science Return
Continuity of Support					
• Facilities Available	Probably Available	Probably Available	Probably Available	Probably Available	Not Applicable
• Mission Personnel	Probably Available	Probably Available	Probable Loss of Mission Personnel	Probable Loss of Mission Personnel	
International Agreements	Possibly Disrupt	Possibly Disrupt	Possibly Disrupt	Possibly Disrupt	Disrupt

Source: JPL 1994a

Launching the Cassini spacecraft and delivery of the Huygens Probe during the Proposed Action's October 1997 primary launch opportunity or during one of the contingency opportunities would enable scientists to acquire extensive new information about the planet Saturn, its atmosphere, moons, rings and magnetosphere. This 4-year science tour of Saturn and its environs would be an opportunity to gain significant insights, both planned and unplanned, into major scientific questions about the creation of the solar system and the conditions that led to life on Earth, in addition to a host of questions specific to the Saturnian system.

Among the scientific goals, the Huygens Probe would collect data on Saturn's largest moon, Titan. The Probe, developed by ESA specifically for the Cassini mission, would descend by parachute through Titan's atmosphere. The instruments mounted on the Probe would directly sample the atmosphere to determine its composition. Once on the surface, the Probe would gather data on the surface composition and landscape and transmit the information to the Cassini Orbiter.

Cassini would also study Saturn's rings, continuing the science efforts begun by the Voyager mission. Long-term closeup observations of the rings by Cassini could help resolve unexplained phenomena, such as the various wave patterns, small and large gaps, clumping of material, and small "moonlets" embedded in the rings.

The Proposed Action represents the combination of spacecraft power system, launch vehicle configuration, and trajectory that would best satisfy all of the mission science objectives. The spacecraft's electrical power would be provided by three RTGs. For the primary opportunity, a Titan IV (SRMU or SRM)/Centaur would launch the Cassini spacecraft from CCAS into a VVEJGA trajectory to arrive at Saturn in 2004. If NASA could not launch Cassini during the primary opportunity, contingency launch opportunities in either December 1997 or March 1999 have been identified. The December 1997 secondary launch opportunity would place Cassini on an 8.8-year VEEGA trajectory, arriving at Saturn in 2006; the March 1999 backup launch opportunity would place Cassini on a 9.8-year VEEGA trajectory, arriving at Saturn in 2008. In the event that the Titan IV (SRMU)/Centaur were not available, a Titan IV (SRM)/Centaur would be used. The primary, secondary, and backup opportunities would remain the same.

The Titan IV (SRMU)/Centaur and the Titan IV (SRM)/Centaur are the only feasible U.S. launch vehicle configurations to meet the October 1997 launch opportunity. The RTG technology is the only power system currently available that meets all the requirements for the mission. Although the potential use of solar power was evaluated, it was not considered feasible at this time because of the large mass that would be required for the solar array. The large mass and dimensions of the array combined with the mass of the Cassini spacecraft would exceed the launch capabilities of the Titan IV (SRMU)/Centaur. In addition, the array size would impose severe limitations on spacecraft maneuverability, constrain instruments field-of-view, and increase the risk of electromagnetic and electrostatic interference impeding the performance of communications equipment.

Therefore, the Proposed Action has the greatest potential to accomplish the mission and its scientific objectives. It could be accomplished in a timely manner without a major disruption of the NASA, ESA, and ASI scientific programs. A launch during the Proposed

Action's contingency opportunities would result in reduced science return compared with the primary launch opportunity. In addition, the contingency opportunities would delay the science return (i.e., 2 years for the secondary opportunity and 4 years for the backup opportunity). This would entail additional costs to NASA and its international partners.

The alternatives to the Proposed Action are the 1999 mission alternative, the 2001 mission alternative, and the No-Action alternative. The 1999 mission alternative would involve dual Shuttle launches from KSC to deliver the upper stages and the Cassini spacecraft into low Earth orbit. An on-orbit mating of the spacecraft and upper stages would be performed by astronauts, followed by spacecraft injection into its VEEGA interplanetary trajectory. The configuration of the upper stages is currently undefined. The backup launch opportunity for this mission would occur in August 2000 using a VEEGA trajectory. The 1999 mission alternative would obtain less science return than the 1997 primary launch opportunity of the Proposed Action.

The 2001 mission alternative would involve a launch from CCAS on a Titan IV (SRMU)/Centaur in March 2001 using a VVVGA (non-Earth gravity-assist) trajectory. The backup launch opportunity would insert the spacecraft into a VEEGA trajectory using a Titan IV (SRMU)/Centaur launch from CCAS in May 2002. This alternative would result in a reduced science return from the primary launch opportunity of the Proposed Action due to the measures that would be taken to enable a launch on the Titan IV (SRMU)/Centaur (i.e., a reduction in the number of Titan flybys from 35 to 21, elimination of the SOI burn delay, and an extension of the initial orbit period). The spacecraft's data gathering activities at Saturn would be restricted to conserve the marginal quantity of propellant available.

The No-Action alternative would cancel the mission, forfeiting the opportunity to acquire significant mission-specific scientific data, which cannot be obtained by any other means. Cancellation of the Cassini mission would also terminate the international partnerships formed to develop the Cassini Orbiter and the Huygens Probe and would disrupt agreements made for other space-related projects.

3. AFFECTED ENVIRONMENT

This section addresses the elements of the environment that could potentially be affected by the Proposed Action and the alternatives. The section is divided into two major areas: 1) the regional area, including the six-county region surrounding Cape Canaveral Air Station (CCAS) (formerly Cape Canaveral Air Force Station [CCAFS]) and Kennedy Space Center (KSC) and 2) the global area. A brief discussion of plutonium levels in the global environment is included to provide a perspective of the types, sources, and levels of plutonium that exist in the environment on a broad scale.

The affected environment has been discussed in detail in previous (Tier 2) Environmental Impact Statements (EISs) for the Galileo (NASA 1989b) and Ulysses missions (NASA 1990). Much of the material has been updated for this document with sources such as the October 1994 *Kennedy Space Center Environmental Resource Document* (NASA 1994). Additional information, including information specific to CCAS, was taken from the *Air Force Environmental Assessment for the Titan IV/Solid Rocket Motor Upgrade Program* (USAF 1990).

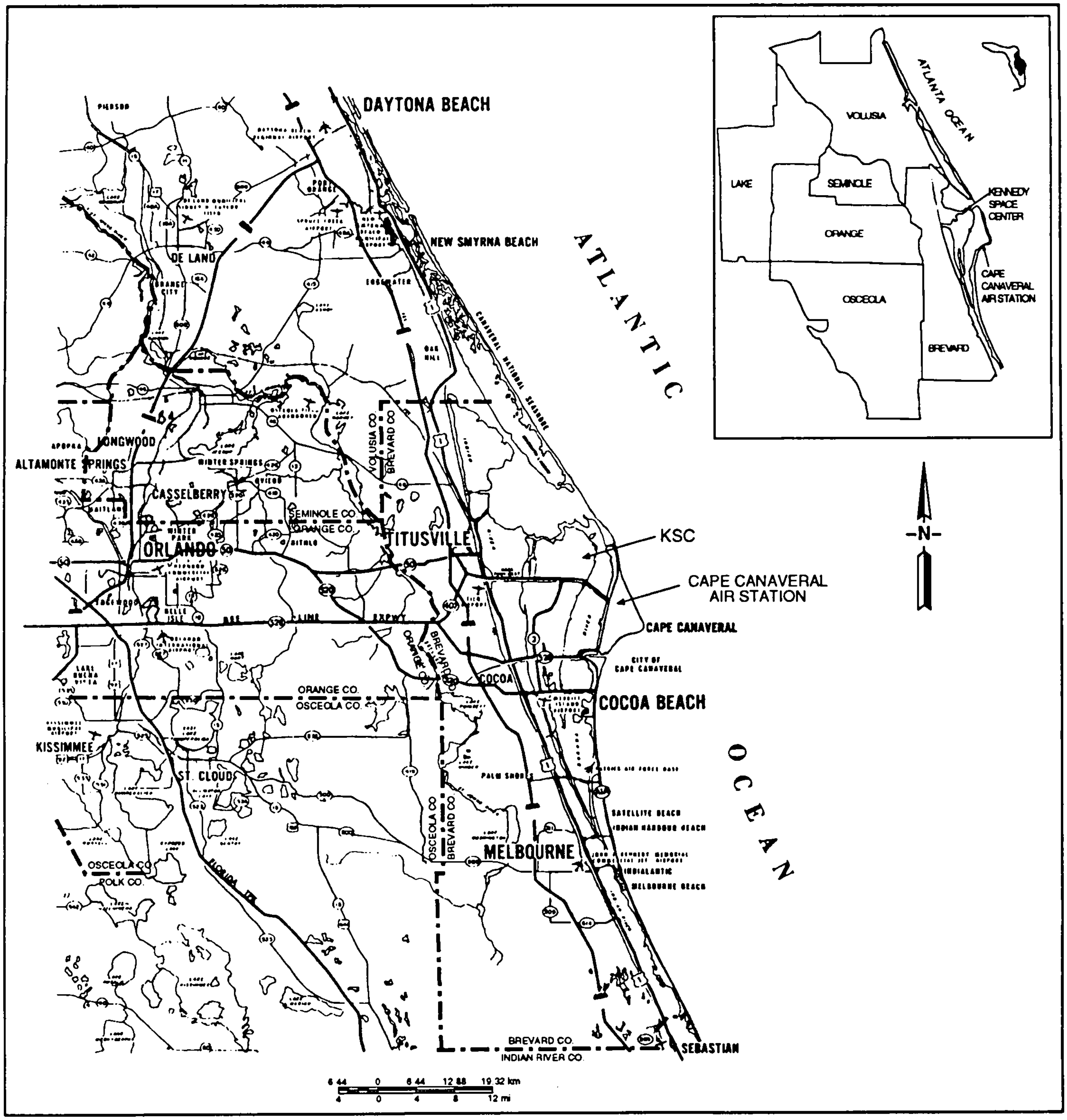
3.1 REGIONAL AREA

For the purpose of this document, the region of interest consists of the six counties—Volusia, Seminole, Lake, Orange, Osceola, and Brevard counties—shown in Figure 3-1.

CCAS is located on the east coast of Florida in Brevard County near the city of Cocoa Beach, approximately 24 km (15 mi) north of Patrick Air Force Base. The station is adjacent to the NASA KSC, Merritt Island, Florida. The station is bounded by KSC on the north, the Atlantic Ocean on the east, the city of Cape Canaveral on the south, and the Banana River and KSC/Merritt Island National Wildlife Refuge on the west. KSC is located in the northeast coastal section of Brevard County, Florida and the southern part of Volusia County, Florida. It is bounded on the north by uninhabited marsh land, on the east by the Atlantic Ocean, on the south by CCAS and on the west by the shallow tidal Indian River. Figure 3-2 illustrates the location of CCAS and KSC relative to Brevard and Volusia Counties.

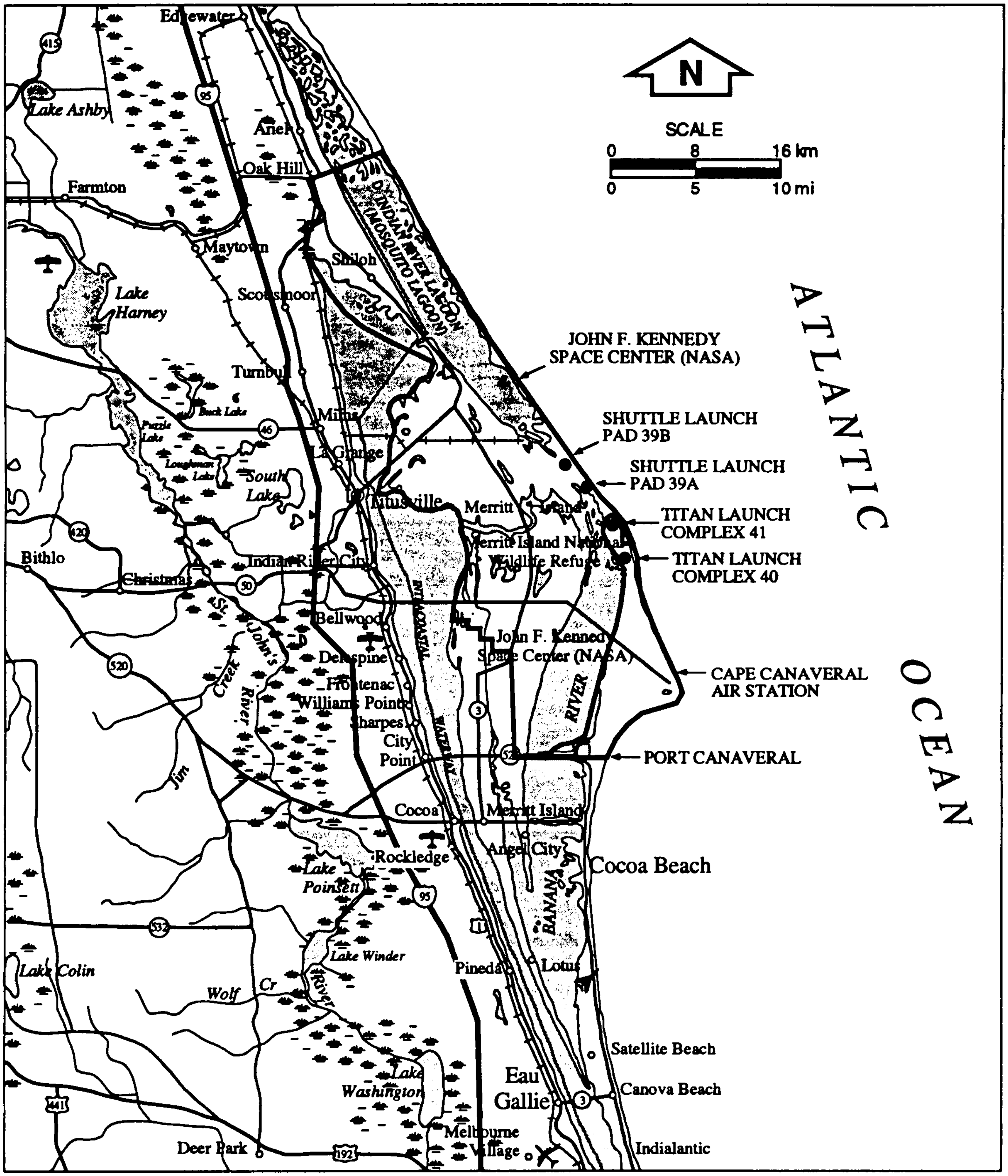
3.1.1 Land Use

About 8 percent (132,742 ha; 328,000 acres) of the total region (1.7 million ha; 4.1 million acres) is urbanized (ECFRPC 1992a), 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 River 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 urban areas.



Source: NASA 1986

FIGURE 3-1. REGIONAL AREA OF INTEREST



Source: NASA 1986, NASA 1994

FIGURE 3-2. LOCATION OF CCAS RELATIVE TO THE REGION

The majority of the region is considered rural, which includes agricultural lands and associated trade and service areas, conservation and recreation lands, and undeveloped areas. Agricultural areas include citrus groves, winter vegetable farms, pasture land and livestock, foliage nurseries, sod farms, and dairy land. With more than 5,000 farms, nurseries, and ranches in the region, about 35 percent (566,580 ha; 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 more than 404,700 ha (1 million acres) (ECFRPC Undated-a). The region also contains about 2,185 ha (5,400 acres) of saltwater beaches and more than 80 acres of archaeological and historic sites (DOI 1991). Numerous 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, five State preserves or reserves, seven State wildlife management areas, and three national wildlife refuges, including the Merritt Island National Wildlife Refuge at KSC.

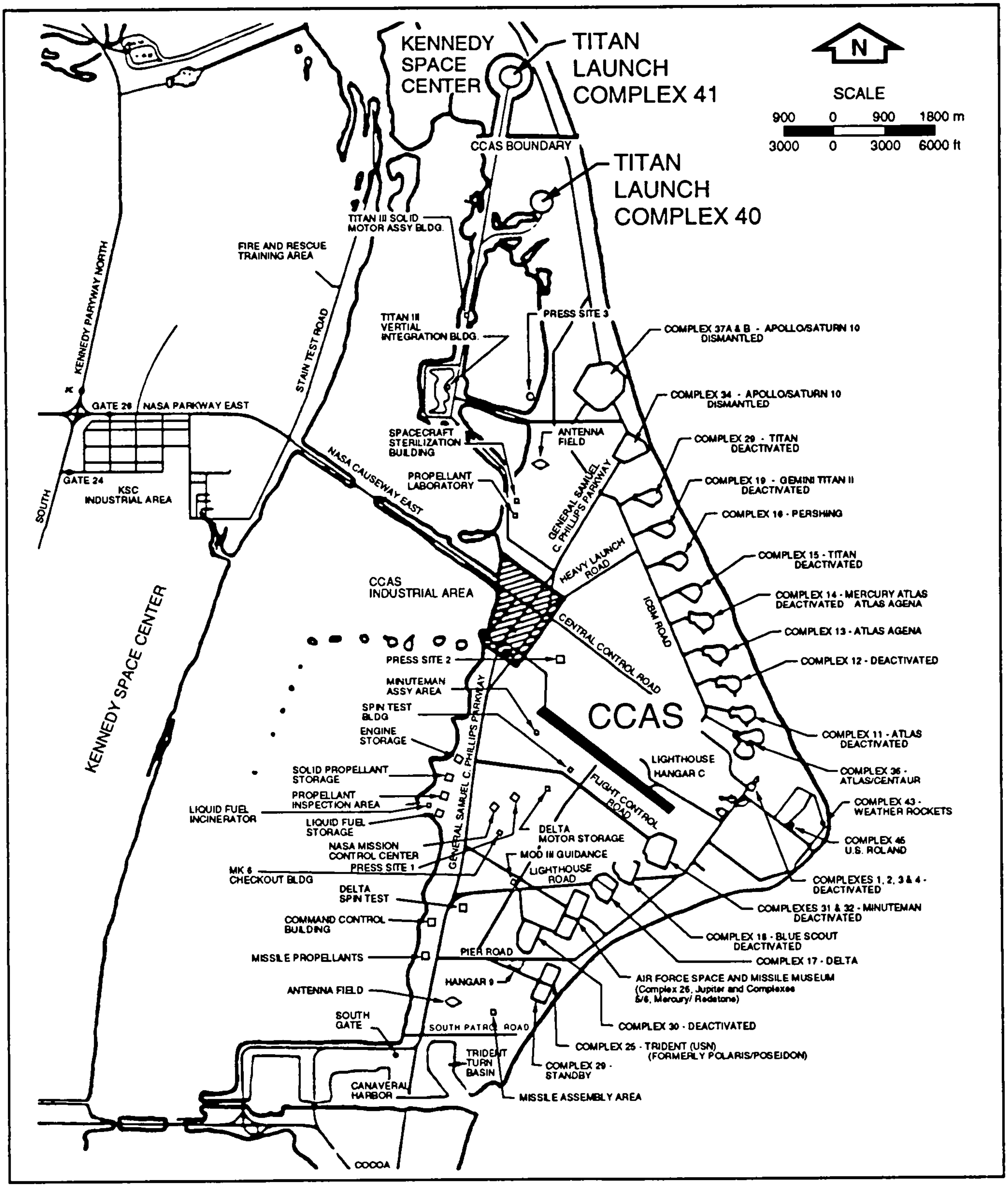
CCAS

CCAS occupies approximately 6,394 ha (15,800 acres) (roughly 64.75 km^2 or 25 mi^2) of the barrier island that also contains the city of Cape Canaveral (see Figure 3-3). Approximately 1,880 ha (4,700 acres) or 30 percent of the station is developed, consisting of more than 40 launch complexes and support facilities, many of which have been dismantled or deactivated (USAF 1990). The remaining 70 percent (about 4,440 ha; 11,100 acres) is unimproved land (USAF 1990). The Titan IV Launch Complexes 40 and 41 are located in the northernmost section of CCAS. Launch Complex 40 has been operational since 1964. Launch Complex 41 was previously used from 1964 to 1977 for test flights of the Titan III A and Titan III C. Subsequently, it was reactivated in 1986 and renovated to support Titan IV launches (USAF 1990).

Launch Complex 40 and 41 (see Figure 3-4) each consist of a launch pad, Mobile Service Tower (MST), Umbilical Tower (UT), Aerospace Ground Equipment (AGE) building, air conditioning shelter, gas storage area, propellant holding areas, and miscellaneous service facilities. Launch Complex 41, as well as Launch Complex 40 to the southeast, has been strengthened and upgraded to accommodate Titan IV launches using the larger and more powerful solid rocket motor upgrade (SRMU) (USAF 1990).

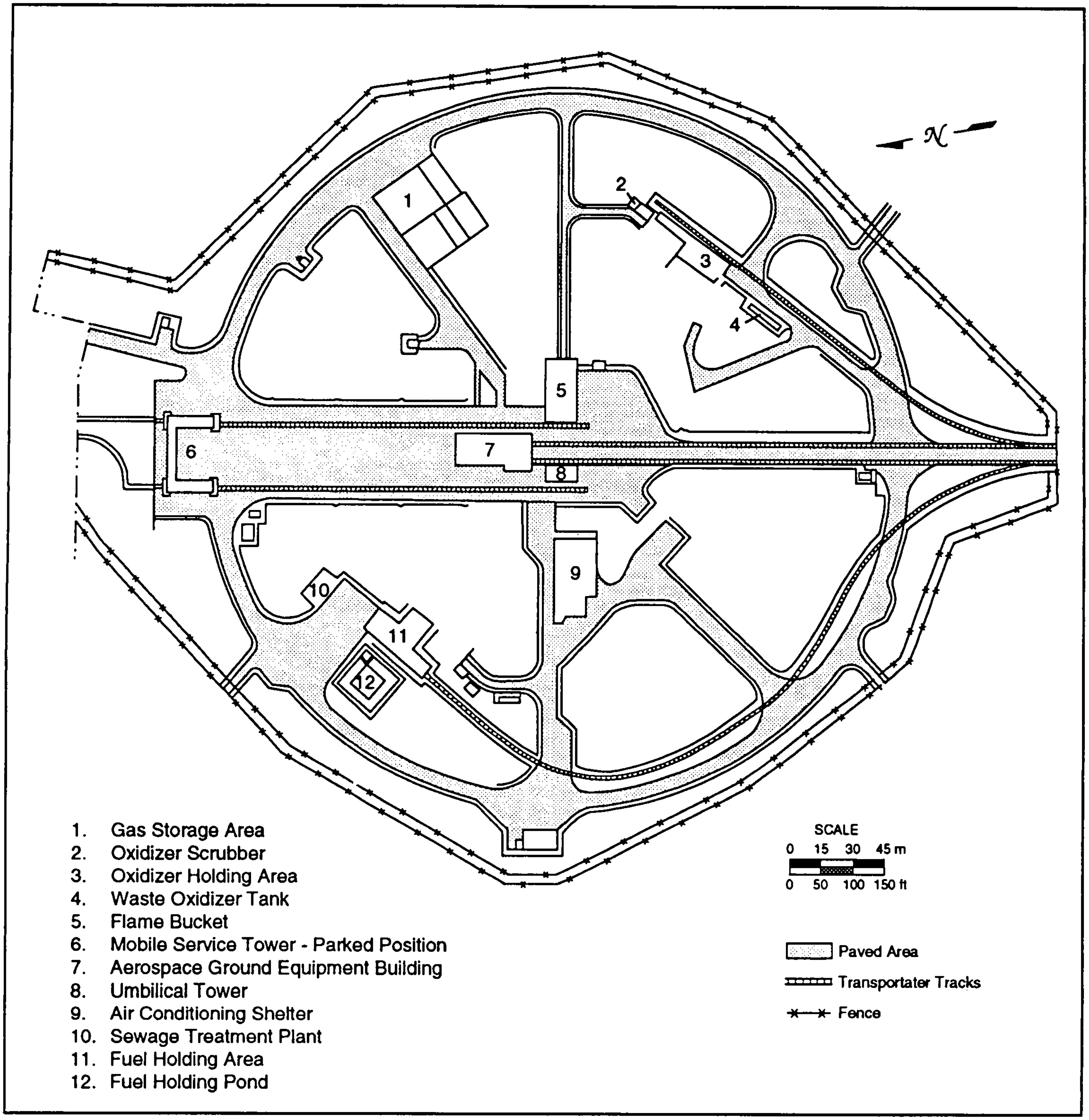
The launch pad is a concrete deck with fixed foundations to support the launch transporter with the mounted Titan IV/Centaur launch vehicle, the MST, and the UT (Martin Marietta 1992). The launch pad deck is 7 m (23 ft) above mean sea level and approximately 4.3 m (14 ft) above the surrounding complex finish grade. Rails for the MST and transporter are nested flush with the deck surface.

A concrete exhaust duct with an opening of 5.5 to 17.7 m (18 to 58 ft), an integral part of the launch pad, deflects solid rocket motor exhaust gases away from the launch pad to reduce the noise (acoustic) and shock wave (overpressure) that result from ignition of the solid rocket motors. The launch complex includes a water deluge system and an overpressure suppression system, which sprays high-pressure water directly into the solid



Source: USAF 1986

FIGURE 3-3. EXISTING LAND USE AT CCAS



Source: USAF 1990

FIGURE 3-4. LAYOUT OF LAUNCH COMPLEXES 40 AND 41 AT CAPE CANAVERAL AIR STATION, FLORIDA

rocket motor upgrade (SRMU) exhaust plume to reduce acoustic loads on the vehicle and the overpressure from the SRMUs.

The MST provides facilities for mating the Centaur and the spacecraft to the Titan IV and for servicing and inspecting the complete integrated flight vehicle. Just prior to launch, the MST is moved from its service position to its park position, north of the launch pad.

The UT is a steel-frame structure anchored to the launch pad that extends approximately 52 m (170 ft) above the top of the launch pad. It provides connections for propellants, pressurization gases, and conditioned air to both the launch vehicle and to the payload fairing. Installations on the tower accommodate both manual and launch-disconnected umbilicals.

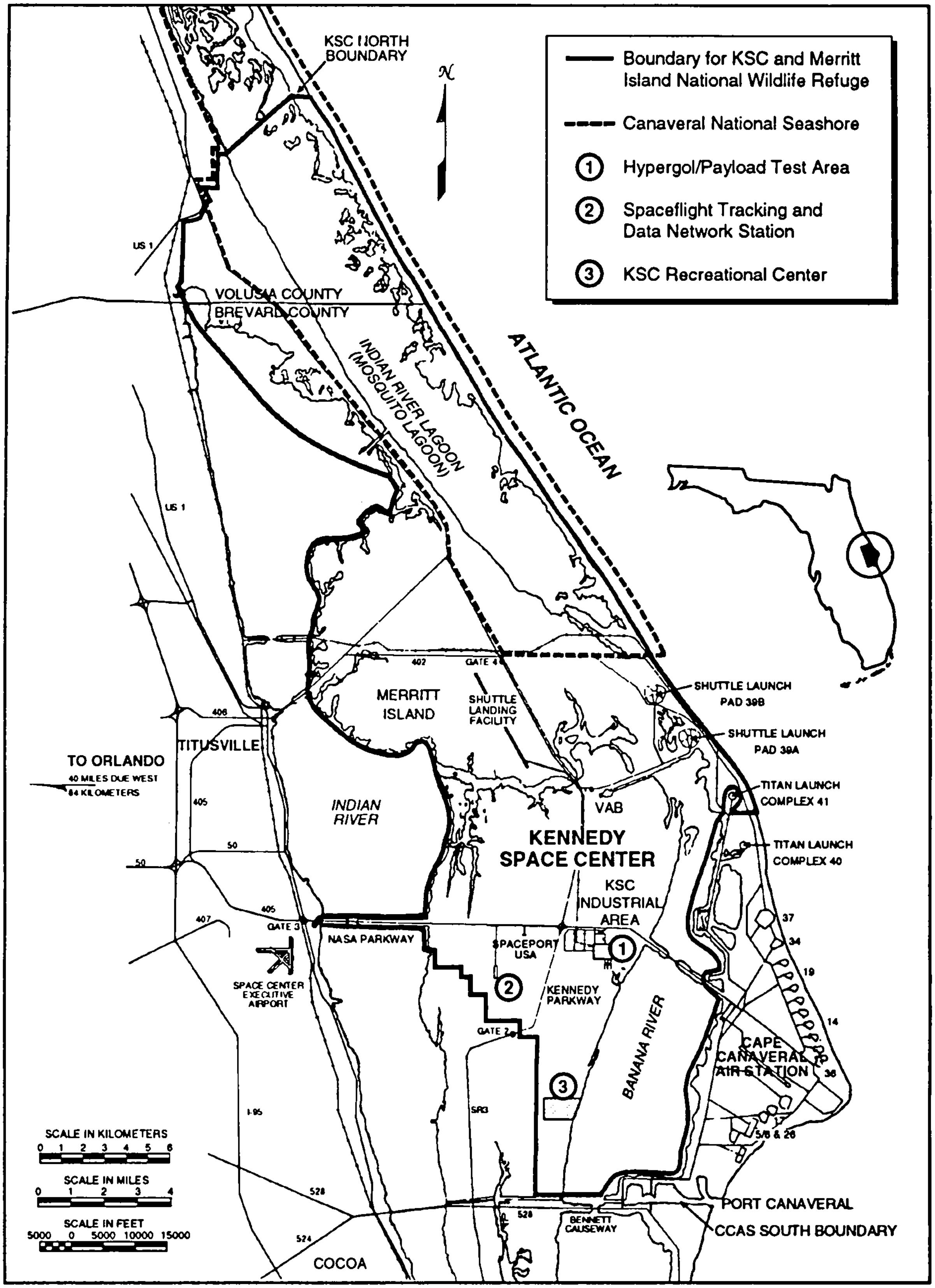
The AGE building is a two-story, reinforced concrete structure located between the MST rails and adjacent to the launch pad. The upper level (first level or level A) houses the two Titan AGE vans and has provisions for two additional vans for either the Centaur or spacecraft AGE. The lower level (second level or level B) contains a rack room and a facility power and air conditioning equipment room, as well as the propellant transfer and pressurization control set, used to control and monitor propellant loading, unloading, and tank pressurization. The building is constructed to withstand exposure to the thermal and acoustical environment produced by the vehicle engine exhaust and is maintained at an air pressure above atmospheric pressure to reduce the possibility of equipment contamination in the building. To ensure a source of uncontaminated air, there are two interchangeable intakes, one located approximately 152 m (500 ft) north and the other approximately 152 m (500 ft) south of the building.

The gas storage area contains storage vessels for high-pressure nitrogen and helium. Separate holding areas contain facilities to store, transfer, and unload propellants for the launch vehicle (unsymmetrical dimethylhydrazine and nitrogen tetroxide) and for the Centaur (liquid hydrogen and liquid oxygen).

A lightning mitigation system has been constructed at both Launch Complexes 40 and 41. This system consists of four towers located at the four corners of the launch pad wired to ground lightning flashes. The towers are more than 91.5 m (300 ft) tall and will secure the area for continued pad activities when thunderstorms are in the area.

KSC

KSC occupies approximately 56,452 ha (139,490 acres) (see Figure 3-5). Approximately 2,148 ha (5,308 acres) or 4 percent of the Center is developed, of which 2,406 ha (5,945 acres) is under NASA operational control. The remaining 54,303 ha (134,182 acres) is undeveloped land (NASA 1994). Nearly 40 percent of KSC consists of open water areas. The Shuttle Launch Complexes 39A and 39B are located in the northeast portion of KSC. Launch Complexes 39A and B have been operational since the



Source: NASA 1990

FIGURE 3-5. EXISTING LAND USE ON KSC

1970s and consist of facilities to support launch of the Shuttle (i.e., Space Transportation System [STS]). Figure 3-6 illustrates the layout of Launch Complexes 39A and 39B.

KSC is the major NASA installation for launch operations and related programs in support of manned space missions. Present and near-future mission plans call for the launching of manned vehicles into low Earth orbit for conducting scientific experimentation. To accomplish these goals, the Shuttle provides the capability to support a wide range of scientific applications (NASA 1994).

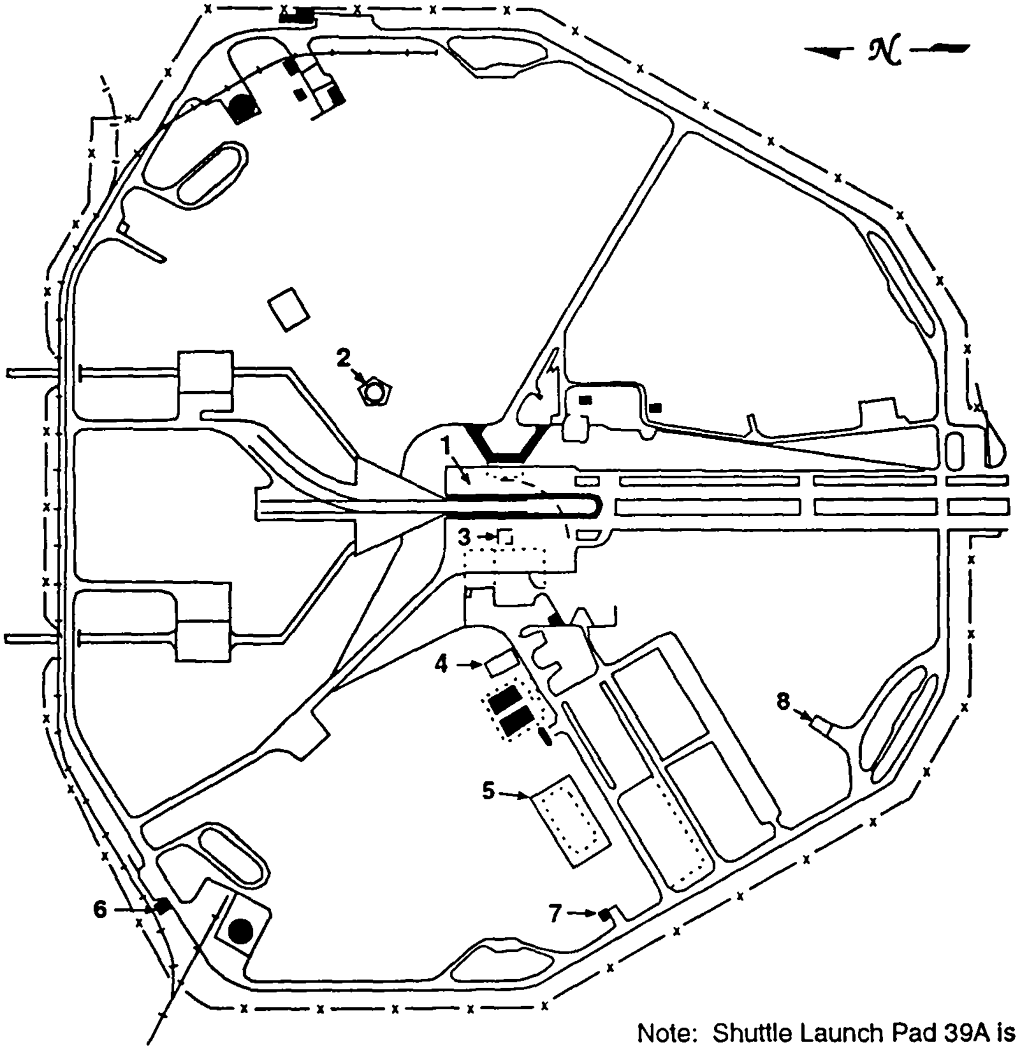
3.1.2 Atmospheric Environment

The structure of the atmosphere can be classified in a number of ways, using either temperature, density, or chemical composition. From the standpoint of the dispersion of atmospheric pollutants, however, a temperature classification scheme is most important. Essentially, the Cassini launch would cause its greatest potential environmental impacts in the lower layers of the atmosphere: the troposphere and the stratosphere. The primary concerns associated with the troposphere are potential violations of the National Ambient Air Quality Standards (NAAQS) developed under the Clean Air Act (CAA) by the U.S. Environmental Protection Agency (EPA) and global warming issues. The principal concern within the stratosphere is ozone depletion.

3.1.2.1 Atmospheric Layers

The troposphere is the atmospheric layer closest to the Earth's surface. All life exists and virtually all weather occurs within this layer. Additionally, this layer accounts for more than 80 percent of the mass and essentially all of the water vapor, clouds, and precipitation contained in the Earth's atmosphere. The troposphere varies from an altitude of 10 km (32,808 ft) at the poles to 15 km (49,200 ft) at the equator. In this layer, the temperature decreases with height at the nominal rate of approximately 6.5°C/km (about 3.57°F/1,000 ft). In addition, vertical convection tends to maintain a well-mixed atmospheric environment in this layer; however, stagnations do occur. As a result of the mixing and scavenging by precipitation, the mean residence time for tropospheric aerosols is short (ranging from a few days to a few weeks). The troposphere and the stratosphere are separated by a narrow region called the tropopause.

The stratosphere extends from the tropopause up to an altitude of approximately 50 km (164,050 ft). In general, vertical mixing is limited within the stratosphere, providing little transport between the layers above and below. Thus, the relatively dry, ozone-rich stratospheric air does not easily mix with the lower, moist ozone-poor tropospheric air. In addition, the lack of vertical mixing and exchange between atmospheric layers provides for extremely long residence times, allowing the stratosphere to often act as a "reservoir" for certain types of atmospheric pollution. The temperature is relatively constant in the lower stratosphere and gradually increases with altitude, reaching approximately 3°C (37.5°F) at the top of the layer. The temperature increase is caused primarily to the adsorption of short-wave radiation by ozone molecules.



Note: Shuttle Launch Pad 39A is functionally the same as 39B.

1. J7-337 Launch Pad B
2. Water Tank
3. Fixed Service Structure
4. Operations Building No. 2
5. Polishing Pond
6. J7-132 Operations Support Building B-1
7. Remote Air Intake
8. Hypergol Fuel Facility

Source: INSRP 1989a

FIGURE 3-6. SHUTTLE LAUNCH PAD 39B AT KSC

3.1.2.2 Meteorology

The climate of the region is subtropical with two definite seasons: long, warm, humid summers and short, mild, and dry winters (NASA 1994). Rainfall amounts vary both seasonally and yearly. The average rainfall is about 130 cm (51 in.), with about 70 percent falling during the wet season (May to October). These rainfall fluctuations result in frequent, although usually not severe, episodes of flooding and drought. The temperature is more constant than precipitation; prolonged cold spells and heat waves are rare. Tropical storms, tropical depressions, and hurricanes, all of which can produce large amounts of rainfall and high winds, occasionally strike the region. Hail falls occasionally during thunderstorms, but hailstones are usually small and seldom cause much damage. Snow is rare.

Figure 3-7 provides wind roses indicating the seasonal wind directions at CCAS and KSC. The winds in September through November occur predominantly from the east to northeast. Winds typically occur from the north to northwest in December through February; from the southeast in March through May and from the south in June through August. Sea breeze (onshore winds) and land breeze (offshore winds) phenomena occur commonly over a 24-hour day due to unequal solar heating of the air over land and ocean. Land breeze (toward the sea) occurs at night when air over land has cooled to a lower temperature than that over the sea; sea breeze (toward the land) occurs during the day when air temperatures are lower over the sea. Temperature inversions occur infrequently (approximately 2 percent of the time).

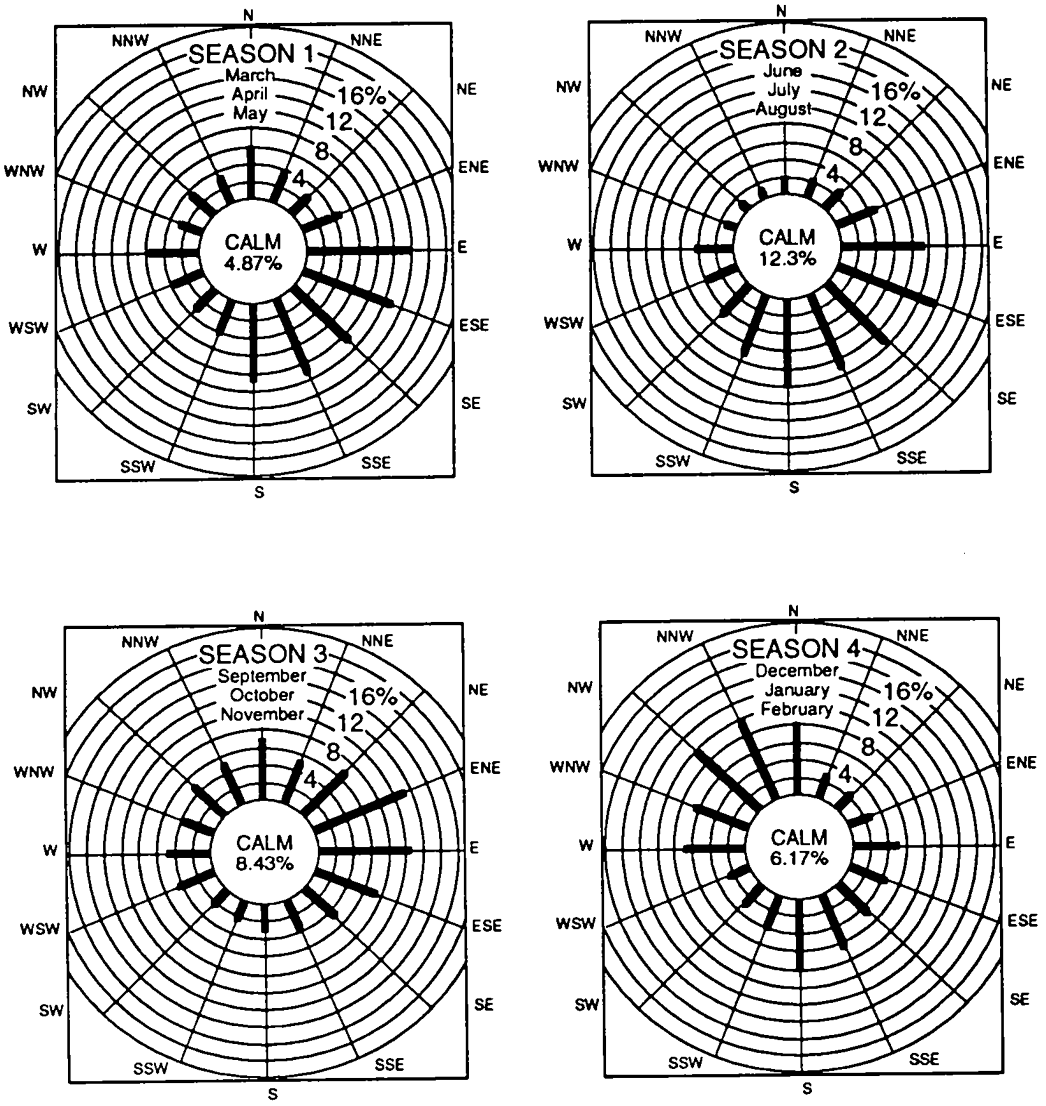
Tornadoes may occur but are rare. The U.S. Air Force (USAF 1986) cited a study that concluded that the probability of a tornado hitting a point within the Cape Canaveral area in any given year is 0.00074, with a return frequency of approximately once every 1,300 years. Tornadoes are rare and damage has been minimal (NASA 1994).

Tropical depressions and hurricanes occur mainly in the months of August through November in Florida. Less than 30 hurricanes have passed within 185 km (100 nautical miles) of the CCAS regional area since 1887 (NASA 1994). Hurricane David (which paralleled the coast in September 1981), Hurricane Hugo (September 1989), and Hurricane Andrew (August 1992) were the last hurricanes to affect the CCAS/KSC area.

Eighty percent of the thunderstorms occurring in this area occur from May through September, with a maximum of 16 thunderstorm days on average in July (NASA 1994). Lightning detection systems indicate that on the average there are 1,400 cloud to ground strikes per month in the summer months within the 350 km^2 (135 mi^2) KSC area (Bionetics Corporation 1990).

3.1.2.3 Air Quality

Air quality at CCAS is considered good, primarily because of the distance of the station from major sources of pollution. There are no Class I or nonattainment areas for NAAQS criteria pollutants (i.e., ozone, nitrogen oxides, sulfur dioxide, lead, carbon monoxide, and particulates) within about 96 km (60 mi) of CCAS. Orange County, to the west of CCAS, was a nonattainment area for ozone until 1987 when it was redesignated



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

Source: NASA 1986

FIGURE 3-7. WIND ROSES INDICATING SEASONAL WIND DIRECTIONS – LOWER ATMOSPHERIC CONDITIONS: CAPE CANAVERAL/MERRITT ISLAND LAND MASS as an ozone attainment area (NASA 1994). Orange County is currently designated as an air quality maintenance area (State of Florida 1991a). Under Section 176(c) of the CAA, the general conformity rules require a Federal action to conform to the applicable State Implementation Plan. The general conformity rules apply to nonattainment areas and to maintenance areas (e.g., Orange County). Because Brevard County, CCAS/KSC and its vicinity are considered to be "in attainment" or "unclassifiable" with respect to NAAQS for criteria pollutants (USAF 1990), these rules do not apply to CCAS/KSC or to the Cassini mission.

Ambient air quality at KSC is monitored by a single permanent air monitoring station (PAMS) (Busacca et al. 1991). The PAMS is located approximately 0.4 km (0.25 mi) southeast of the Environmental Health Facility (Building L7-1557). Six exceedances of the standard were observed at the PAMS site since 1988 (NASA 1994). Historically, ozone levels can reach peak concentrations during any of the spring and fall months (Busacca et al. 1991). Table 3-1 provides ambient air quality data for 1993.

3.1.3 Noise

Monitoring of ambient noise levels at CCAS has not been performed (USAF 1990). The 24-hour average ambient noise level at KSC is appreciably lower than the EPA recommended upper level of 70 decibels (dBA). This is on a scale ranging from approximately 10 dBA for the rustling of grass or leaves to 115 dBA, the unprotected hearing upper limit for exposure on a missile or space launch. The backwoods and National Wildlife Refuge areas of KSC are exposed to relatively low ambient noise levels, in the range of 35 to 40 dBA (NASA 1994).

Noise generated at CCAS, however, is expected to include sources from day-to-day operations, launches of space vehicles, industrial operations, construction, aircraft operating in the vicinity, boats, and vehicular traffic. The noise caused by the day-to-day operations at CCAS and KSC probably approximates that of any urban industrial area reaching levels of 60 to 80 dBA (USAF 1990). The launch of a space vehicle generates intense, but relatively short-duration noise levels at low frequencies. At the launch pad, the maximum sound pressure can exceed 160 dBA (NASA 1994). Peak noise levels from industrial and construction activities from mechanical equipment, such as diesel locomotives, cranes, and rail cars, could range from approximately 89 to 111 dBA. Vehicular traffic noise ranges from 85 dBA for a passenger automobile to 110 dBA for a motorcycle (NASA 1994). (As enforced by the Occupational Safety and Health Administration [OSHA], continuous exposure for longer than 8 hours per day to noise levels above 85 dBA requires monitoring for hearing damage; the maximum short-term [15 minute] occupational exposure level is 115 dBA.)

3.1.4 Geology and Soils

The region of interest is underlain by a series of limestone formations, with a total thickness of several thousand feet. The lower formations (the Avon Park and Ocala) contain the Upper Floridan Aquifer, which is under artesian pressure in the vicinity of CCAS/KSC. At CCAS/KSC, the Upper Floridan Aquifer commences at a depth of about

TABLE 3-1. SUMMARY AIR QUALITY DATA FROM KSC (1993)

Criteria Pollutant	Federal and State Standard[a]	January	February	March	April	May	June	July	August	September	October	November	December
Ozone (ppb)	120 (hr-avg)[b]	18 (99.9%)	32 (100.0%)	35 (99.9%)	35 (82.1%)	32 (89.0%)	22 (62.1%)	74 (96.2%)	75 (73.9%)	35 (69.9%)	36 (99.9%)	16 (100.0%)	17 (100.0%)
Sulfur Dioxide (ppb)	140 (24-hr)[c,d] 500 (3-hr)[d]	1 1 (98.0%)	1 1 (72.1%)	1 1 (99.3%)	1 1 (85.4%)	1 1 (88.4%)	1 2 (62.1%)	4 17 (96.2%)	3 19 (76.3%)	1 1 (69.9%)	1 1 (99.7%)	1 2 (94%)	1 1 (8.5%)
Nitrogen Dioxide (ppb)	(max. value) (10-min avg) 50 (annual-avg)[d]	26 17 13 (100.0%)	23 22 16 (100.0%)	41 24 13 (100.0%)	35 22 8 (85.4%)	32 29 11 (89.0%)	35 32 20 (62.1%)	10 10 33 (96.2%)	16 15 18 (76.3%)	24 19 10 (69.9%)	- - 12 (100.0%)	- - 10 (100.0%)	- - 11 (100.0%)
Carbon Monoxide (ppm)	35 (hr-avg)[b] 9 (8-hr)[c]	1.615 1.365 (99.6%)	0.497 0.465 (99.7%)	0.801 0.737 (99.9%)	0.548 0.434 (86.4%)	0.569 0.394 (89.0%)	1.282 0.925 (62.1%)	0.731 0.379 (96.2%)	2.057 1.544 (76.2%)	1.8 0.614 (69.9%)	0.994 0.492 (99.9%)	0.853 0.727 (99.7%)	1.439 1.262 (100.0%)

Source: NASA 1994

a. Federal and State standards are identical except for sulfur dioxide; State of Florida 24-hr standard is 100 ppb.
b. Maximum hourly average concentration (not to be exceeded more than once per year).
c. Maximum time-period average concentration (not to be exceeded more than once per year).
d. Annual arithmetic mean cannot be exceeded.

NOTE: 21 days are required to yield a valid month. (%) = Percent of valid data for the month.

80 m (260 ft) and is about 110 m (360 ft) thick (USAF 1990). Beds of sandy clay, shells, and clays of the Hawthorn formation overlie the Floridan Aquifer, forming the principal confining beds for that aquifer (i.e., the Hawthorn formation isolates the Floridan Aquifer from the shallower aquifers). The Hawthorn formation lies at a depth of about 30 m (100 ft) at CCAS/KSC and is up to 50 m (160 ft) thick. Overlying the Hawthorn formation are Upper Miocene, Pliocene, Pleistocene, and Recent deposits, which form secondary semi-confined aquifers and the surficial aquifer lying at depths up to about 30 m (100 ft) at CCAS/KSC. CCAS and KSC are located on a barrier island composed of relict beach ridges.

The U.S. Department of Agriculture's Soil Conservation Service has mapped the soils in the CCAS/KSC area and has identified five major soil associations. (The locations of the major soils associations are given in *Kennedy Space Center Environmental Resource Document* [NASA 1994]). The principal soils in the vicinity of Launch Complexes 40 and 41 are highly drained, sandy soils (percolation rate greater than 51 cm [20 in.] per hour) on level or moderately sloping topography (USAF 1990). The soils near Launch Complexes 39A and 39B are marshy, very poorly drained, and saline on nearly level terrain (NASA 1994).

3.1.5 Hydrology and Water Quality

3.1.5.1 Surface Waters

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 and its tributaries in the region are classified by the State as Class I surface water (potable water supply) and serve as the source of potable water for the city of Melbourne and for much of the surrounding population (State of Florida 1991c).

Major inland water bodies in the CCAS/KSC area are the Indian River, Banana River, and Mosquito Lagoon (see Figure 3-2). These water bodies are shallow estuarine lagoons with average water depths of 0.6 to 0.9 m (2 to 3 ft), except for the portions maintained as part of the Intercoastal Waterway, between Jacksonville to the north and Miami to the south. The Indian and Banana Rivers join at Port Canaveral and form a combined area of 60,000 ha (150,000 acres) in Brevard County. This area receives drainage from 218,500 ha (540,000 acres) of surrounding area (USAF 1990). Launch Complexes 39A, 39B, 40 and 41 are located on the barrier island between the Atlantic Ocean and the Banana River. Most precipitation at the complex infiltrates directly into the soils with any surface runoff flowing toward the Banana River (USAF 1990). 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 at KSC. Navigation locks within Port Canaveral virtually eliminate any significant oceanic influence on the Banana River. Public navigation is prohibited within the manatee refuge portion of the Banana River north of State Road 528 (see Section 3.1.6.4 for a discussion of endangered and threatened species).

3.1.5.2 Surface Water Quality

The major surface water resources in the region include the St. Johns River and associated tributaries, the Indian River Lagoon system, the Banana River, and, along the western edge of the region, a portion of the Kissimmee River, which forms part of the border of Osceola County. The St. Johns River system serves as a source of potable water for parts of the region, including the city of Melbourne (State of Florida 1991c).

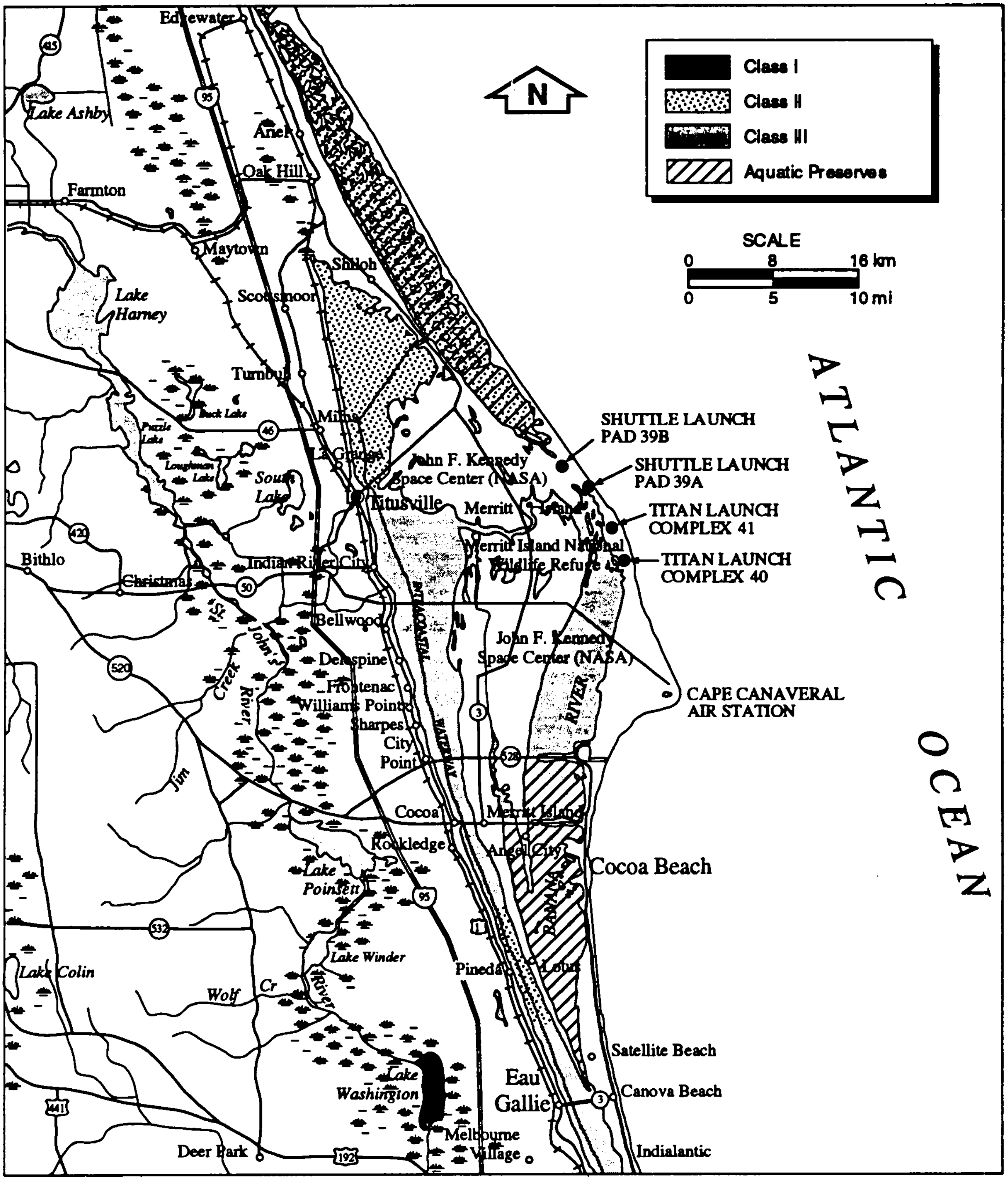
The State of Florida has adopted water quality standards, as required under the Federal Clean Water Act of 1977, and has designated each surface water resource as one of five classes (Class I through Class V), based upon potential use and value. (Class I waters are subject to the most stringent standards, reflecting their value as potable water sources; Class V waters have much less stringent standards, reflecting their potential value for navigation, utility, and industrial use.) Within the region, the St. Johns River and its tributaries have been designated as Class I (i.e., potable water supply) by the State (State of Florida 1991c). In the immediate vicinity of CCAS and KSC (Figure 3-8), Mosquito Lagoon has been designated by the State as Class II (i.e., shellfish propagation and harvesting), as has the northern-most segment of the Indian River extending from the NASA railway spur crossing and a second segment of Indian River south of Merritt Island (NASA 1994). The remaining of the surface waters in the immediate vicinity of CCAS and KSC (i.e., Banana Creek, Banana River, and the Indian River south of Titusville) have been designated as Class III waters (i.e., recreation and fish and wildlife management).

Florida's Aquatic Preserve Act of 1975 facilitated the designation of certain state-owned submerged lands and associated coastal waters as Aquatic Preserves (NASA 1994). Aquatic Preserves have exceptional biological, aesthetic, and scientific values, and such activities as oil and gas drilling, dredging, and effluent discharges are substantially restricted. In the vicinity of KSC, Aquatic Preserves include the entire Mosquito Lagoon and a portion of the Banana River south of State Road 528 (Figure 3-8).

A special designation, Outstanding Florida Waters (OFW), has been established for certain water bodies within the State that demonstrate recreational or ecological significance. This designation constitutes the highest level of protection afforded surface waters in the State. The OFW designation can apply to waters within State or national parks, wildlife refuges, aquatic preserves, and other State and Federal areas. Within the region, 38 water bodies are designated OFW (State of Florida 1991d). In the vicinity of CCAS, the surface waters adjacent to Merritt Island National Wildlife Refuge, Mosquito Lagoon, and Canaveral National Seashore, as well as the Banana River Aquatic Preserve and portions of the Indian River near Sebastian Inlet State Recreation Area about 68 km (42 mi) south of Launch Complex 41, are designated OFW (Figure 3-9).

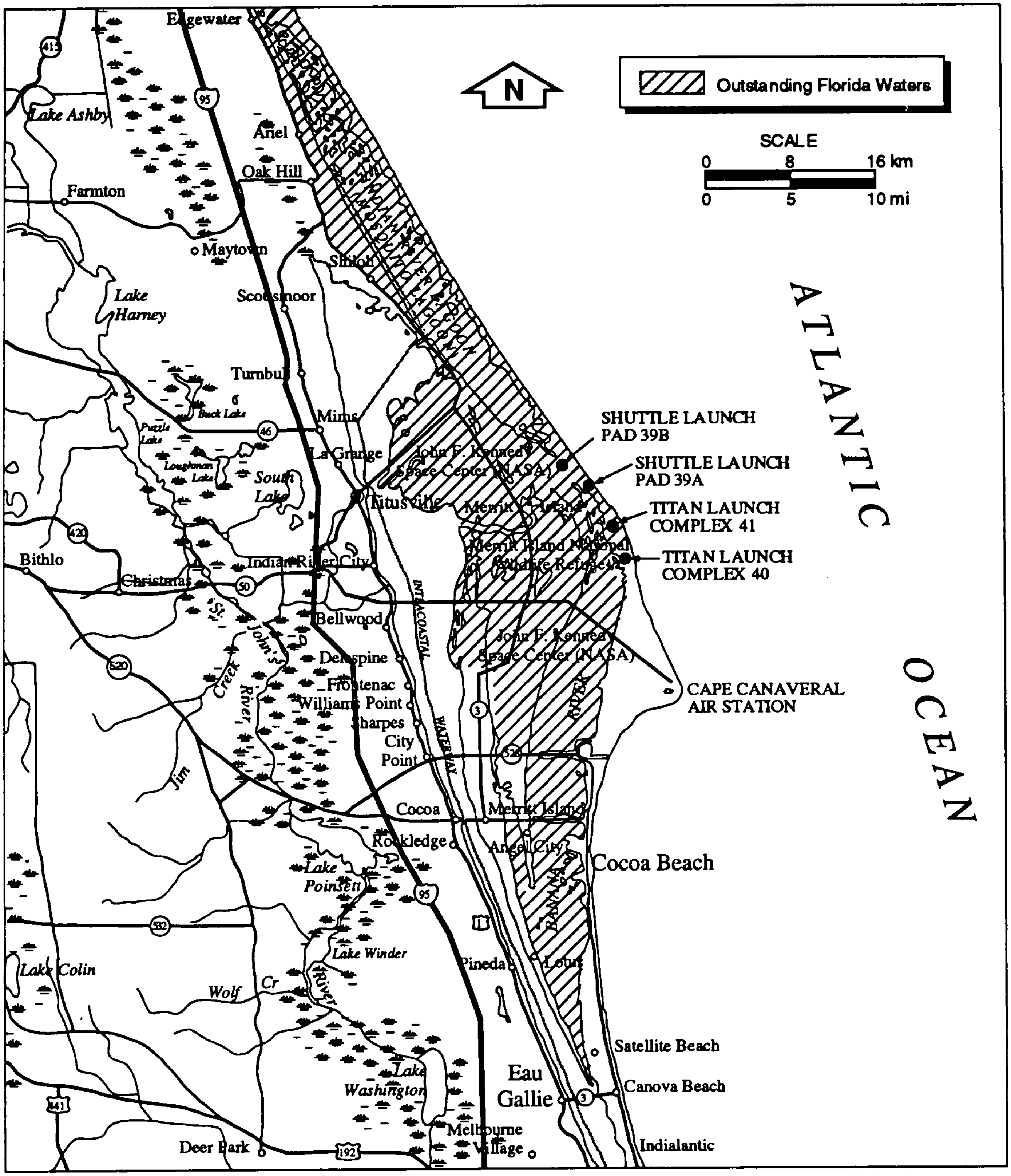
The Indian River Lagoon has been selected as an Estuary of National Significance through U.S. EPA's National Estuary Program. The goal of this program is to balance conflicting uses of the Nation's estuaries while restoring or maintaining their natural character (NASA 1994).

Surface water quality near CCAS and KSC is monitored at 11 long-term monitoring stations that are maintained by NASA. These stations are located in Mosquito Lagoon, the



Source: NASA 1994

FIGURE 3-8. CCAS/KSC SURFACE WATER CLASSIFICATIONS AND AQUATIC PRESERVES



Sources: NASA 1994, State of Florida 1991d

FIGURE 3-9. OUTSTANDING FLORIDA WATERS

Banana River, Banana Creek, and at other locations on and near KSC. Other monitoring stations in the general area are maintained by Brevard County, the U.S. Fish and Wildlife Service (FWS), and the Florida Department of Environmental Protection (FDEP) (NASA 1994). In general, the water quality in the monitored surface waters has been characterized as good, although data from a recent study of water quality monitoring programs prepared for NASA indicate that certain parameters (i.e., primarily phenols and silver) consistently exceed State water quality criteria with pH, iron and aluminum occasionally exceeding criteria. Nutrients and metals, when detected, have generally been below the Class II standards. The Banana River segment to the north of NASA Parkway East is subject to stormwater runoff from the Titan IV assembly and launch areas. Because of the runoff, the salinity of the northern segment of the river tends to be somewhat lower than that of the southern segment, although both segments tend to be brackish to saline (15 to 36 parts per thousand salinity at NASA Causeway East [USAF 1990]). Recent water quality data from the northern segment of the Banana River, given in Table 3-2, indicate the trends noted above for phenols, aluminum, iron, zinc, and silver. Because of the relatively high salinity of the river, Class III marine standards are cited where appropriate.

3.1.5.3 Groundwater

Three principal geohydrologic units underlie the area. In order of descending depth, these units are a surficial aquifer, secondary semi-confined aquifers (found below confining layers but above and within the Hawthorn formation), and the Floridan Aquifer (NASA 1994, USAF 1990).

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. Figure 3-10 illustrates the recharge area in the vicinity of CCAS and KSC for the surficial aquifer. 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.

Wells that tap the surficial unconfined aquifer are largely used for non-potable or individual domestic uses, although this source is also used for some municipal public supply systems (e.g., the cities of Mims and Titusville, which are about 16 km [10 mi] northwest of the CCAS/KSC launch sites, and Palm Bay, located about 64 km [40 mi] south of the CCAS/KSC launch sites in Brevard County).

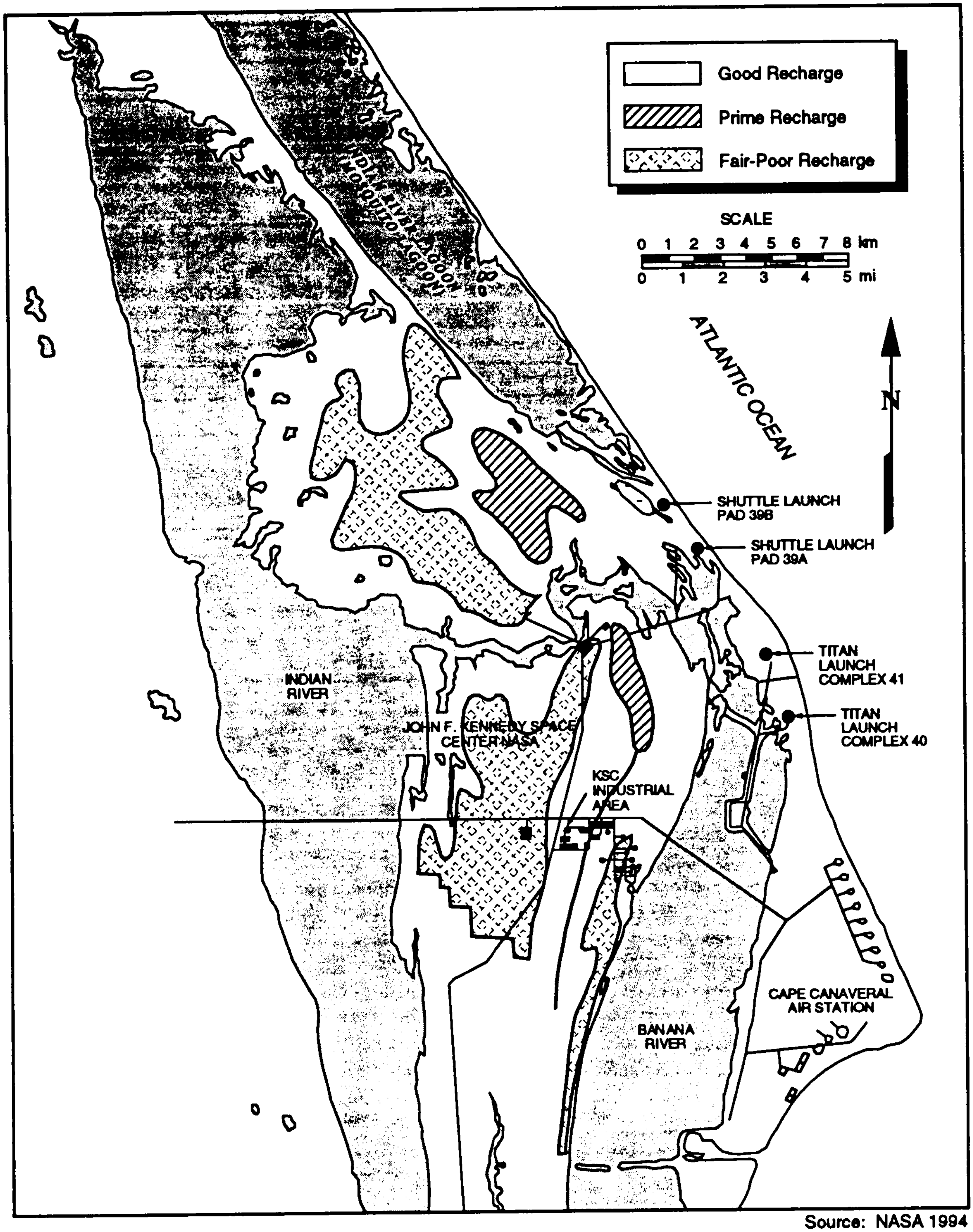
Groundwaters under artesian and semi-confined conditions in the secondary aquifers and Floridan Aquifer near CCAS/KSC have upward flow potentials. Recharge to the secondary aquifers is minor and depends on leakage through the surrounding lower permeability beds. Because of the thickness (55 m [160 ft]) and the relatively impermeable nature of the confining units of the Hawthorn formation, however, it is thought that, in general, no significant natural inter-aquifer leakage is occurring from the Floridan Aquifer into the more shallow aquifers (NASA 1994). Because of recharge characteristics, the more shallow aquifers, and the surficial aquifer in particular, are more pertinent to launch vehicle operations than the deeper, isolated Floridan Aquifer.

TABLE 3-2. SUMMARY OF WATER QUALITY MONITORING DATA FOR NORTH BANANA RIVER, PEPPER FLATS, SAMPLED IN 1991

Parameters	Average	Range	FDEP Class III Standards
Conductivity (μmhos/cm)	34,200	12,300 - 58,000	Varies
Total Suspended Solids (mg/l)	33.3	4.0 - 145.0	No Standard
Turbidity NTU	2.7	0.1 - 7.1	29 NTU Above Background
Oil and Grease (mg/l)	0.6	<0.2 - 6.7	<5.0; No Taste or Odor
Phenols (μg/l)	137	6 - 822	1.0, varies
Alkalinity (mg/l)	163.2	97.6 - 408.0	≥20 (fresh)
pH	8.3	7.5 - 9.3	6.5 - 8.5 (marine)
Total Kjeldahl Nitrogen (mg/l)	2.34	<0.02 - 8.70	No Standard
Nitrate Nitrogen (mg/l)	0.05	<0.02 - 0.3	No Standard
Ortho Phosphate (mg/l)	0.032	<0.025 - 0.20	No Standard (marine)
Chlorophyll A (mg/m^3)	5.6	<0.5 - 36.7	No Standard
Biological Oxygen Demand (mg/l)	3.5	<1.0 - 16.0	[a]
Chemical Oxygen Demand (mg/l)	660	180 - 1570	No Standard
Dissolved Oxygen (mg/l)	6.2	4.8 - 8.8	≥4 (marine)
Total Organic Carbon (mg/l)	6.6	1.9 - 50.1	No Standard
Aluminum (mg/l)	0.65	<0.10 - 6.33	≤1.5 (marine)
Cadmium (μg/l)	0.21	<0.01 - 3.60	9.3 (marine)
Chromium (mg/l)	0.018	<0.001 - .05	0.05 (Cr^{+6}) (marine)
Iron (mg/l)	0.29	<0.04 - 0.98	≤0.3 (marine)
Zinc (μg/l)	50	<10 - 170	86 (marine)
Silver (μg/l)	16.59	<0.05 - 68.40	≤0.05 (marine)

Sources: Bionetics Corporation 1991, NASA 1994, State of Florida 1991c

[a] Based on dissolved oxygen limits.



Source: NASA 1994

FIGURE 3-10. POTENTIAL RECHARGE FOR SURFICIAL AQUIFER

3.1.5.4 Quality of Groundwater

Almost all (89 percent) of the freshwater used in the region is drawn from groundwater supplies, principally the Floridan Aquifer (ECFRPC 1992a). The Floridan Aquifer covers 212,000 km^2 (82,000 mi^2) of Florida and is 610 m (2,000 ft) thick in some areas (FSU 1984). In portions of the region, such as at CCAS and KSC (where the Floridan Aquifer is under artesian pressure) and in an area bordering the St. Johns River, the Floridan Aquifer is considered too saline for potable water use (ECFRPC 1992a). CCAS obtains its potable water from the city of Cocoa, which in turn, draws its water from non-brackish areas of the Floridan Aquifer (USAF 1990). KSC also receives its water from a permitted public supply utility within the St. Johns River Water Management District (NASA 1994). The region contains some effective recharge areas for the Floridan Aquifer. These areas are located primarily in the upland portions of Lake, Orange, Seminole, Osceola, and Volusia Counties and comprise very porous, sandy soils, where up to 30 percent of the total annual rainfall enters the Floridan Aquifer.

Groundwater in the State of Florida has been established as four classes: Class G-I (i.e., potable water; total dissolved solids less than 3,000 mg/l) through G-IV (i.e., non-potable water; total dissolved solids [TDS] of 10,000 mg/l or more). The majority of the State's groundwaters, including the groundwater underlying CCAS and KSC, are classified as G-II (i.e., potable water use; total dissolved solids less than 10,000 mg/l) (State of Florida 1991b).

Overall, water in the surficial unconfined aquifer in the vicinity of CCAS and KSC meets State of Florida Class II groundwater secondary quality standards for potable water use with the general exception of chloride, iron, and/or total dissolved solids (NASA 1994, USAF 1990). The concentrations of these parameters are considered to be elevated because of the influence of adjacent saline surface waters.

Tables 3-3 and 3-4 summarize groundwater quality data from shallow groundwater wells installed within and around the perimeter of Launch Complexes 40 and 41. These data indicate that the shallow groundwater is generally of good quality. However, wells at both complexes contained concentrations of TDS and iron above the Florida Secondary Drinking Water Standards. In addition, orthophosphate, total phosphate, sulfate, ammonia, chloride, magnesium, and boron were found at somewhat elevated concentrations in the local vicinity when compared to the water quality in background wells. Previous investigations of groundwater near Launch Complexes 40 and 41 found cadmium, chloride, iron, manganese, and/or TDS above Florida Drinking Water Standards. In addition, some samples had traces of 1,1,1-trichloroethane, benzene, and dimethyl-hydrazine (USAF 1990, Reagan 1993, Reagan 1995).

Initial groundwater studies at Launch Complexes 39A and 39B indicated minor groundwater contamination of aluminum (Al), cadmium (Cd), chromium (Cr), iron (Fe), and lead (Pb) with trace and periodic detection of volatile organic compounds (NASA 1994).

The groundwater of the secondary semi-confined aquifer ranges from moderately brackish to brackish, primarily because of very slow, upward leakage from the Floridan

TABLE 3-3. GROUNDWATER MONITORING DATA FOR LAUNCH COMPLEX 40, SAMPLED ON NOVEMBER 4, 1994

Parameter Monitored (mg/l)[a]	MW-1[b]	MW-2	MW-3	MW-4	MW-5	Florida Drinking Water Standards[c]
Ortho Phosphate	0.02	0.06	0.04	0.02	<0.02	No Listing
TP	0.03	0.09	0.09	0.08	0.09	No Listing
Sulfate	5.0	17.0	17.0	32.0	90.0	250.0
Zinc	<0.01	0.31	<0.01	<0.01	<0.01	5.0
Surfactants	<0.125	<0.063	<0.063	<0.063	<0.063	0.5[d]
pH (standard units)	7.41	7.05	7.13	6.99	7.01	6.5-8.5
TDS	194.0	310.0	706.0	618	816	500.0[e]
Aluminum	<0.05	0.05	<0.05	<0.05	<0.05	0.2
Ammonia	<0.02	0.03	1.61	8.09	2.38	No Listing
Beryllium	<0.001	<0.001	<0.001	<0.001	<0.001	0.004
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	0.005
Chloride	4.61	16.7	240	79.7	165	250.0
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	0.10
Copper	<0.01	<0.01	<0.01	<0.01	<0.01	1.0
Iron	<0.02	<0.02	0.53	<0.02	<0.02	0.3
Lead	<0.015	<0.015	<0.015	<0.015	<0.015	0.015
Nickel	<0.005	<0.005	<0.005	<0.005	<0.005	0.1
Nitrate	0.51	0.18	<0.01	<0.01	<0.01	10.0
Magnesium	3.68	4.43	6.68	34.2	20.9	No Listing
Boron (μg/l)	<50.0	<50.0	50.0	290.0	110.0	No Listing
MMH (μg/l)	<5.0	<5.0	<5.0	<5.0	<5.0	No Listing
UDMH (μg/l)	<10.0	<10.0	<10.0	<10.0	<10.0	No Listing

Source: Reagan 1995

a. Units are measured in mg/l except where noted.
b. Background monitoring well.
c. Florida Drinking Water Standards, Florida Administrative Code, Title 17, Chapter 17-550.
d. Standard for foaming agents was used for surfactants.
e. The TDS standard may be greater than 500 mg/l if no other standard is exceeded.

TABLE 3-4. GROUNDWATER MONITORING DATA FOR LAUNCH COMPLEX 41, SAMPLED ON NOVEMBER 7, 1994

Parameter Monitored (mg/l)[a]	MW-1[b]	MW-2	MW-3	MW-4	MW-5	Florida Drinking Water Standards[c]
Ortho Phosphate	<0.02	<0.02	0.77	2.45	0.58	No Listing
TP	0.06	1.76	0.82	0.05	0.62	No Listing
Sulfate	2.5	37.0	1.2	6.60	176	250.0
Zinc	<0.01	<0.01	0.01	<0.01	<0.01	5.0
Surfactants	<0.125	<0.063	<0.063	<0.063	<0.025	0.5[d]
pH (standard units)	6.99	7.26	6.87	6.68	6.81	6.5-8.5
TDS	294.0	372.0	442.0	428.0	922.0	500.0[e]
Aluminum	<0.05	<0.05	<0.05	0.07	<0.05	0.2
Ammonia	0.02	0.93	0.36	0.03	1.78	No Listing
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	0.005
Chloride	12.7	46.8	88.6	22.3	36.1	250.0
Iron	0.864	<0.02	0.94	5.11	0.74	0.3
Lead	0.015	<0.015	<0.015	<0.015	<0.015	0.015
Nickel	<0.05	<0.05	<0.05	<0.05	<0.05	0.1
Nitrate	0.93	<0.01	<0.01	0.01	0.01	10.0
Magnesium	3.64	6.35	3.43	7.96	38.2	No Listing
Boron (μg/l)	<50.0	64.0	120.0	<50.0	240.0	No Listing
MMH (μg/l)	<5.0	<5.0	<5.0	<5.0	<5.0	No Listing
UDMH (μg/l)	<10.0	<10.0	<10.0	<10.0	<10.0	No Listing

Source: Reagan 1995

a. Units are measured in mg/l except where noted.
b. Background monitoring well.
c. Florida Drinking Water Standards, Florida Administrative Code, Title 17, Chapter 17-550.
d. Standard for foaming agents was used for surfactants.
e. The TDS standard may be greater than 500 mg/l if no other standard is exceeded.

Aquifer (NASA 1994). Water from the Floridan Aquifer in the vicinity of CCAS and KSC is highly mineralized (principally chlorides) primarily because of the natural and induced (due to pumping) lateral seawater intrusion and a lack of flushing due to the distant recharge areas (e.g., Polk and Orange Counties) (NASA 1994). The Floridan Aquifer in the vicinity of CCAS and KSC has been ranked as having a low potential for well field acceptability.

3.1.5.5 Offshore Environment

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

Out to depths of approximately 18.3 m (60 ft), sandy shoals dominate the underwater topography. The sea floor continues to deepen out to about 100 km (62 mi) from the coastline, where the bank slopes down to depths of 732 to 914 m (2,400 to 3,000 ft) to the Blake Plateau. The Blake Plateau extends out to about 370 km (230 mi) from the shore at KSC/CCAS. Figure 3-11 shows the bathymetry of the offshore areas.

Offshore currents usually reflect the general northern flow of the Gulf Stream, as illustrated in Figure 3-12 (National Oceanic and Atmospheric Administration [NOAA] 1980). Studies of water movements in the area indicate a shoreward direction of the current for the entire depth, surface to bottom, in the region out to depths of 18 m (60 ft) (about 33 km [20.5 mi] offshore) at speeds of several miles per day. Wind-driven currents generally determine the current flow at the surface. During the autumn (September through November), the prevailing winds are out of the northeast, with occasional winds out of the south. The prevailing winds transport surface waters toward the shore, with an offshore component in shallow bottom waters that diminishes rapidly with distance offshore (INSRP 1989c). The net effect is that material suspended in the water column tends to be confined to the area near the coast, and heavier material (e.g., sand) is deposited in this area.

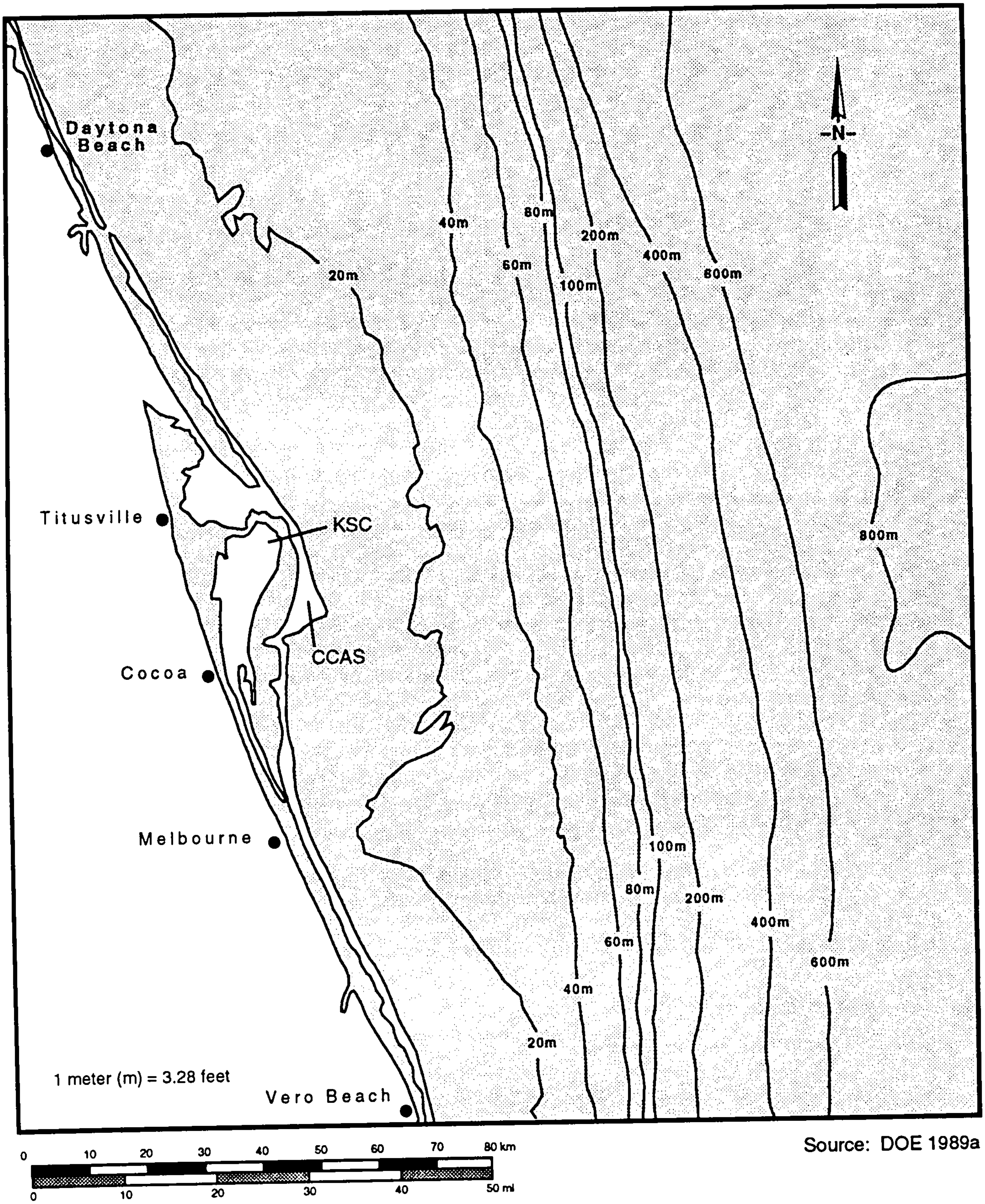
The occasional northward winds result in a net movement of surface waters offshore, with an inshore movement of the higher density bottom waters. Materials suspended in the surface waters are transported in an offshore direction, with the heavier bottom materials moving in shore.

In the region out to the sloping bank (100 km [62 mi]), the flow is slightly to the north and tends 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 (AEC 1975).

3.1.6 Biological Resources

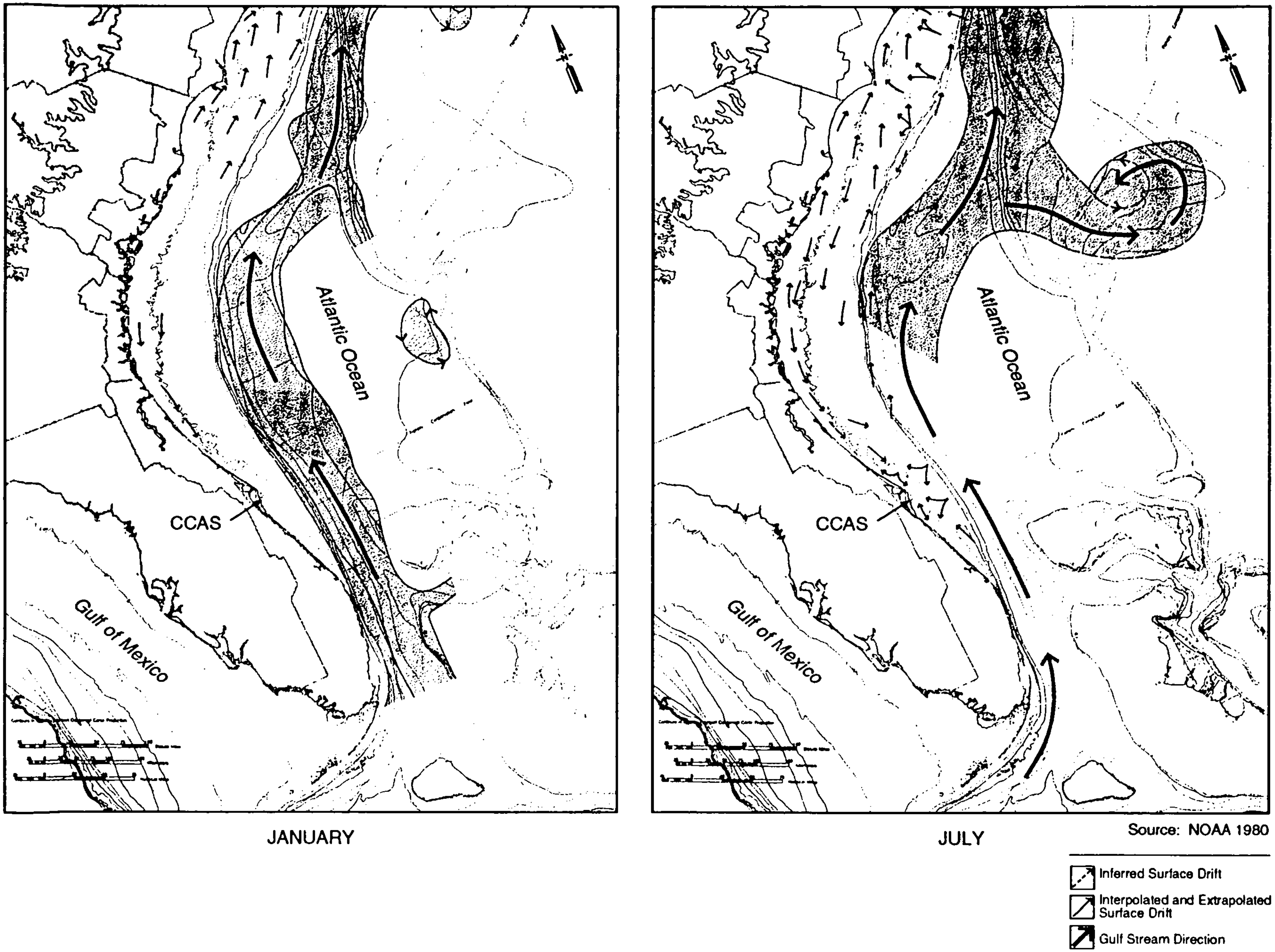
3.1.6.1 Floodplains and Wetlands

Titan IV Launch Complexes 40 and 41 are located on a greater than 500-yr floodplain (NASA 1994). Wetlands near the launch area consist largely of mixed salt-tolerant grasses and mangroves. Wetlands in the CCAS/KSC area include freshwater ponds and canals, brackish impoundments, tidal lagoons, bays, rivers, vegetated marshes, and mangrove swamps. These wetlands provide resources for vast numbers of marine organisms, waterfowl, and terrestrial wildlife. Many of the wetlands within the Merritt



Source: DOE 1989a

FIGURE 3-11. OFFSHORE WATER DEPTH NEAR CCAS/KSC REGION



Source: NOAA 1980

FIGURE 3-12. OCEAN CURRENTS AND WATER MASSES OFFSHORE OF CCAS/KSC FOR JANUARY AND JULY

Island National Wildlife Refuge are managed for overwintering waterfowl habitat and host about 200,000 waterfowl each year.

The wetlands adjacent to Launch Complex 41 are mixed, consisting of salt-tolerant grass marsh with some black mangrove and sea oxeye vegetation areas. The wetlands at Launch Complex 40, which are separated from the complex by a narrow band of wax myrtle/Brazilian pepper vegetation to the west, consist of white/mixed mangrove with scattered areas of mixed salt-tolerant grass marsh areas interspersed (USAF 1990).

Shuttle Launch Complexes 39A and 39B are surrounded by 100 year floodplain (NASA 1994). Wetlands on KSC comprise approximately 35 percent of the land area. Sensitive coastal mangrove communities and aquatic preserves are present next to Launch Complexes 39A and 39B (NASA 1979).

3.1.6.2 Terrestrial Resources

The region has several 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 404,700 ha [1 million acres]) of the total land and water acreage within the region (about 1.7 million ha [4.1 million acres]).

Table 3-5 provides an overview of the 11 general land cover types throughout the 6-county region. Freshwater and coastal wetlands comprise about 23 percent of the total area of the 6-county region, followed by xeric grassland (21 percent), scrub and shrub (17 percent), water (12 percent), and hardwood/pine forest (11 percent) (ECFRPC 1988).

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

The majority of the land surrounding Launch Complexes 39A, 39B, 40 and 41, including KSC/Merritt Island National Wildlife Refuge and the Mosquito Lagoon/Cape Canaveral National Seashore areas, is undeveloped and in a near-natural state. These areas host a variety of vegetative communities, ranging from mangrove swamps and salt marshes to freshwater wetlands and coastal dunes and beaches. Sixty-eight reptile and amphibian species; more than 300 bird species, including 8 to 9 rookeries of nesting birds; and more than 25 mammal species use these communities (NASA 1994). A bird rookery is located about 0.5 km (0.3 mi) south of Launch Complex 39A and 2.5 km (1.3 mi) north of Launch Complex 41.

Approximately 70 percent (4,400 ha [11,100 acres]) of the total acreage (6,394 ha [15,800 acres]) at CCAS is undeveloped and dominated by three principal vegetative communities (Figure 3-13). The coastal dune community is the smallest (320 ha; 800 acres), extending from the high tide line of the Atlantic Ocean across the beach into the dunes along the coastal perimeter of CCAS (USAF 1990). Inland from the coastal

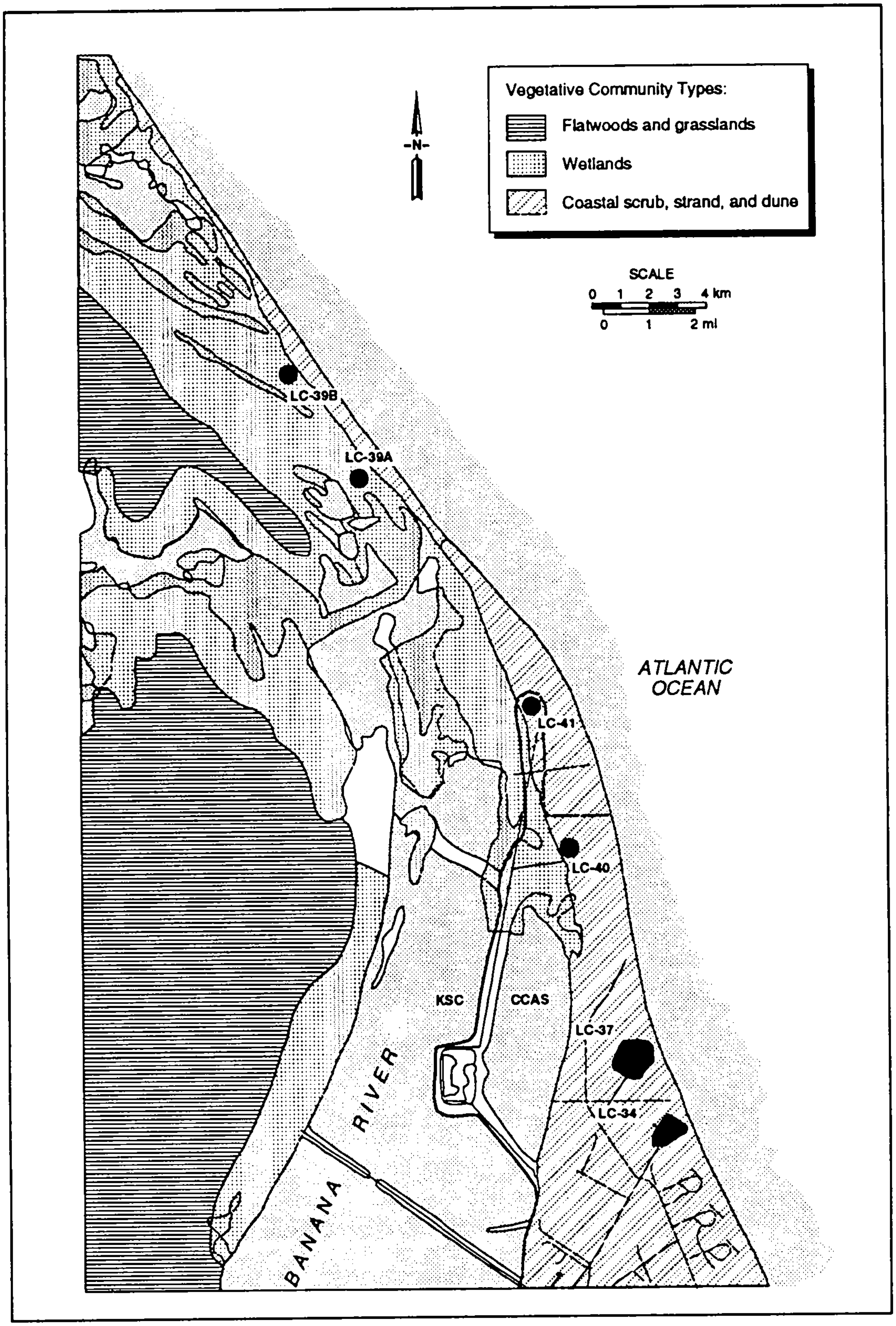
TABLE 3-5. MAJOR LAND COVER TYPES WITHIN THE REGION, BY COUNTY (ACREAGE[a] AND PERCENT)[b]

Type of Land Cover	Brevard County		Lake County		Orange County		Osceola County		Seminole County		Volusia County		Region Total	
	Acreage	%	Acreage	%	Acreage	%	Acreage	%	Acreage	%	Acreage	%	Acreage	%
Coastal Strand	1,050	0.13	0	0.00	0	0.00	0	0.00	0	0.00	657	0.08	1,707	0.04
Xeric Grassland	108,457	13.51	89,604	12.08	139,117	21.66	434,402	46.01	45,937	21.55	76,856	9.48	894,486	21.53
Hardwood/Pine Forest	73,492	9.16	59,617	8.04	87,415	13.61	60,308	6.39	17,204	8.07	182,406	22.50	480,488	11.57
Scrub/Shrub	102,363	12.75	218,044	29.40	119,224	18.56	79,970	8.47	33,053	15.50	155,060	19.13	707,799	17.04
Hardwood Hammock	23,312	2.90	45,587	6.15	34,588	5.38	13,706	1.45	23,191	10.88	60,621	7.48	201,031	4.84
Coastal Wetland	22,129	2.76	0	0.00	0	0.00	0	0.00	0	0.00	17,846	2.20	39,978	0.96
Freshwater Swamp	185,636	23.13	176,512	23.80	104,830	16.32	238,997	25.31	38,949	18.27	162,584	20.06	907,614	21.85
Water	175,268	21.83	83,751	11.29	57,851	9.01	77,598	8.22	21,186	9.94	93,134	11.49	508,849	12.25
Urban/Bare Ground	90,203	11.24	68,563	9.24	99,359	15.47	39,236	4.16	33,692	15.80	60,401	7.45	391,509	9.43
Citrus Orchard	19,305	2.40	0	0.00	0	0.00	0	0.00	0	0.00	1,040	0.13	20,347	0.49
Other Agriculture	1,520	0.19	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
TOTAL	802,733	100.00	741,677	100.00	642,384	100.00	944,215	100.00	213,212	100.00	810,605	100.00	4,153,807	100.00

Source: ECFRPC 1988

a. One acre equals 0.40 hectares.

b. The data for this table were compiled directly from the computer data base referenced. The level of precision implied by the numbers is an artifact of the computer compilation process; therefore, data should be viewed only as approximate acreages and approximate percentages.



Source: NASA 1979

FIGURE 3-13. MAJOR VEGETATION COMMUNITIES NEAR CCAS/KSC LAUNCH SITES dune community is the coastal strand community, covering about 920 ha (2,300 acres) of CCAS. Further inland is the coastal scrub community, which occupies the largest portion of the undeveloped area of CCAS (3,760 ha; 9,400 acres). Three other ecologically important communities exist at CCAS, although in smaller amounts (Figure 3-13). Mangrove swamp (180 ha [450 acres]) is the largest community of the three, followed by salt marsh (56 ha [140 acres]) and freshwater wetland (80 ha [20 acres]). Mangrove and salt water swamps surround Launch Complexes 39A and 39B at KSC.

Coastal strand and dune communities are marked by extremes in temperature and prolonged periods of drought (NASA 1990). Vegetation on the dunes is 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, including beach sunflower and camphorweed. The beach areas, while largely unvegetated, still provide significant wildlife resources. The tidal zone supports a large number of several species 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 the beaches of the Cape Canaveral area. In addition, research indicates that these beaches are important to nesting sea turtles (USAF 1990).

Strand occurs between the coastal scrub community and the salt spray zone of the dune system. The growth characteristics of strand vegetation produce 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. The white-tailed deer, raccoon, mice, 14 species of birds, such as red-tailed hawk and the red-headed woodpecker, and only 2 species of reptile (i.e., gopher tortoise and eastern diamondback rattlesnake), among others, use this community (USAF 1990).

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. Ten species of mammals, including white-tailed deer, armadillo, feral hogs, and bobcat use this habitat type at CCAS. In addition, 14 species of birds (similar to those inhabiting the coastal strand) and 5 species of reptiles use the scrub community.

3.1.6.3 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.

A total of 141 species of freshwater, estuarine, and marine fish have been documented within the northern portions of the Indian River Lagoon near KSC/CCAS (ECFRPC 1988). Of these, 65 species are considered commercial fish and 85 are sport fish and/or are fished commercially. One species known to inhabit the river, the rainwater killifish (*Lucania parva*), while not on the Federal or State threatened or endangered lists, has been listed by the Florida Committee on Rare and Endangered Plants and Animals, a group consisting largely of research biologists, as a "species of special concern," and by the Florida Natural Areas Inventory as "imperiled statewide" (ECFRPC 1991a).

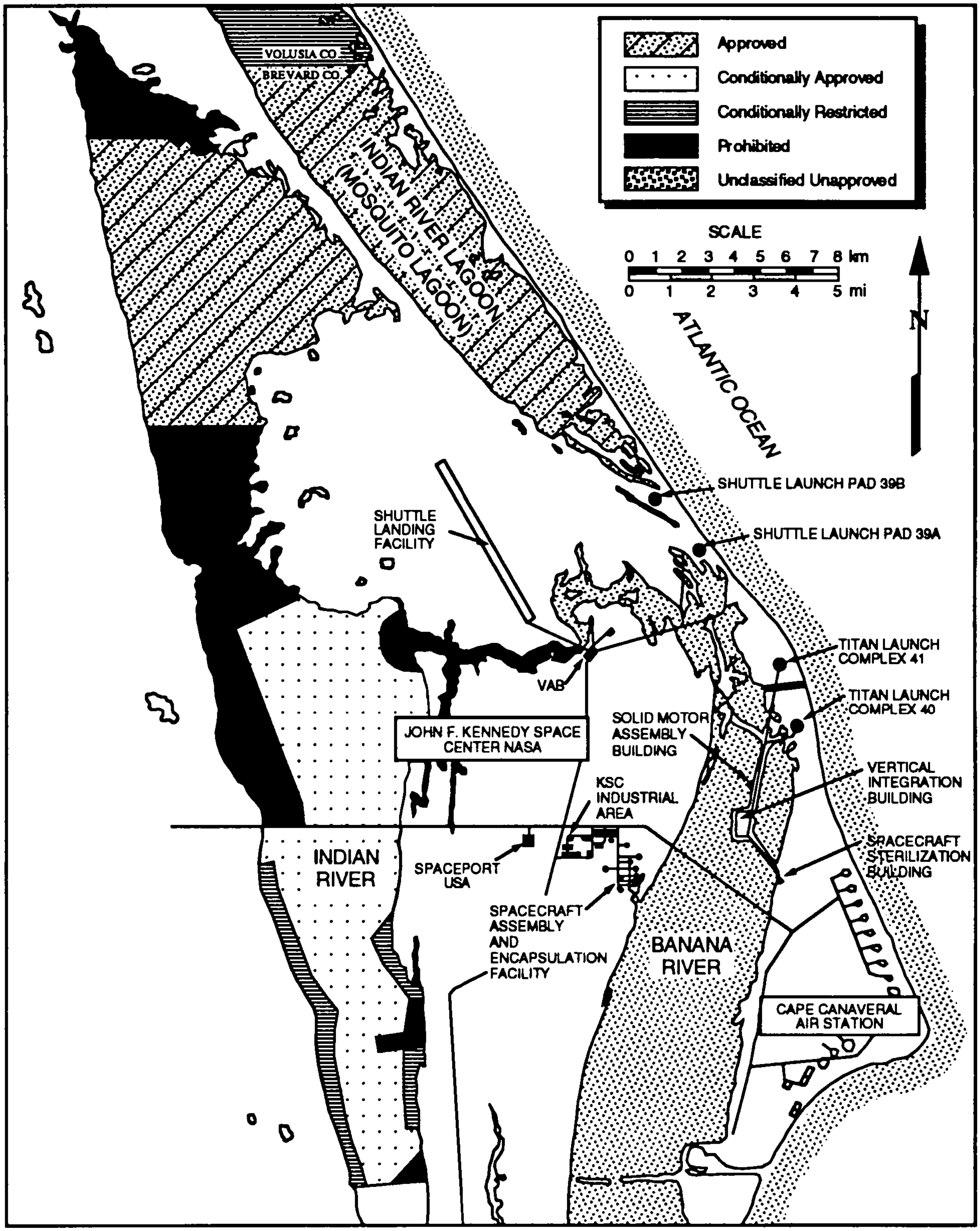
Shellfishing is an important component of the commercial and recreational fishing effort. In 1990, Brevard County produced 100 percent of the Florida east coast landings of calico scallops 392,656 kg (872,568 lb). Furthermore, Brevard County landings of clams accounted for 81.6 percent of the Florida east coast clam harvest. Volusia County accounted for 3.25 percent of clam landings off the Florida east coast (State of Florida 1990). Clams are taken primarily from tidal mud flat areas. Commercial fishing is an important economic asset to the region. Brevard County and Volusia County ranked second and fourth respectively, among the 12 east coast Florida counties in terms of 1990 finfish landings. Brevard ranked second in invertebrate landings (e.g., crab, clams, and oysters) and first in shrimp landings, with Volusia fifth in both categories (State of Florida 1990). Mosquito Lagoon is considered among the best oyster and clam harvesting areas on the east coast (NASA 1994). Figure 3-14 illustrates the shellfish harvesting areas in the vicinity of KSC/CCAS.

3.1.6.4 Endangered and Threatened Species

The Federal Government's Threatened or Endangered Species List, prepared by the U.S. FWS, currently recognizes 29 endangered or threatened species in this region. Another 63 species, including 30 plants, are being reviewed for possible listing. The State of Florida's list includes 53 species considered endangered or threatened. The Florida Committee on Rare and Endangered Plants and Animals gives endangered or threatened status to 60 species. The Florida Natural Areas Inventory includes 57 species in its top two most endangered categories. Roughly half of all the endangered and threatened species identified by these lists occurs in wetlands, principally estuarine environments; the other half depends on upland habitats (ECFRPC 1991b). No federally designated flora exist at CCAS, although coastal vervain (*Verbena maritima*), a dune species, has been reported on both CCAS and KSC and is being evaluated for listing as threatened. Prickly-apple cactus (*Cereus gracilis*), which is being considered for threatened status, may occur at KSC. Other species which have been reported at KSC and are being evaluated for listing as threatened include Curtiss reedgrass (*Calamovilfa curtissii*) which has been reported in the southern and central regions of KSC, and tampa vervain (*Verbena tampensis*) which occurs in disturbed areas adjacent to hardwood hammocks (NASA 1994).

Table 3-6 lists 21 federally protected wildlife species known to occur in the vicinity of CCAS/KSC. Table 3-6 contains seven endangered species, nine threatened species, and five that may be listed as threatened (NASA 1994). Table 3-6 also indicates the status of each of the federally listed species at CCAS/KSC (USAF 1990).

About 15 percent of the total U.S. population of the West Indian Manatee (*Trichechus manatus latirostris*) occurs in the waters bordering CCAS and KSC (NASA 1994). The following areas at CCAS/KSC have been designated as critical habitat for manatee by the FWS (see Figure 3-6): the entire inland section of the Indian River, the entire inland section of 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



Source: NASA 1994

FIGURE 3-14. SHELLFISH HARVESTING AREAS NEAR CCAS/KSC

TABLE 3-6. FEDERALLY LISTED THREATENED AND ENDANGERED FAUNA OCCURRING NEAR CCAS AND KSC

Common Name	Scientific Name	FWS	FGFWFC	FCREPA	Status at CCAS	Status at KSC
West Indian Manatee	*Trichechus manatus latirostris*	E	E	T	Re	Re
Southeastern Beach Mouse	*Peromyscus polionotus niveiventris*	T	T	NL	Re	Re
Florida Mouse	*Peromyscus floridanus*	C2	SSC	T	Re	Re
Round-Tailed Muskrat	*Neofiber alleni*	C2	NL	SSC	Re-possible	U
Bald Eagle	*Haliaeetus leucocephalus*	E	T	T	V	Re/Tr
Arctic Peregrine Falcon	*Falco peregrinus tundrius*	T	E	E	Tr	Tr
Wood Stork	*Mycteria americana*	E	E	E	Re	Re
Roseate Tern[a]	*Sterna dougallii*	T	T	T	N/O	R
Piping Plover	*Charadrius melodus*	T	T	SSC	V	V
Florida Scrub Jay	*Aphelocoma coerulescens coerulescens*	T	T	T	Re	Re
Bachman's Sparrow	*Aimophila aestivalis*	C2	NL	NL	V	R
Reddish Egret[b]	*Egretta rufescens*	C2	SSC	R	V	N
Atlantic Ridley Sea Turtle	*Lepidochelys kempi*	E	E	E	O/NN	O/NN
Loggerhead Sea Turtle	*Caretta caretta caretta*	T	T	T	O/N	O/N
Leatherback Sea Turtle	*Dermochelys coriacea coriacea*	E	E	R	O/N	O/N
Hawksbill Sea Turtle	*Eretmochelys imbricata imbricata*	E	E	E	O/NN	O/NN
Atlantic Green Sea Turtle	*Chelonia mydas mydas*	E	E	E	O/N	O/N
American Alligator	*Alligator mississippiensis*	T/(S/A)	SSC	SSC	Re	Re
Eastern Indigo Snake	*Drymarchon corais couperi*	T	T	SSC	Re	Re
Atlantic Salt Marsh Snake	*Nerodia fasciata taeniata*	T	T	E	N/O	Re
Gopher Tortoise	*Gopherus polyphemus*	C2	SSC	T	Re	Re

Sources: NASA 1994, USAF 1990

a. Rare migrant observed at KSC only.
b. KSC a major nesting area.

KEY:
FWS: U.S. Fish and Wildlife Service
FGFWFC: Florida Game and Freshwater Fish Commission
FCREPA: Florida Commission on Rare and Endangered Plants and Animals

E: Endangered
T: Threatened
T/(S/A): Threatened/similarity of appearance
SSC: Species of Special Concern
R: Rare
NL: Not listed
Re: Resident year-round
C2: Proposed listing as threatened

V: Visitor; does not nest at CCAS
Tr: Transient; occurs seasonally
N: Nesting
O/N: Occurs on beach or offshore; nests
O/NN: Occurs on beach or offshore; no nests
N/O: Not observed
U: Status undetermined

the normal needs of the survival of the species). On March 11, 1990, FWS established the waters of the Banana River from State Road 528 north to the NASA Parkway East causeway as a manatee refuge.

Loggerhead (*Caretta caretta caretta*), Atlantic green (*Chelonia mydas mydas*), and leatherback (*Dermochelys coriacea coriacea*) turtles use the beach areas at CCAS and KSC as nesting habitat. Nesting typically occurs between May and October (USAF 1990).

Populations of the southeastern beach mouse (*Peromyscus polionotus niveiventris*) are high at CCAS largely because of the amount of dune grassland habitat at the station (USAF 1990). Population studies in 1989 determined the beach mice population to be between 11,000 and 15,000 for all desirable habitats at CCAS. On KSC, the beach mice habitat narrows and the population density decreases (USAF 1990).

Arctic peregrine falcons (*Falco peregrinus tundrus*) use the dune habitat at CCAS for overwintering. In addition, a wood stork (*Mycteria americana*) rookery is located about 2 km (1.4 mi) northwest of Launch Complex 41 and about 4 km (2.8 mi) from Launch Complex 40 (USAF 1990). This rookery was abandoned in 1991. Florida scrub jays (*Aphelocoma coerulescens coerulescens*) use the scrub habitat in the vicinity of the complexes; nests have been observed 201 m (660 feet) away from Launch Complex 41. A 1988 survey estimated the entire CCAS scrub jay population to be between 900 and 1,800 birds, with a maximum of about 200 of these within a 0.6 km (0.4 mi) radius of Launch Complexes 40 and 41. Scrub jay populations at the Merritt Island National Wildlife Refuge appear to have declined in recent years, according to a recent survey that located about 3,600 birds versus 10,000 in earlier surveys (NASA 1994).

Approximately 20 nesting locations used by bald eagles (*Haliaeetus leucocephalus*) have been located at KSC. The nest area nearest to CCAS Launch Complexes 40 and 41 is about 10 km (6 miles) to the west, near the KSC industrial area (NASA 1994). Bald eagles are visitors at CCAS and do not nest year-round. In 1990, eight sites at KSC were active, and five eaglets were fledged. In 1991, five nests were active, and four eaglets were fledged (Busacca et al. 1991).

Osprey (*Pandion haliaetus*), listed by the Convention on International Trade in Endangered Species of Wild Flora and Fauna, were thought to be actively using 25 out of 54 possible nesting sites near KSC (NASA 1994). Eleven of the active nests were located on manmade structures. Between 1988 and 1990, the number of Osprey young produced on KSC ranged from 35 to 44 individuals (Busacca et al. 1991). The closest known nesting site is about 5 km (3.1 mi) south of Launch Complex 41.

Bobcats (*Lynx rufus*) are also listed by the convention on International Trade in Endangered Species of Wild Flora and Fauna. Bobcats are reportedly common in scrub, strand, and ruderal grass habitats at KSC (NASA 1994).

In addition to the 21 species listed in Table 3-6, FWS lists 5 species of whale as endangered:

- Finback (*Balaeroptera physalus*)
- Humpback (*Megaptera novaeangliae*)
- Northern right (*Eubalaena glacialis*)
- Sei (*Baeaenoptera borealis*)
- Sperm (*Physeter catodon*)

These whales occur in the coastal waters near CCAS. The National Marine Fisheries Services under the National Oceanic and Atmospheric Administration is proposing to designate a critical habitat area for the northern right whale (*Eubalaena glacialis*) pursuant to the Endangered Species Act. The habitat proposed for designation involves the water adjacent to the coast of Georgia and Florida, which includes the Cape Canaveral area (58 FR 29186).

3.1.7 Socioeconomics

3.1.7.1 Population

Major population centers within 97 km (60 mi) of KSC/CCAS include Orlando, Daytona Beach, Titusville, and Melbourne (see Figure 3-1).

The U.S. Census Bureau has designated three Metropolitan Statistical Areas (MSAs) within the region—Orlando MSA (Orange, Osceola, and Seminole Counties), the Daytona Beach MSA (Volusia County), and the Melbourne-Titusville-Palm Bay MSA (Brevard County) (ECFRPC 1991a). The population in Lake County, although growing faster than the State average, is split between many small- to medium-sized municipalities and rural areas.

The regional population grew at a faster rate from 1980 to 1990 than the State. The region grew by 49 percent (1,336,495 to 1,994,542); the State only grew by 32.7 percent (9,746,324 to 12,937,926). By the year 2000, it is anticipated that 2,575,400 people will be living in the region (a 29.1-percent increase) (ECFRPC 1991a). The population in Brevard County (the location of CCAS) for 1990 was 398,978, a 46.2-percent increase since 1980.

All counties are expected to experience population increases through the year 2000. Orange County is expected to remain the most populated county, growing to 843,600 in the year 2000 (a 24.5-percent increase from 1990), followed by Brevard County, with an increase to 533,600 (a 33.7-percent increase) (ECFRPC 1991a).

Of the approximately 2 million people in the region in 1990, about 86 percent were white, 11 percent black, 2 percent Native American/Eskimo/Aleut/Pacific Islander/Asian, and the remaining 1 percent not falling into any of the above racial categories (ECFRPC 1992b). About 6 percent of the total 1990 population was of hispanic origin (across all races). About 9 percent of the regional population (about 189,000 people) lived within 32 km (20 mi) of the Titan IV and Shuttle launch complexes at CCAS/KSC. The racial composition reflected the overall regional population as 88 percent white, 10 percent black and 2 percent falling into the remaining two categories. Hispanic representation was about 6 percent across all races. The uncontrolled population area nearest the launch complexes is about 16 km (10 mi) to the southeast, and contained less than 2 percent of the total regional population. Racial composition was approximately 97.5 percent white, 1.0 percent black and 2 percent divided amongst the remaining two categories; about 2 percent were of hispanic origin (across all races).

3.1.7.2 Economy

The region's economic base is tourism and manufacturing. Regional tourism now attracts more than 20 million visitors annually. Walt Disney World and Sea World, near Orlando, along with KSC, are among the most popular tourist attractions in the State (ECFRPC 1992a).

Economic sectors providing significant employment include services, with 301,300 employees (34.9 percent of total non-agricultural employment); retail trade, with 183,900 (21.3 percent); government, with 113,800 (13.1 percent); manufacturing, with 94,200 (10.9 percent); construction, with 48,300 (5.6 percent); finance and real estate, with 43,000 (5.0 percent); wholesale trade, with 41,200 (4.8 percent); and transportation and public utilities, with 38,000 (4.4 percent) (ECFRPC 1991a).

At the beginning of 1991, 984,434 people were employed in the region (863,800 non-agricultural and 120,634 agricultural). A total of 593,796 people were employed in Orange, Seminole, and Osceola Counties, 180,491 in Brevard, 153,720 in Volusia, and 56,427 in Lake (ECFRPC 1991a). The unemployment rate for the region at the beginning of 1991 was 6.6 percent (a 22-percent increase from the 1990 rate of 5.3 percent), with Lake County (8.2 percent) having the highest unemployment rate of the six counties within the region (ECFRPC 1991a).

The current employment pool at CCAS comprises military and civilian personnel, all associated with the U.S. Air Force. Military personnel are assigned to Patrick Air Force Base (PAFB), approximately 15 miles away from the duties they perform at CCAS. Most people employed on base are contractor personnel from companies associated with the missile testing and space launch operations. As of September 30, 1990, the total economic impact of PAFB on the region within a 50-mile radius of the base was estimated at $590,103,976. In addition, as of September 30, 1990, 4,281 secondary jobs were created within the region, and local employment, supported by annual expenditures to operate PAFB, was estimated at 16,425 (PAFB 1990).

At the end of September 1993, 18,253 personnel were employed at KSC. This population included contractor, construction, tenant, and permanent civil service employees (NASA 1994).

The 1990 median annual household income across the six-county region ranged from $7,237 to $76,232, with both ends of the range occurring in Orange County (ECFRPC Undated-b). Within 32 km (20 mi) of the launch complexes, the median income ranged from $10,940 to $55,606 with most of the census tracts within this area recording median incomes in excess of $25,000. At the nearest uncontrolled population area (16 km [10 mi]) from the launch complexes, the median income was $34,000.

3.1.7.3 Transportation

The region's road network includes five major limited access highways: Interstate 4, Interstate 95, Florida's Turnpike, the Spessard L. Holland East-West Expressway, and the Martin L. Andersen Beeline Expressway. In addition, numerous Federal, State, and county roads are located in the region (ECFRPC 1992a). Primary highways serving CCAS include Interstate 95, US-1, State Route (SR)-A1A, and SR-520. CCAS is linked to the highway system by the south gate via SR-A1A, NASA Causeway, and General Samuel C. Phillips Parkway (see Figure 3-3). Road access to KSC is from SR-3 and Phillips Parkway from the south, NASA Causeway (SR-405) and the Beach Road (SR-406) from the west, and Kennedy Parkway from the north. All roads to KSC have control access points which are manned 24 hours per day, seven days a week (NASA 1994).

Rail service for freight is available in all six counties, although passenger service is limited. Rail transportation in the KSC/CCAS area is provided by Florida East Coast Railway. A mainline traverses the cities of Titusville, Cocoa, and Melbourne. Launch Complexes 40 and 41 are serviced by a branch line from Titusville through KSC (see Figure 3-2).

The region has three major airports: Orlando International Airport, already the 43rd busiest airport in the world in number of passengers, Daytona Beach Regional, and Melbourne Regional (ECFRPC 1992a). Melbourne Regional Airport, the closest air transportation facility of the three, is located 48 km (30 mi) south of CCAS (see Figure 3-2). CCAS contains a skid strip used for Government aircraft and delivery of launch vehicles. Any air freight associated with the operation of Launch Complexes 40 and 41 arrives at the CCAS skid strip.

Port Canaveral, the nearest navigable seaport, has approximately 480 m (1,600 ft) of dockage available at existing wharf facilities.

3.1.7.4 Public and Emergency Services

A mutual agreement exists among the city of Cape Canaveral, KSC, and the range contractor at CCAS for reciprocal support in the event of an emergency or disaster (USAF 1990).

Health care in the region is provided at 28 general hospitals (6,600 beds total), 3 psychiatric hospitals, and 2 specialized hospitals. Medical services for CCAS are provided primarily at the Air Force Space Command Hospital at Patrick Air Force Base and at Wuesthoff Hospital and the Parrish Medical Center, which are both located outside of CCAS in the vicinity of Cocoa Beach. The two offsite hospitals have a total of 458 beds. CCAS is also equipped with a dispensary, which is located in the industrial area. The medical personnel at the dispensary are employed by a private company, under contract to NASA (USAF 1990). Medical services are provided at KSC by an occupational health facility and an emergency aid clinic.

Recreational facilities in the CCAS, which are for base personnel only, are located in the industrial and port areas and include a fitness center, softball field, picnic pavilion, a U.S. Navy service club, and a naval recreation facility. Cultural facilities on station include the Air Force Space and Missile Museum and the original NASA mission control, which are all located at the southern portion of the base. Off-base military and civilian personnel use recreational and cultural facilities available within the communities. A Visitor Information Center is located in the southwest portion of KSC. No public school facilities are present on CCAS/KSC (USAF 1990).

Nearly 90 percent of the people in the six-county region rely on public systems for potable water. CCAS obtains its potable water from the city of Cocoa water system under a contract and uses 11.3 million liters (3 million gallons) per day (USAF 1990). The Cocoa water system draws its supplies from the Floridan Aquifer. The onsite water distribution systems are sized to accommodate the short-term high-volume flows required by the launch deluge system. To support launches, the distribution system at CCAS was constructed to provide up to 30,000 gal/min for 10 min (USAF 1990). During a Titan IV launch, about 1.5 million liters (400,000 gal) of water are used by the deluge system, the OVSS, and pad washdown. In comparison, approximately 3.3 million liters (863,000 gal) of water are used for each Shuttle launch.

3.1.7.5 Historic/Archaeologic Resources

There are 81 sites within the region that are listed on the National Register of Historic Places (DOI 1991), 2 on the National Registry of Historic Landmarks, and 1 area (Emeralda Marsh) on the National Registry of Natural Landmarks (48 FR 8686).

An archaeological/historical survey of CCAS conducted in 1982 determined that Cape Canaveral has been inhabited for 4,000 to 5,000 years (USAF 1986). The survey located 32 prehistoric and historic sites and several uninvestigated historic localities. A midden site (Br 79) is located near the eastern edge of Launch Complex 39A (NASA 1979). All other recorded archaeological sites are located more than 2 km (1.2 mi) away from any of the launch sites under consideration. The initial results of the field survey indicated that many of the archaeological resources had been severely damaged by the construction of roads, launch complexes, powerlines, drainage ditches, and other excavation. Launch Pads 5, 6, 13, 14, 19, 26, 34, the mission control center at CCAS, and Launch Pads 39A and 39B at KSC are all listed on the National Register of Historic Places (DOI 1991).

3.2 GLOBAL ENVIRONMENT

This section provides a general overview of the global environment, including population distribution and density, general climatological characteristics, and surface type (i.e., ocean, rock, soil) and also briefly discusses the global atmospheric inventory of plutonium. The information provided for global demographics was extracted primarily from the *World Demographic Update Through 1990 for Space Nuclear System Safety Analysis*, prepared for the U.S. Department of Energy (Halliburton NUS 1992). This document used 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. Each of the cells covered an area of the Earth equal to 708,438 km^2 (273,528 mi^2).

3.2.1 Population Distribution and Density

Table 3-7 lists the distribution of the Earth's population across each of the 20 equal area latitude bands. Figure 3-15 illustrates the land-adjusted population densities within the latitude bands. These exhibits show that, with the exception of the four more southern latitude bands, the total population among the bands varies by about one order of magnitude. The greatest population densities (see Figure 3-13) occur in a relatively narrow grouping of the four northern bands between latitudes 17 and 44 degrees north (bands 4 through 7).

3.2.2 Climatology

Figure 3-16 illustrates the worldwide climatic types, which range from the perpetual frost of the polar climates to the dry desert climates.

3.2.3 Surface Types

The worldwide distribution of surface types is an important characteristic in considering the potential consequences of accident scenarios analyzed for the Cassini mission. Table 3-7 provides a breakdown of the total land fraction for each of the 20 equal area latitude bands noted previously. The total land fraction was further subdivided by the fraction consisting of soil cover and rock cover. For the most densely populated bands (bands 4 through 7), the land fraction varies from about 33 percent (band 7) to about 45 percent (band 4), with the soil fraction dominating (75 percent in band 4 to 92 percent in band 7).

3.2.4 Worldwide Plutonium Levels

Plutonium (Pu-238), used in the primary fuel for the Cassini spacecraft radioisotope thermoelectric generators (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 levels of plutonium in the environment. This information provides a perspective against which to compare the scope of postulated incremental releases of plutonium into the environment that could result from a Cassini mission accident.

During the period 1945 through 1974, above-ground nuclear weapons tests produced about 1.63×10^{16} Becquerels (Bq) (440,000 curies [Ci]) of plutonium in the environment (EPA 1977, AEC 1974). About 97 percent (about 1.59×10^{16} Bq [430,000 Ci]) 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 3.7×10^{14} Bq [10,000 Ci]) consisted primarily of Pu-238 (about 3.3×10^{14} Bq [9,000 Ci]), along with Pu-241 and Pu-242. (Some of the Pu-238 and -241 has decayed since the time of release.) Consequently, above-ground nuclear testing is the major source of worldwide plutonium distribution in the environment.

TABLE 3-7. LATITUDE BAND POPULATION AND SURFACE CHARACTERISTICS

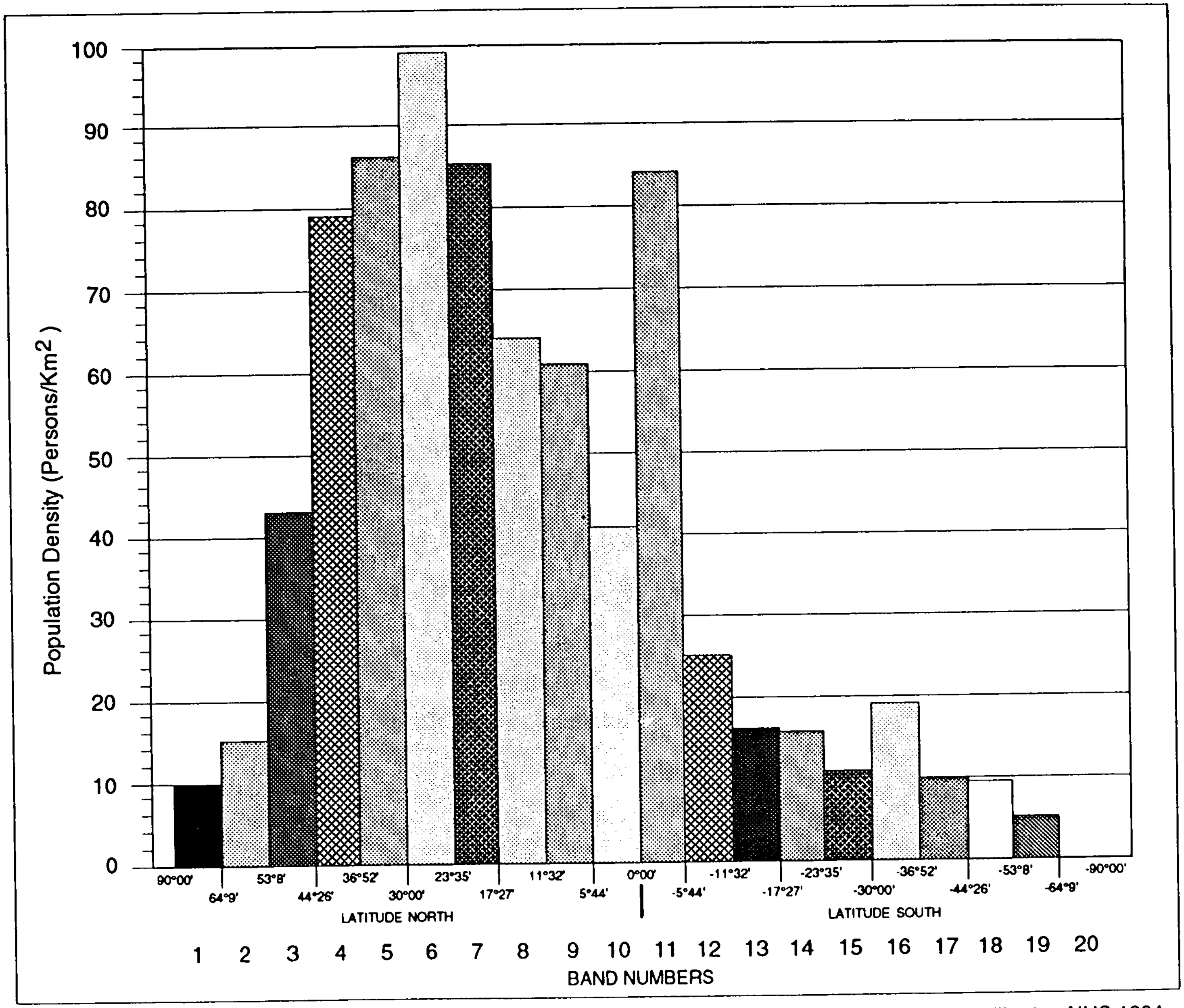
Latitude Band	Band Population[a]	Population Density,[b] Persons/km^2 (Persons/mi^2)	Band Surface Fractions			
			Water	Land	Land Rock Fraction	Land Soil Fraction
1	6.07×10^7	10.0 (3.86)	0.7332	0.2668	1.00[c]	0.0[c]
2	2.02×10^8	15.1 (5.83)	0.4085	0.5915	1.00[c]	0.0[c]
3	5.37×10^8	42.7 (16.49)	0.4456	0.5544	0.251[c]	0.749[c]
4	7.99×10^8	78.7 (30.39)	0.5522	0.4478	0.251	0.749
5	8.37×10^8	86.2 (33.28)	0.5718	0.4282	0.153	0.847
6	8.81×10^8	98.7 (38.11)	0.6064	0.3936	0.088	0.912
7	6.33×10^8	84.9 (32.78)	0.6710	0.3290	0.076	0.924
8	3.60×10^8	63.9 (24.67)	0.7514	0.2486	0.058	0.924
9	3.31×10^8	60.6 (23.90)	0.7592	0.2408	0.077	0.923
10	1.99×10^8	40.9 (15.79)	0.7854	0.2146	0.084	0.916
11	1.99×10^8	84.0 (32.43)	0.7630	0.2370	0.044	0.956
12	1.23×10^8	24.8 (9.58)	0.7815	0.2185	0.055	0.945
13	8.15×10^7	16.3 (6.29)	0.7799	0.2201	0.085	0.915
14	8.53×10^7	15.5 (5.98)	0.7574	0.2426	0.089	0.911
15	5.40×10^7	10.8 (4.17)	0.7796	0.2204	0.092	0.980
16	5.76×10^7	18.8 (7.26)	0.8646	0.1354	0.112	0.888
17	1.03×10^7	9.8 (3.78)	0.9538	0.0462	0.296	0.704
18	4.62×10^6	9.4 (3.63)	0.9784	0.0216	0.296[c]	0.704[c]
19	7.45×10^5	4.7 (1.81)	0.9930	0.0070	1.00[c]	0.0[c]
20	$< 10^3$	<0.1 (<.04)	0.3863	0.6137	1.00[c]	0.0[c]

Source: Halliburton NUS 1994a

[a] Represents 1990 level (Halliburton 1992).

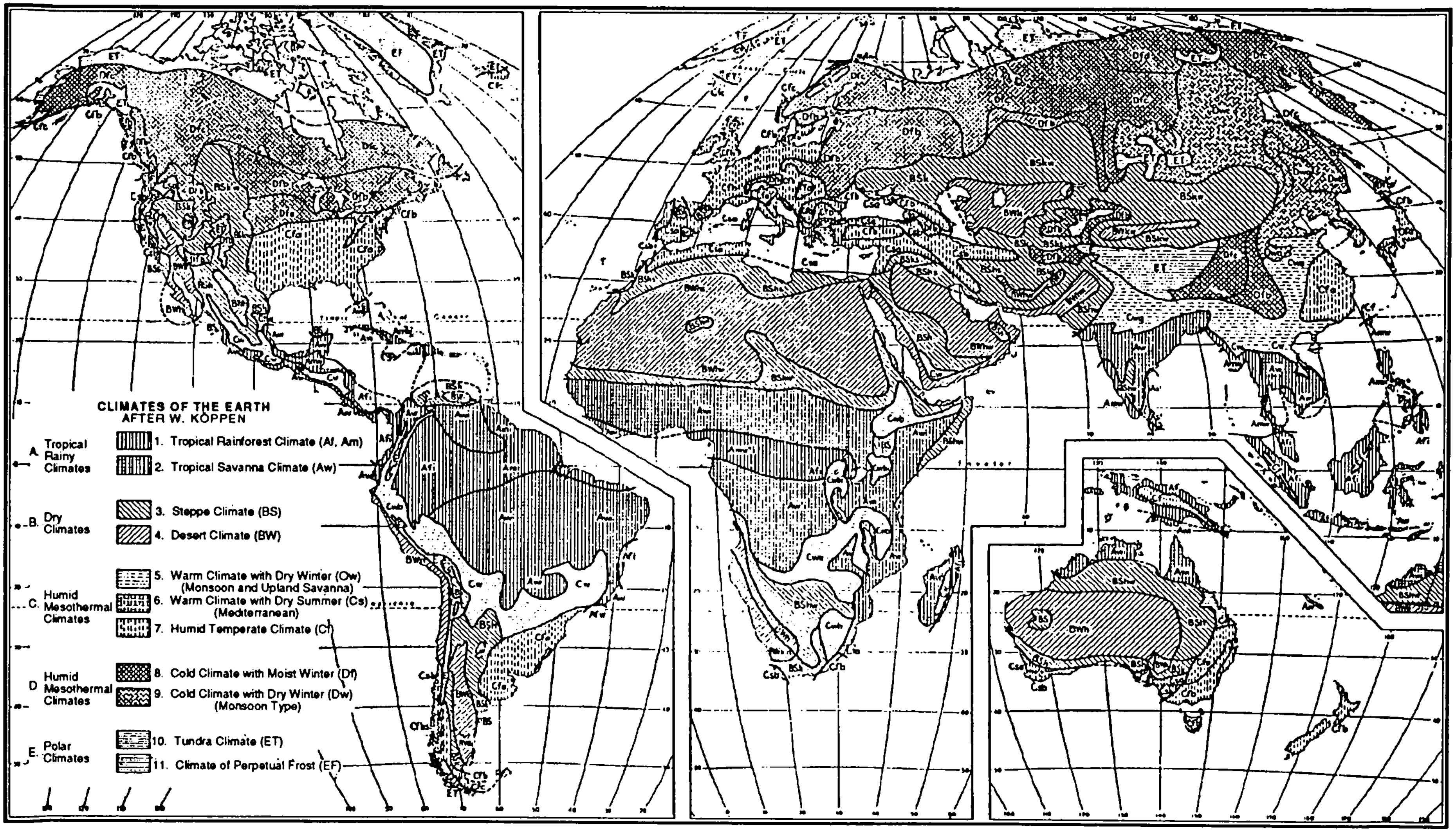
[b] Population density on land fraction (Halliburton NUS 1994a).

[c] Assumed values.



Source: Halliburton NUS 1994a

FIGURE 3-15. WORLD POPULATION (BAND LAND AREA) DENSITY BY LATITUDE BANDS



Source: NUS 1982

FIGURE 3-16. WORLDWIDE CLIMATES

Table 3-8 indicates that the Pu-238 in the atmosphere from weapons tests (about 3.3×10^{14} Bq [9,000 Ci]) was increased by the 1964 reentry and burnup of a Systems for Nuclear Auxiliary Power (SNAP)-9A RTG, which released 6.3×10^{14} Bq (17,000 Ci). This release into the atmosphere was consistent with the RTG design philosophy of the time. (Subsequent RTGs, including the RTGs on the Cassini spacecraft, have been designed to contain the Pu-238 fuel to the maximum extent possible, recognizing that there are mass and configuration requirements relative to the spacecraft and its mission that must be considered with the design and configuration of the power source and its related safety requirements.) Since 1964, essentially all of the SNAP-9A release has been deposited on the Earth's surface (AEC 1974). About 25 percent (approximately 1.5×10^{14} Bq [4,000 Ci]) of that release was deposited in the northern latitudes, with the remaining 75 percent settling in the southern hemisphere. In April 1986, approximately 3.7×10^{19} Bq (100,000,000 Ci) of various radioisotopes were released to the environment from the Chernobyl accident (NRC 1987). Approximately 3.0×10^{13} Bq (810 Ci) were Pu-238.

The heat source for the SNAP-27 RTG released from the Apollo 13 spacecraft during reentry survived impact and has been resting in one of the deepest areas of the Pacific Ocean, the Tonga Trench, with no evidence of any radioactive release (see Section 2.2.4.2).

The total plutonium released to the ocean environment by overseas nuclear reprocessing plants between 1967 and 1987 is approximately 7.4×10^{14} Bq (20,000 Ci) (IAEA 1976, NCRP 1987, UNSCEAR 1988). Assuming that 15 percent of the total was Pu-238 (based upon the 1980-85 fraction in Britain's Sellafield releases), about 1.1×10^{14} Bq (3,000 Ci) of Pu-238 have been added from these sources, bringing the total of Pu-238 dispersed into the environment up to about 1.1×10^{15} Bq (29,810 Ci).

TABLE 3-8. MAJOR SOURCES AND APPROXIMATE AMOUNTS OF PLUTONIUM-238 DISTRIBUTED WORLDWIDE

Sources	Amount (Becquerels [curies])
Atmospheric Testing 1945-74 Deposited near testing sites and worldwide	3.3×10^{14} (9,000)
Space Nuclear - SNAP-9A, 1964	6.3×10^{14} (17,000)
Overseas Nuclear Reprocessing Plants, 1967-1987	1.1×10^{14} (3,000) (estimated; see text)
Chernobyl Nuclear Power Station, 1986	3.0×10^{13} (810)
Total[a]	1.1×10^{15} (29,810)

Source: updated from DOE 1980

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

4. ENVIRONMENTAL IMPACTS

This section presents information on the potential environmental impacts of the Proposed Action, the 1999 mission alternative, the 2001 mission alternative, and the No-Action alternative, which were presented in Section 2. The impacts are examined for two areas, defined in Section 3 as the affected environment: 1) the regional area, including the six-county region surrounding Cape Canaveral Air Station (CCAS) and Kennedy Space Center (KSC) and 2) the global area.

The impacts that would be associated with the preparations for a normal launch of the Cassini spacecraft aboard the Titan IV expendable launch vehicle configured with either the conventional steel cased, 7-segment Solid Rocket Motors (SRMs), or the 3-segment graphite-composite cased Solid Rocket Motor Upgrades (SRMUs) have been addressed in previous U.S. Air Force (USAF) National Environmental Policy Act (NEPA) documentation (USAF 1986, USAF 1990). Additional NEPA documentation was prepared for the Titan IV activities in 1988 (USAF 1988a, USAF 1988b). The Tier 2 Galileo Environmental Impact Statement (EIS) (NASA 1989b), the Tier 2 Ulysses EIS (NASA 1990), the Kennedy Space Center (KSC) EIS (NASA 1979), and the KSC *Environmental Resources Document* (NASA 1994) were also used to prepare this section. The impacts associated with a normal Shuttle launch are well known and have been addressed in other NEPA documentation (NASA 1989b, NASA 1990).

Sections 4.1 (Proposed Action) and 4.2 (1999 mission alternative) describe the environmental impacts associated with launch and an Earth-gravity-assist (EGA) trajectory. Section 4.3 (2001 mission alternative) presents the environmental impacts for launch and a non-EGA trajectory, and Section 4.4 discusses the No-Action alternative.

4.1 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

The Proposed Action is to prepare for and implement the Cassini mission, launching the Cassini spacecraft on a Titan IV (SRMU or SRM)/Centaur. The primary opportunity is in October 1997 with contingency opportunities in December 1997 and in March 1999. The October 1997 primary launch opportunity would put the spacecraft on a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) to Saturn, and the secondary and backup opportunities would utilize Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectories.

Sections 4.1.1 through 4.1.3 address the impacts of a normal launch of the Cassini spacecraft onboard the Titan IV (SRMU or SRM)/Centaur launch vehicle. The impacts addressed for a normal launch would apply to any of the Proposed Action launch opportunities (i.e., primary, secondary, and backup). Section 4.1.4 discusses accidents involving nonradiological impacts for the Proposed Action. Sections 4.1.5 through 4.1.9 discuss the potential launch accidents that could result in a release of plutonium dioxide fuel from the Cassini radioisotope thermoelectric generators (RTGs) and the consequences of the accidents. These sections also address the possibility for both short- and long-term inadvertent reentries.

4.1.1 Environmental Impacts of Preparing for Launch

The Cassini Orbiter (i.e., the spacecraft without the Huygens Probe) would be assembled at the Jet Propulsion Laboratory (JPL) in Pasadena, California. The assembly consists of routine industrial activities and testing of spacecraft systems in JPL's Spacecraft Assembly Building. During assembly, the spacecraft would be inert (i.e., no propellants, pyrotechnics, RTGs, or RHUs would be onboard); therefore, no anticipated environmental impacts of any consequence would be associated with these activities.

Once assembly and testing is completed, the Orbiter would be delivered to the Payload Hazardous Servicing Facility (PHSF) at the KSC. The Propulsion Module Subsystem would be delivered separately first by its contractor to the Spacecraft Assembly and Encapsulation Facility (SAEF2) at KSC, where it would be fueled and pressurized before being delivered to the PHSF. The Huygens Probe would be assembled in Europe and transported by the European Space Agency (ESA) to the PHSF at KSC. At the PHSF, the entire spacecraft (including the RTGs, RHUs, and the High Gain Antenna from the Italian Space Agency) would be integrated and tested (JPL 1993d).

The RTGs would then be removed from the spacecraft and delivered to the RTG storage facility at KSC. The RTGs would later be integrated with the spacecraft on the launch pad, at either Launch Complex 40 or 41 at CCAS (JPL 1993d).

The RTGs and RHUs would be transported to KSC by the U.S. Department of Energy (DOE) from DOE's Mound Plant in Miamisburg, Ohio. Prior to final assembly at Mound, the RTGs would exist as separate components. The RTG and RHU manufacturing process is initiated at DOE's Savannah River Site in Aiken, South Carolina, where the plutonium dioxide used as fuel is chemically processed. The plutonium dioxide powder is then shipped from Savannah River to Los Alamos National Laboratories in New Mexico where the powder is formed into pellets suitable for use in the RTGs and RHUs. The pellets are encapsulated in iridium cladding (for the RTGs) or in platinum-rhodium cladding (for the RHUs) at Los Alamos and prepared for shipment to Mound Plant. The electrical units (the aluminum outer shell) used for the RTGs are assembled by Martin Marietta (formerly General Electric) in Pennsylvania. All components are shipped to Mound, where final assembly of the RTGs takes place. Final assembly of the RHUs occurs at Los Alamos. The impacts of these manufacturing activities have been addressed in existing DOE NEPA documentation, *Environmental Assessment for Radioisotope Heat Source Fuel Processing and Fabrication* (DOE 1991).

Industrial activities at CCAS associated with integrating the Cassini spacecraft with the Titan IV would involve the use of solvents to clean parts and tools. In compliance with the Clean Air Act (CAA) and the State of Florida permitting requirements, the USAF uses only appropriate chemicals for these activities. In addition, small quantities of hazardous waste generated by the pre-launch activities would either be recycled or disposed of properly.

Processing the launch vehicle prior to launch (e.g., receipt of components, inspection, storage, assembly, testing, and transport to the launch pad) would generate noise primarily in the Titan Integrate-Transfer-Launch (ITL) area (see Figure 3-3) and at

Launch Complex 40 or 41 (USAF 1990). Noise levels ranging from about 88 decibels A-weighted (dBA) to 100 dBA (at the source) would be generated by diesel locomotives and cranes involved in pre-launch activities. At a distance of about 120 m (400 ft), these levels would decrease to 55 to 70 dBA. Offsite populations would not be adversely affected by pre-launch noise, and workers at the ITL in and around these types of noise-producing activities would be protected by appropriate protective equipment.

The following activities are associated with preparations for the launch of the mission:

- Post-test spacecraft mechanical assembly; integration of RHUs with both the Orbiter and the Huygens Probe
- Integration of Huygens Probe to the Orbiter to complete the Cassini spacecraft
- Integration of the spacecraft with the Titan IV (SRMU or SRM)/Centaur at CCAS
- Installation of RTGs 2 to 4 days prior to launch
- Pre-launch activities at CCAS, including fueling of the Cassini spacecraft, Titan IV core launch vehicle, and Centaur and other activities up to Time Zero (T=0 s), when the SRMUs or SRMs are ignited and the launch vehicle with the Cassini payload begins to lift off from CCAS.

Pre-launch activities would take place primarily within the buildings of the Titan ITL (see Figure 3-3) area and at Launch Complex 40 or 41 (see Figure 3-4). These activities would result in the release of treated industrial and nonindustrial (sanitary) wastewaters from the Titan ITL area and Launch Complex 40 or 41. These releases would be subject to State of Florida permits and permit requirements. The treated nonhazardous wastewaters would be released to percolation ponds, where they would infiltrate the soils and eventually be transported toward the Banana River (USAF 1986, USAF 1988b, USAF 1990). Stormwater runoff at the ITL and at the launch complex would be collected and transported separately for release directly to the Banana River, under permit by the St. Johns River Water Management District. No substantial long-term impacts on surface water quality are expected from these pre-launch activities.

Prior to the launch, Aerozine-50 (a hydrazine-based fuel) and nitrogen tetroxide (written as NTO or N_2O_4) fuel vapors could escape during vehicle fueling or during filter changeout and system maintenance (USAF 1986, USAF 1988b, USAF 1990). The USAF designed and installed a fuel vapor incinerator system (FVIS) to collect and burn Aerozine-50 vapors resulting from bulk propellant transfer (e.g., Titan IV fueling). In addition, an oxidizer vapor scrubber system (OVSS) was designed to control NTO vapor releases. Air pollution permits have been granted for the FVIS and OVSS units at Launch Complexes 40 and 41 (Willard 1994).

Personnel would be potentially exposed to external radiation during the transportation and handling of the RTGs and RHUs before launch. Radiation exposure levels would be monitored to ensure that the doses were within acceptable limits and that installation procedures were carefully implemented so that the expected exposure levels would be as low as reasonably achievable and would not exceed 0.05 Sievert/yr (5 rem/yr).

Pre-launch activities associated with the Cassini mission would not adversely affect the terrestrial environment. These activities (e.g., receipt of components, storage, assembly, and testing) would take place primarily inside buildings within the ITL area.

In summary, completing preparations, including the pre-launch activities for the Cassini mission should not adversely affect either CCAS or the surrounding areas.

4.1.2 Environmental Impacts of a Normal Launch of the Cassini Spacecraft Using a Titan IV (SRMU or SRM)/Centaur

The environmental impacts that would be associated with a normal launch of the Cassini spacecraft on a Titan IV expendable launch vehicle with a Centaur upper stage, discussed in this section, are expected to be the same for any of the Proposed Action launch opportunities. The environmental impacts include potential impacts on land use, air quality, noise, water, biological resources, socioeconomics, and historical/archeological resources. This section also summarizes the impacts of radiation exposure.

The following subsections address the anticipated impacts associated with launch of the Cassini spacecraft onboard the proposed launch vehicle, the Titan IV expendable configured with two SRMUs, the latest strap-on solid rocket boosters, and a Centaur upper stage. Because NASA may decide at some point to use the conventional strap-on booster, the SRM, launch impacts using a Titan IV configured with the SRM are also addressed. As noted in Section 2.2.6, the two types of solid rocket motors are somewhat different with respect to characteristics that could affect the magnitude of anticipated impacts associated with a normal launch and with the accident environments that could impinge upon the spacecraft's three RTGs. These differences are briefly summarized in Table 4-1.

The differences between the two solid rocket motors are primarily quantitative differences in the anticipated impacts associated with a normal launch wherein the solid rocket motors and their exhaust products are the principal drivers. In that regard, the following discussions of normal launch impacts associated with the Proposed Action focus on the SRMU-equipped launch vehicle, followed by a relative comparison of the impacts that would be associated with use of the conventional SRM booster on the Titan IV.

4.1.2.1 Impacts on Land Use

The launch of the Cassini spacecraft from either Launch Complex 40 or 41 at CCAS would be entirely compatible with the uses designated for the Titan launch complex and CCAS (see Section 3.1.1). CCAS was established in the 1950s to provide launch, tracking, and support facilities for the Department of Defense (DOD), NASA, and other user programs (USAF 1986, USAF 1988b, USAF 1990). Launch Complexes 40 and 41 were constructed in 1963 and 1964 to support the launching of Titan boosters at CCAS (USAF 1990). Launch Complex 40, which has been used since 1964, was recently

TABLE 4-1. CHARACTERISTICS OF THE TITAN IV SRMU AND SRM

Characteristics	SRMU	SRM
Number of Segments	3	7
Type of Casing	Graphite fiber, with aluminum nose cone	Steel, with steel nose cone
Fuel Load (2 motors)	626,204 kg (1,380,000 lb)	536,364 kg (1,180,000 lb)
Type of Fuel	Hydroxyl terminated polybutadiene binder (HTPB) (88-89% solids—aluminum and ammonium perchlorate)	Polybutadiene acrylonitrile binder (PBAN) (84% solids—aluminum and ammonium perchlorate)
Lift Capacity	22,680 kg (50,000 lb) to LEO; 5,773 kg (12,700 lb) to geosynchronous orbit	18,140 kg (40,000 lb) to LEO; 4,545 kg (10,000 lb) to geosynchronous orbit
Exhaust Emissions (% by weight)		
Aluminum oxide (Al_2O_3)	35.88	30.45
Carbon monoxide (CO)	21.93	27.50
Carbon dioxide (CO_2)	2.49	2.97
Chloride (Cl_2)	0.25	0.05
Iron chloride ($FeCl_2$)	0.00	0.39
Hydrogen chloride (HCl)	21.14	20.67
Hydrogen (H_2)	2.21	2.48
Water (H_2O)	7.69	6.97
Nitrogen (N_2)	8.34	8.50
Nitrogen oxides (NO_x)	<0.01	<0.01

Sources: USAF 1990, JPL 1994a

graded along with Launch Complex 41 to handle the Titan IV launch vehicle equipped with the heavier, more powerful SRMU (USAF 1990). Launch Complex 41 was used for Titan launches from 1964 to 1977. Reactivated in 1986, it was upgraded specifically to accommodate Titan IV launches (USAF 1986) with additional upgrading to accommodate the Titan IV (SRMU) combination (USAF 1990). The launch of the Cassini spacecraft from either Launch Complex 40 or 41, therefore, would not impact existing land uses, nor would it adversely affect or preclude any planned future uses of the Titan launch complexes at CCAS.

The impacts on land use would not vary between an SRMU- or an SRM-equipped Titan IV launch vehicle.

4.1.2.2 Impacts on Ambient Air Quality

Impacts to ambient air quality would arise largely from the exhaust cloud formed near the launch pad in the first few seconds after SRMU's ignition at T = 0 seconds. The cloud will consist of the SRMU exhaust products released primarily during the first 6 or 7 seconds after ignition (USAF 1990). It is during this period when the launch vehicle would be slowly lifting off the launch pad and emitting more SRMU exhaust products per unit distance traveled than at any other time during the launch of the Cassini spacecraft. After the first 10 seconds (T + 11 seconds), the vehicle would have cleared the launch site and would be accelerating rapidly away. For the purposes of this EIS, it is conservatively assumed that the first 10 seconds of SRMU burn is the principal contributor to the exhaust cloud. Table 4-2 provides estimates of the amount of SRMU fuel (and SRM fuel) typically burned over time increments extending from ignition at T = 0 seconds to the end of the SRMU burn at T + 146 seconds at which time the SRMU casings would be jettisoned. (The SRM burn would be complete at T + 126 seconds, at which point the SRM cases would be jettisoned.)

Looking at only the first 10 second time interval (0 to 10 s), a total of about 51,469 kg (113,232 lb) of solid propellant would have been burned by the two SRMUs in lifting the launch vehicle and its Cassini payload clear of the launch site. Using the typical composition of SRMU exhaust products listed in Table 4-1, the amount of each product produced in the first 10 seconds after ignition can be approximated as follows:

• Al_2O_3	18,467 kg	(40,627 lb)
• CO	11,287 kg	(24,831 lb)
• CO_2	1,282 kg	(2,820 lb)
• Cl_2	129 kg	(284 lb)
• HCl	10,880 kg	(23,937 lb)
• H_2	1,137 kg	(2,501 lb)
• H_2O	3,958 kg	(8,708 lb)
• N_2	4,293 kg	(9,445 lb)
• NO_x	<5 kg	(<11 lb)

TABLE 4-2. TYPICAL WEIGHT HISTORIES OF SOLID PROPELLANT EXPENDED—SRMU AND SRM

Elapsed Time (s)	SRMU Propellant Expended[a]		SRM Propellant Expended[a]	
	kg	(lb)	kg	(lb)
0	0	(0)	0	(0)
0-10	51,469	(113,232)	50,916	(112,016)
10-20	55,506	(122,114)	60,301	(120,601)[b]
20-25	28,433	(62,552)[b]	32,037	(70,482)
25-50	137,746	(303,042)	130,826	(287,818)
50-80	134,122	(295,068)	122,414	(306,036)
80-90	43,457	95,606	40,414	(88,910)
90-116	110,688	(243,513)[b]	90,904	(199,988)
116-126	37,405	(82,291)[b]	7,061	(15,534) [burn complete]
126-130	13,915	(30,612)[b]	Jettisoned	
130-135	8,542	(18,792)[b]	----	
135-146	11,081	(24,378)[b] [burn complete]	----	
	Jettisoned		----	

Source: Martin Marietta 1989, Martin Marietta 1992

---

a. Subject to conventional rounding.

b. Interpolated values.

These products found in the exhaust cloud are the principal contributors to local impacts on ambient air quality following a Titan IV launch. The USAF provided extensive discussion of the exhaust cloud and its impacts on air quality in its 1990 Environmental Assessment (USAF 1990) which are summarized here. It can be readily seen from Table 4-1 and the above that hydrogen chloride (HCl), aluminum oxide particulates (Al_2O_3), and carbon monoxide (CO) are the principal constituents of the SRMU exhaust, and in turn, the exhaust cloud.

The cloud would be characterized by high concentrations of exhaust products near the pad (e.g., the USAF has estimated HCl and Al_2O_3 at several thousand ppm), as well as by high heat and thermal and mechanical turbulence. Under most wind conditions, the exhaust cloud would begin to rise about 1 minute after SRMU ignition, or at a distance of about 0.5 km (0.3 mi) from the launch pad (USAF 1990). As the exhaust cloud rises, the concentrations would drop rapidly due to the turbulent mixing of the buoyant plume and deposition of larger particles and droplets containing HCl scrubbed from the exhaust cloud, along with aluminum oxide particulates (Al_2O_3) on the launch complex. Measurements of a Titan III exhaust cloud at an altitude of 0.5 km (1,640 ft) and at a distance of 0.5 km (0.3 mi) away from the launch pad, yielded peak levels of HCl of 42.6 mg/m^3 (28 ppm). Allowing for the larger SRMU on a Titan IV, the USAF estimated that HCl concentrations would exceed 224 mg/m^3 (150 ppm) within 0.6 km (0.4 mi) of the launch pad (USAF 1990).

The HCl in the SRMU exhaust would be largely in a dry form (i.e., the principal source of water for dissolution of the HCl would be from the deluge water and the moisture content of the ambient air; the water vapor emissions from the Titan IV main engines would not be a factor until T + 135 seconds when the Stage 1 engine ignites). Some of the HCl would be converted to hydrochloric acid through mixing with the portion (about 300,000 l [80,000 gal]) of deluge water vaporized by the heat of the SRMU exhaust. The larger droplets of the HCl aerosol would tend to quickly rain out of the exhaust cloud near the launch pad. Biological monitoring of a 1989 Titan IV launch (using conventional SRMs) at Launch Complex 41 determined that no wet deposition fell outside the perimeter fence, located about 183 m (about 600 ft) from the center of the launch complex. Because the SRMU would burn only slightly more fuel in the first 10 seconds than the conventional SRM (Table 4-2), it is reasonable to assume that the area of acid deposition from an SRMU launch should be about the same as that determined for the earlier launch from Launch Complex 41.

The exhaust cloud would rise and mix with the ambient air, further reducing the ambient concentrations, and the cloud would begin to disperse while being transported downwind. If offshore land breezes (toward the Atlantic Ocean) are in effect at the time Cassini would be launched, they would tend to push the exhaust cloud out over the ocean. This would generally be the case with an early morning launch. If, however, the land breezes were not blowing at the time of launch during any of the Proposed Action launch opportunities (primary—October 1997, secondary—December 1997, backup—March 1999), seasonal prevailing winds (Figure 3-7) could tend to push the cloud back over land.

Conservative USAF modeling of HCl concentrations (assuming all HCl in the exhaust was gaseous with no reduction in levels from droplet fallout near or on the launch pad) has estimated that at distances beyond about 0.6 km (0.4 mi) the concentrations of HCl would drop rapidly to about 18.2 mg/m^3 (12 ppm) at 5 km (3.1 mi) from the launch pad (USAF 1990). As a means of comparison, the National Research Council Emergency Exposure Level for worker populations is 30.4 mg/m^3 (20 ppm) for continued performance of tasks under emergency conditions for periods lasting from 1 to 24 hours (AIHA 1989). The National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) have an exposure ceiling limit of 7 mg/m^3 (5 ppm) for worker populations. The 1-Hour, Short-Term Public Emergency Guidance Level for the public recommended by the National Research Council is 1.52 mg/m^3 (1 ppm) for HCl.

Using the Rocket Effluent Exhaust Dispersion Model (REEDM), the USAF estimated the ground-level concentrations beyond the CCAS property boundary of HCl and particulates (Al_2O_3) emitted from a Titan IV (SRMU) launch using meteorological scenarios typically encountered at CCAS (USAF 1990). The exhaust concentrations were developed for the conventional SRM and then scaled up for the larger SRMU. The REEDM predicted that the maximum HCl concentrations at the nearest uncontrolled area, about 12 km (7.5 mi) from the launch pad would, for each of the meteorological scenarios modeled, be well below the 1-Hour, Short-Term Public Emergency Guidance Level of 1.5 mg/m^3 (1.0 ppm) recommended by the National Research Council. The highest 1-hour concentration in offsite areas was predicted to be 0.33 mg/m^3 (0.22 ppm) (summer, light wind scenario) (USAF 1990).

Acidic precipitation would be possible if rain showers occur in the area shortly after launch, with rain falling through the exhaust cloud containing high concentrations of HCl. One such event was recorded in 1975 following the launch of a Titan III from CCAS (USAF 1990). In this instance, rain showers fell through the exhaust cloud resulting in acidic precipitation of pH = 1 about 5 km (3.1 mi) from the launch site. At a distance of about 10 km (6 mi), the pH had risen but was still very acidic at a pH = 2. (A pH of 7 is neutral.) Such an event is not expected with launch of the Cassini spacecraft. Current launch rules preclude launches when rain clouds are in the launch area.

The emissions of the other dominant exhaust products, particulates (Al_2O_3) and CO, are not expected to result in any substantial impact on the local environment. Release of these materials to the atmosphere by factories and other stationary sources is regulated under the Clean Air Act (CAA). The CAA regulations are designed for stationary sources that emit pollutants on a continuous basis. Thus, a comparison of a Titan launch, which emits exhaust products from a rapidly moving rocket constantly gaining altitude, with CAA emissions standards is useful, but should be viewed with these limitations in mind. EPA has established National Ambient Air Quality Standards (NAAQS) for emissions from stationary sources including particulates, CO and NO_x. The NAAQS for particulates and CO can be used to gauge the effects of a Titan IV (SRMU) launch on ambient air quality.

Estimation by the U.S. Air Force, using the REEDM model, of the maximum particulate levels in downwind areas at distances beyond the nearest CCAS property line, 12 km (7.5 mi) from the launch site (USAF 1990) also indicated that the NAAQS for particulates would not be exceeded. The respirable particulate (e.g., PM-10) levels estimated by the Air Force were 0.025 mg/m^3 (25 μg/m^3), substantially below the NAAQS f 0.15 mg/m^3 (150 μg/m^3). The Air Force analysis further assumed that if all the particulates generated by the Titan IV (SRMU) were in the respirable size range, and occurred at a time when the highest recorded ambient total particulate levels in the Titusville/Merritt Island area were also occurring (104 μg/m^3 in 1986), the maximum predicted respirable particulate concentration would be 129 μg/m^3, still below the NAAQS for respirable particulates.

While the Air Force did not model carbon monoxide emissions, useful comparisons can be made with the air emissions modeling performed for what would have been NASA's Advanced Solid Rocket Motor (ASRM) (NASA 1989a). Although the ASRM program has been discontinued, modeling of the air quality impacts of a 2-minute static test firing of a single fully-fueled ASRM (544,218 kg [1.2 million lb] of HTPB fuel) using the same formulation fuel as the SRMU, indicated that on a time-averaged basis, neither the NAAQS for CO (40 mg/m^3 [35 ppm] averaged over 1 hour) or respirable particulates (150 μg/m^3 averaged over 24 hours) would have been exceeded in offsite areas. Given that the fuel inventory of the single ASRM would have been only slightly less than that of two SRMUs, when combined with the fact that the SRMUs would emit ground-level exhaust products for only a few seconds versus the 2-minute ASRM static test ground-level releases, it is reasonable to assume that launch of the Cassini mission would result in CO or particulate levels well below the respective NAAQS standards. In fact, if one were to compare the total exhaust emissions from an SRMU-equipped Titan IV to the troposphere (i.e., to an altitude of about 10 to 15 km [about 33,000 to 49,000 ft] attained in about 50 seconds by the SRMU-equipped Titan IV), it can be determined from Table 4-2 that the SRMU would burn about 77 percent less fuel than the ASRM static test. Thus, using the same time-weighting approach, it would also be reasonable to assume that the SRMU-equipped Titan IV exhaust would not reach the CO or particulate NAAQS throughout the entire troposphere.

Therefore, the launch of the Cassini spacecraft onboard the Titan IV (SRMU)/Centaur would not have an adverse impact on air quality in offsite areas and, in fact, would be well below the NAAQS standards for stationary sources. In addition, meteorological conditions would be monitored prior to launch, with site-specific models used to predict areas where rocket exhaust emissions could potentially reach adverse levels for on-base and off-base populations. These evaluations would affect the decision to launch on a given day.

Given that an SRM-equipped Titan IV would burn slightly less fuel than an SRMU-equipped Titan IV in the first 10 seconds after ignition (Table 4-1), and considering the differences in the fuel formulations and exhaust products (Table 4-1), the exhaust cloud would be somewhat smaller, with about the same amount of HCl (10,524 kg [23,153 lb]) as the SRMU exhaust cloud (10,880 kg [23,937 lb]). The amount of carbon monoxide would be about 24 percent greater, while particulate levels would be about 16 percent less. Thus, overall, there should be little difference in impacts on ambient air quality if an SRM-equipped Titan IV is used to launch Cassini.

When viewed in the context of other launches and ongoing operations at CCAS, Cassini would be one contributor to air emissions generated at CCAS, as well as in the region. On a cumulative basis, the relatively short-term Cassini launch event would not substantially affect the long-term air quality in the region.

4.1.2.3 Impacts on the Upper Atmosphere

As the launch vehicle trajectory passes through the atmospheric layers, the exhaust emissions from the solid rocket motors, the Titan IV main engines and the Centaur will be distributed along the flight path into the upper atmosphere. The SRMU's emission products were previously discussed in Section 4.1.2.2. The Titan IV liquid-fueled main engines emit predominately 41-percent N_2, 35-percent water, and 18-percent CO_2, with the remaining 6 percent consisting of CO, molecular hydrogen (H_2), molecular oxygen (O_2), and even smaller amounts of NO_x and hydroxide ion (OH^-). The Centaur main engine exhaust consists primarily of water because the fuel is liquid oxygen and liquid hydrogen (Martin Marietta 1992).

The impacts of concern from the emissions of solid- and liquid-rocket propellants into the upper atmosphere include the potential effects of the exhaust gases on regional weather, global warming, and the incremental contribution of these emissions to ozone (O_3) depletion. The types and magnitudes of potential effects are all very small but differ depending on which atmospheric layer they are deposited in (AIAA 1991). NASA continues to pursue an intensive research program to evaluate the impacts of high-altitude aircraft on the upper troposphere and the lower stratosphere. This research will ultimately help to further assess the effects of launch exhaust plumes in this region of the atmosphere and their respective impacts (AIAA 1991).

Measurements of the effects of rocket exhausts on the upper atmosphere are sparse and difficult to conduct; therefore, models are commonly used to predict the potential effects. The accuracy of the models is limited by the difficulty in modeling simultaneous and complex chemical reactions concurrently with three-dimensional stratospheric transport effects. Two-dimensional models usually characterize the chemistry more accurately than the atmospheric transport and circulation effects; three-dimensional models are more accurate in predicting transport effects but less comprehensive in assessing chemical effects (i.e., they generally include fewer constituents and less complex chemistry). Current research in this area is focused on the inclusion of heterogeneous phase chemistry in three-dimensional models to obtain better resolution of atmospheric chemical and transport processes in model studies. At the current time, however, this research is incomplete and the results are inconclusive. It is anticipated that the incorporation of these techniques in the numerical models will improve the ability of the models to more accurately simulate and thus better support the current observational stratospheric data sets (Jackman 1994, AIAA 1991).

When evaluating the potential effects of rocket exhaust on the environment, it is important to understand that the effects differ depending on the atmospheric layer where the emissions occur (AIAA 1991). The Earth's atmosphere can be considered a sequence of strata, with boundaries defined by the relative temperature differentials among them. The principal layers of interest would be the troposphere and the stratosphere, as discussed in Section 3.1.2.1. Spacecraft launches are initiated within the troposphere (where the exhaust cloud is formed). Section 4.1.2.2 addresses ambient air impacts in this layer. In the troposphere, the operation of solid rocket motors could affect local or regional climatic patterns. In the stratosphere, the potential reduction in the ambient concentration of ozone is a concern.

Effects of Exhaust Gases on the Troposphere

The troposphere is the portion of the atmosphere that most affects the incoming sunshine and outgoing thermal (infrared) radiation from the Earth's surface. In the troposphere, the presence or absence of clouds, either from natural processes or from artificial cloud "seeding" (nucleation), has a major climatic effect. Cloud formation may be initiated or enhanced by the presence of cloud condensation nuclei (CCN) from rocket exhaust products. Water droplets condense around CCN particles to form clouds and later precipitation.

The total amount of SRMU exhaust products emitted to the troposphere (including the exhaust cloud) can be approximated from Table 4-2 by summing over the time interval from T = 0 seconds to the 20 to 25-second interval (total = 273,154 kg [600,946 lb]). The SRMUs would release both particulates (e.g., Al_2O_3 and soot) and gases (e.g., CO, HCl, Cl_2, H_2, water vapor [H_2O], trace hydrocarbons, and NO_x) that could affect the troposphere (AIAA 1991). Table 4-3 provides a breakdown of the total SRMU emissions to the troposphere (including the exhaust plume), by constituent, using the weight percentages found in Table 4-1. Launch vehicle exhaust trails, specifically the Al_2O_3 particulates and soot, could possibly trigger some cloud formation (like "contrails" from high-altitude aircraft). The Al_2O_3 and soot particles could act as CCN in atmospheric layers with low levels of CCN. It has been postulated that under a highly aggressive and ambitious Shuttle launch program (e.g., 52 launches per year), the concentration of CCN in the northern hemisphere's upper troposphere would approximately double (Turco et al. 1982). An increase of this magnitude could lead to increased cloud cover, increased precipitation, and decreased incoming solar radiation (AIAA 1991). Since launches would occur infrequently, normal atmospheric processes such as transport and wet and/or dry deposition could serve to reduce local concentrations of CCN. Thus, no long-term modifications in local weather patterns are expected to be caused by launch vehicle operation.

The Earth's unique ability to capture a high percentage of the outgoing long-wavelength surface radiation has typically been referred to as the greenhouse effect. Atmospheric gases capable of inhibiting the transmission of long-wavelength radiation are generally referred to as greenhouse gases. The most effective greenhouse gas is water vapor (H_2O) because of its abundance in the free troposphere and its relatively broad absorption window, which allows water vapor to absorb energy in both the low- and high-energy bands of the infrared spectrum. Carbon dioxide is the second most important greenhouse gas, primarily because of its lower concentration and narrow infrared absorption window. Additional atmospheric trace gases that are considered greenhouse gases include methane, NO_x and assorted chlorofluorocarbons.

TABLE 4-3. SRMU EXHAUST CONSTITUENTS EMITTED TO THE TROPOSPHERE (INCLUDES EXHAUST PLUME)

SRMU Constituent	Amount Emitted	
	kg	(lb)
Al_2O_3	98,008	(217,378)
CO	59,903	(131,787)
CO_2	6,802	(14,964)
Cl_2	683	(1,503)
HCl	57,745	(127,039)
H_2	6,037	(13,281)
H_2O	21,006	(46,213)
N_2	22,781	(50,118)
NO_x	<27	(<59)

With respect to use of an SRM-equipped Titan IV to launch Cassini, it can be determined by comparing the 0 to 50 second emissions of the SRM with those of the SRMU (Table 4-2), that the SRM would emit slightly more solid rocket exhaust products to the troposphere (274,080 kg [602,976 lb] vs. 273,154 kg [600,946 lb] for the SRMU). Because the SRM fuel formulation is different from the SRMUs, the exhaust product composition is somewhat different also (Table 4-1). Applying the percent composition against the total weight of SRM fuel burned in the troposphere, it can be determined that the amount of Al_2O_3 particulates from the SRM would be about 15 percent less. Thus, CCN particles would be less with an SRM, and there would be less tendency for cloud formation in the SRM exhaust trail. The levels of greenhouse gases (CO_2 and H_2O) would also vary, with the SRM producing about 20 percent more CO_2, but about 9 percent less water than the SRMU. Overall, the impacts of SRM exhaust gases on the troposphere would not vary greatly from those produced by the SRMU.

Because the Cassini launch would be a singular input of pollutants into the free troposphere; it is not expected to have a substantial long-term impact on global climate. The two main greenhouse gases (CO_2 and H_2O) generated by the Cassini launch are believed to only contribute minutely to global warming. The amount of CO_2 deposited in the atmosphere by rocket launches is approximately 4×10^{-5} percent of all anthropogenic CO_2 and only 5×10^{-7} percent of total CO_2 production, including natural sources (AIAA 1991). Additionally, another study showed that Shuttle launches were responsible for adding approximately 8×10^{7} kg/yr (17.6×10^{7} lb/yr) of water to the troposphere while natural processes in the tropics account for the input of 1×10^{12} kg/yr (2.2×10^{12} lb/yr) of H_2O (Wayne 1991). Therefore, the overall contribution of chemical rocket engines to global warming is probably negligible.

Effects of Exhaust Gases on the Stratosphere

The stratosphere is the main ozone production region of the Earth. The ozone in the stratosphere effectively absorbs incoming ultraviolet (UV) radiation so that the majority of radiation with wave lengths shorter than 300 nanometers does not reach the Earth's surface. In the stratosphere, the primary concern associated with launches is the potential incremental effects of these exhaust gases on the ozone layer. Ozone levels vary widely and cyclically; they vary by up to 10 percent daily, up to 50 percent seasonally and latitudinally, and up to 1 percent annually. Eleven-year cycles in ozone levels, which coincide with Sun spot cycles, also occur. The recent trend in global O_3 levels is a 2 to 3 percent decrease in the last 11 years. This is occurring at an average rate of 0.2 to 0.8 percent per year, depending on the season of measurement. Ozone levels over the Antarctic are decreasing much more rapidly, averaging 3 percent per year (Stolarski et al. 1991).

The concentration of O_3 at a given location is a function of the chemical processes that control the production and destruction of O_3 and of stratospheric O_3 transport processes. Production of O_3 within the stratosphere is controlled by the photodissociation of molecular O_2. However, the destruction of ozone is driven by various photochemical processes, which generally involve some type of catalytic process. Thus, ozone is constantly being created and destroyed within the stratosphere. This results in a dynamic, nonlinear balance between O_3 chemistry and the mean stratospheric O_3 circulation (AIAA 1991).

The presence of compounds formed directly or indirectly from rocket exhaust can decrease levels of O_3 in the immediate vicinity of the rocket exhaust plume. These compounds include HCl, Cl_2, H_2, and H_2O (Harwood et al. 1991). NO_x can also influence O_3 degradation (AIAA 1991). The total amount of SRMU exhaust products emitted to the stratosphere can be estimated from Table 4-2, by summing over the time periods from 50-80 seconds to the end of burn at T + 146 seconds. The composition of these emissions, using the percentages in Table 4-1, is provided in Table 4-4.

The destruction process primarily associated with the use of SRMs involves chlorine (Cl_2), where a single chlorine atom could be causal in the destruction of hundreds of ozone molecules through the breakdown of O_3 into chlorine monoxide (ClO) and oxygen (O_2). Subsequently, the ClO can be further dissociated into free chlorine and oxygen. Thus, an important consequence of this catalytic process is that the chlorine is not removed from the stratosphere during these two reactions; it remains free to continually react with other atmospheric species before being removed from the stratosphere. Certain chlorine compounds are predicted to remain in the upper atmosphere for 2 to 3 years before being removed by natural processes (AIAA 1991).

TABLE 4-4. SRMU EXHAUST CONSTITUENTS EMITTED TO THE STRATOSPHERE

SRMU Constituent	Amount Emitted	
	kg	(lb)
Al_2O_3	128,885	(283,547)
CO	78,775	(173,305)
CO_2	8,944	(19,677)
Cl_2	898	(1,975)
HCl	75,937	(167,061)
H_2	7,939	(17,466)
H_2O	27,623	(60,771)
N_2	29,958	(65,908)
NO_x	<36	(<79)

Numerous studies have been conducted to assess the effects of chlorine from launch vehicle exhausts on stratospheric ozone levels. The studies have attempted to evaluate the localized, regional, total column, and global impacts on O_3 levels. Local impacts were found to be large but of short duration. Measurements of ozone levels within the exhaust trail of a Titan III SRM at an altitude of 18 km (59,058 ft) taken 13 minutes (780 seconds) after launch showed a 40-percent reduction in ozone concentrations (Harwood et al. 1991). Modeling studies predicted a greater than 80-percent reduction in ozone levels within 1 km (0.62 mi) of an exhaust plume for a period of 1 to 3 hours, after which the levels were projected to rapidly return to normal (Karol et al. 1992).

Other models addressing the effects of rocket exhaust on ozone levels near the exhaust trail indicated smaller reductions. Investigations of chlorine and NO levels due to the launches of the Shuttle and the Russian Energia concluded that local, short-term O_3 reductions can possibly be greater than 8 percent (Karol et al. 1992). Local effects of similar magnitude may also be produced by the nitrogen oxides chemistry, which is an exhaust product of the Russian Energia rocket (Karol et al. 1992). The recovery period to normal background levels for the areas near the exhaust plume projected in the models is less than 3 hours to 1 day for all altitudes within the stratosphere, but the projected time varied depending on the model parameters used (Karol et al. 1992). These studies concluded that rocket emissions for the launch schedules being modeled would cause no significant detectable O_3 decreases in the stratosphere.

Denison et al. (1994) has modeled the local effects of ozone depletion from solid rocket motor exhaust using a plume dispersion model to simulate the chemistry from the combustion chamber, incorporating afterburning, through the hot plume and cool plume dispersion phases. The results of this study indicate that afterburning chemistry of the reactive exhaust products can cause local, short-term (on the order of minutes) ozone destruction episodes. This result is substantially less than the recovery period of several hours observed in the model results (Karol et al. 1992). More importantly, these results indicate that the inclusion of heterogeneous chemistry does not have a major impact on the estimated local plume chemistry. Thus, this study has shown the effect of solid rocket effluents to be short-term and that the homogeneous chemistry dominates over heterogeneous phase reactions for local plume chemical transformations.

A recent modeling study assessed the magnitude of regional increases of chlorine in the stratosphere and the regional effects of those increases on O_3 levels (Prather et al. 1990). The study focused on the potential effects from six launches of Titan IV rockets and nine Shuttle launches per year. For homogeneous chlorine chemistry only, the results indicated that the effects on the ozone layer are minor and short-lived. A three-dimensional model (Prather et al. 1990) was used to compute the regional effects of solid rocket motor exhaust from a single Shuttle launch over a 1,000 km^2 (386 mi^2) area. At an altitude of 40 km (131,240 ft), total chlorine was calculated to increase by a few percent 2 days after launch. Subsequently, ozone decrease is expected to be less than 1 percent at that height (Prather et al. 1990).

The localized impacts of launch vehicle operation on total column O_3 levels along the flight path might also be important. The effectiveness of the ozone layer in filtering ultraviolet radiation is affected by both the amount of O_3 in a given atmospheric layer and the amount of O_3 in the total air column in the atmosphere. Reductions in O_3 levels in the total column ozone from Shuttle operations were found both through models and through measurements to be far less than localized stratigraphic losses. This effect occurs because the vehicle's trajectory is not vertical; therefore, not all of the exhaust plume is deposited in one vertical column of air. Measurements (with an accuracy of ±4 percent) of total column ozone within a 40 km by 40 km (618 mi^2) area were taken between several hours to 1 day after a launch at the KSC. These showed no decrease in total O_3 concentration. One model predicted that the total column ozone in the area near a launch site would be reduced less than 10 percent, even though the same model showed a greater than 80-percent localized reduction in ozone along the flight path in specific atmospheric strata (AIAA 1991).

A number of researchers have attempted to predict the global impacts associated with rocket launches using computer models (Karol et al. 1992, Krüger et al. 1992, Prather et al. 1990). Stratospheric chlorine increases due to nine Shuttle and six Titan IV launches per year were predicted to be about 0.3 percent in northern latitudes in one study (Prather et al. 1990). Global ozone depletion due to this launch schedule was computed to be less than 0.1 percent in several studies. One study (Prather et al. 1990) calculated 0.0065-percent ozone loss, and another study (Karol et al. 1992) predicted by scaling 0.0072- to 0.024-percent loss.

The destruction of ozone through contact with molecular chlorine, nitrogen, and sulfates involves relatively simple and homogeneous reactions among gaseous atmospheric constituents. Heterogeneous processes (i.e., reactions that occur on the surfaces of particles or that involve solid/liquid, liquid/gas, or solid/gas interactions) can also affect ozone levels (Leu 1988, AIAA 1991, Harwood et al. 1991). Heterogeneous reactions have been linked to O_3 destruction within the polar winter stratosphere of the Antarctic ozone hole (Harwood et al. 1991).

In recent years, there have been major advances in our understanding of the role of stratospheric heterogeneous reactions in increasing the abundance of active chlorine compounds in the lower stratosphere. Specifically, studies investigating Polar Stratospheric Clouds (PSCs) and stratospheric sulfate aerosols have been undertaken. The key element in understanding the perturbed chemistry of the polar stratosphere is the conversion of reservoir compounds into catalytically active species and their precursors on the surface of PSCs. These reservoir compounds are extremely important to overall stratospheric chemistry dynamics. Efforts are currently underway to incorporate these heterogeneous-type processes and the effects of PSCs on stratospheric chemistry into new and existing gas phase atmospheric chemistry models. At this time, however, this field is considered to be in its adolescence. Additionally, many of the concepts on which the existing modeling studies are based are not yet well quantified (Wayne 1991, Poole et al. 1992).

With regard to rocket launches, the pollutant of greatest concern in the area of heterogeneous chemistry is HCl vapor which is released from the ammonium perchlorate solid rocket boosters. The ozone depletion from these engines was originally estimated at 1 to 2 percent, based on 60 launches per year. However, more recent estimates are much lower. Current researchers investigating the effects of heterogeneous phase chemistry into the atmospheric circulation/chemistry models speculate that the new algorithms will slightly enhance the catalytic conversion/activation of chlorine in the stratosphere, which will subsequently moderately increase the total amount of modeled ozone depletion in the lower stratosphere. However, current preliminary investigations do not substantiate any large deviations (e.g., generation of an ozone hole) from earlier study results of the effects of rocket launches on stratospheric ozone depletion (Denison et al. 1994, Jackman 1995, Kaye 1994, Ko 1994, Lamb 1995, Wayne 1991).

Use of an SRM-equipped Titan IV would result in substantially fewer emissions of solid rocket exhaust products to the stratosphere (260,793 kg [573,745 lb]) than would an SRMU-equipped vehicle (359,210 kg [790,262 lb]). With respect to the constituents of concern (HCl, Cl_2, H_2, H_2O), HCl and H_2O are the principal contributors from both the SRM and SRMU. SRM emissions would be smaller, however, with HCl at 29 percent less than from the SRMU, H_2 at 19 percent less, and H_2O at 34 percent less. (This can be quickly determined by using the SRM constituent composition in Table 4-1, and applying it against the total SRM exhaust emissions to the stratosphere noted above.) It should be noted, however, that the Titan IV liquid-fueled main engine on the SRM-equipped vehicle would ignite while still in the stratosphere (at about T + 118 seconds), as would the main engine on the SRMU-equipped vehicle (at about T + 135 seconds). The principal difference is that the main engines of the SRM-equipped vehicle would be emitting water (and nitrogen and CO_2) to the stratosphere for almost 20 seconds longer than the SRMU-equipped Titan IV. (The SRMU-equipped Titan IV is almost out of the stratosphere when its main engine ignites at T + 135 seconds.) Overall, use of an SRM-equipped Titan IV to launch Cassini would probably have somewhat less impact on the stratosphere than would the Titan IV (SRMU).

The current state-of-the-science does not allow comprehensive global three-dimensional stratospheric chemistry simulations, which can assess long-term cumulative impacts on global ozone concentrations within the stratosphere from multiple launch scenarios. Current Federal, academic and private-sector research is focused on incorporating three-dimensional heterogeneous phase chemistry in local-scale stratospheric models to assess the potential for singular launch events to cause severe ozone depletion in the immediate vicinity of the rocket plume (i.e., an "ozone hole"). The preliminary results from such studies (e.g., Denison et al. 1994) indicate that while the inclusion of such chemical processes does improve the accuracy of model output, the magnitude of these improvements is very small. Thus, it could be hypothesized that the incorporation of heterogeneous phase chemistry in three-dimensional models, while important and necessary, would not substantially alter the current results being observed and reported for homogeneous phase chemistry models alone. Until these more complex simulations are completed, verified and validated, long-term cumulative effects of solid rocket effluents must be assessed solely on the model studies using only homogeneous phase chemistry (e.g., Prather et al. 1990). Given this information and the limited understanding of heterogeneous phase chemistry on the local rocket exhaust plume, it is not expected that the launch of Cassini in conjunction with other launches would produce a discernible, long-term cumulative impact on ozone concentrations within the global stratosphere.

4.1.2.4 Impacts of Noise and Sonic Boom

Initially, the launch of the Titan IV (SRMU) would involve igniting only the SRMUs. The liquid-fueled main engines of the core Titan IV vehicle would not be ignited until 135 seconds into the flight when the vehicle would be at an altitude of about 51.8 km (170,000 ft) and several miles down range over the ocean. The USAF evaluation of expected noise levels from the SRMUs indicates that neither workers nor the public would be adversely affected by the noise from the launch (USAF 1990). Although the maximum sound pressure near the launch pad could reach 170 dBA (a level that could damage human hearing), launch workers would either be evacuated to safe areas prior to SRMU ignition or, for those who work closer to the launch pad, housed in buildings designed to reduce the noise to 115 dBA and further protected by protective devices. (The maximum short-term occupational exposure limit is 115 dBA.) The nearest location where members of the public could be found during launch and where they could be exposed to the noise would be about 6 km (4 mi) away at KSC. The nearest population centers are about 16 km (10 mi) away. At the KSC locations, noise levels would be about 110 dBA and would last from 1 to 2 minutes; at the nearest population centers, the noise level would reach about 100 dBA for a similar period of time. Therefore, noise from the Cassini launch would not be expected to adversely affect either workers at the launch site or the unprotected public in the CCAS region.

Sonic booms occur during liftoff and reentry of suborbital and orbital stages of space launch vehicles. A sonic boom is experienced as an abrupt noise caused by a vehicle traveling at speeds greater than the speed of sound. Sonic booms are shock wave pressures traveling through air surrounding the path of the vehicle. The flight path characteristics, such as altitude, and acceleration and body characteristics, such as mass and volume, influence the intensity of sonic booms.

In the history of the space launch vehicle operations from CCAS by the USAF, no known problems have resulted from sonic booms (USAF 1986), primarily because the ascent route of all vehicles is over open ocean. The designed reentry of spent suborbital stages and orbital stages is also over open seas. These two factors place sonic booms away from land regions where human populations reside. All ships in the area that could be affected are routinely warned of the impending launches, and the incident of the sonic boom, if it is experienced at all, would be expected and inconsequential. Therefore, sonic booms associated with the launch of the Cassini spacecraft would be expected to have no adverse impacts.

A Titan IV vehicle equipped with smaller conventional steel-cased SRMs would generate similar sound levels during launch as the SRMUs. Launch area workers would be protected as noted above, and the nearest members of the public (visitors at KSC) would be subjected to launch noise levels for 1 to 2 minutes. Noise levels at the nearest population centers about 16 km (10 mi) away would also be similar to those from the SRMUs. Also, as with the SRMU-equipped Titan IV, sonic boom from the Titan IV (SRM) would occur over the ocean.

The noise from other launches using Titan IV (SRMUs or SRMs) or other vehicles would be brief but intense. Because launches would not be simultaneous, noise should not cause a cumulative impact. If, however, the number of launches from CCAS (KSC) increased, the frequency of launch noise in the CCAS region would also increase. No significant long-term health impacts would be expected except that individuals who are sensitive to noise could be irritated (USAF 1990).

4.1.2.5 Impacts on Geology and Soils

Assuming similar impacts from an SRMU- or SRM-equipped Titan IV as observed for the Shuttle (Hinkle and Knott 1985), the deposition of HCl from the exhaust cloud on the soil adjacent to the launch site would result in a temporary acidification (i.e., the soil pH and buffering capacity would be temporarily reduced). The deposition of Al_2O_3 particulates would also increase the concentration of aluminum in the nearby soils.

Use of an SRM-equipped Titan IV launch vehicle would result in similar impacts of about the same magnitude as from the SRMU-equipped vehicle. HCl emissions in the exhaust clouds of the two boosters are about the same (Section 4.1.2.2). Particulate (Al_2O_3) deposition would, however, be less from the SRM-equipped vehicle.

The cumulative impact of multiple launches on the near-field soil has been a reduction in the capacity of the soil to buffer the temporary acidification observed following a launch and increased concentrations of metals (aluminum, iron, and zinc). Cumulative impacts on far-field soils (i.e., over 1 km [0.6 mi]) from the launch site are relatively insignificant because the deposition of particulates and chlorides is less than 3 percent of the maximum observed near the launch site (NASA 1990). An SRM-equipped launch vehicle would contribute slightly less to cumulative impacts compared to an SRMU-equipped vehicle.

4.1.2.6 Impacts on Hydrology and Water Quality

Surface Water

The exhaust cloud formed by SRMU ignition products contains both Al_2O_3 particulates and HCl in solid, aerosol, and/or droplet form. Nearly 1,510,000 l (400,000 gal) of water is used for deluge, noise and fire suppressant, and launch pad washdown water during and after each launch. Approximately 20 percent of the deluge/noise/fire suppressant water (300,000 l; 80,000 gal) is vaporized and/or blown on to areas surrounding the launch complex and mixes into the exhaust cloud. Because the deluge/noise/fire suppression systems are the only source of water (aside from any naturally occurring humidity in the ambient air) involved in the launch (the liquid-fueled engines of the core Titan IV are not ignited until 135 seconds after liftoff), the Titan IV (SRMU) exhaust is relatively dry and will not contain large amounts of aqueous HCl. The exhaust cloud will be, at least initially, forced to the east toward the Atlantic Ocean by the exhaust duct at either launch complex. The Atlantic Ocean is about 610 m (2,000 ft) to the east of Launch Complex 41, slightly further from Launch Complex 40. If Cassini is launched in October (i.e., the primary launch opportunity under the Proposed Action) in the early morning hours, as most launches are, offshore land breezes are possible. In this event, the exhaust plume and the entrained deluge/noise/fire suppression water would move out over the Atlantic Ocean, and droplets of aqueous HCl and drier forms of HCl could settle from the exhaust cloud onto the ocean. The large volume and buffering capacity of the ocean waters, combined with the relatively swift currents (see Section 3.1.4.5), would quickly neutralize and dilute the acidification imparted by contact with the plume and deposition of dry and/or aqueous HCl. Thus, it is unlikely that the ocean waters would experience any significant acidification from the launch of the Cassini spacecraft.

If the offshore land breezes are not blowing at the time of launch, the exhaust plume could be directed away from the ocean by the prevailing seasonal winds. Seasonal winds tend to be in an onshore direction during the month of the primary (October 1997) and backup contingency (March 1999) launch opportunities. Land and sea breezes tend to decrease in frequency during the winter months (i.e., December for the 1997 secondary contingent launch opportunity). Prevailing winds at that time of year tend to be in a southeasterly to southerly direction and could push the exhaust cloud over the ocean or south along the eastern side of the Banana River (Figure 3-13). In this case, nearby inland waters that the exhaust cloud passes over would probably experience short-term acidification. In the case of the Banana River to the west of Launch Complexes 40 and 41, the duration of acidification would be relatively short because of the river's large volume and its large buffering capacity. The marsh or wetlands area, to the west of each launch complex along the river (see Figure 3-13), would be most susceptible to acidic deposition from the exhaust plume. Acidic deposition could adversely affect an area extending about 61 m (200 ft) into the marsh from its closest point to Launch Complex 41 (USAF 1986). If the exhaust plume is directed over the marsh, the HCl deposition would probably depress the pH (i.e., increase acidity) of the marsh waters. The pH would be expected to return to normal within a few hours because of the normal buffering capacity (USAF 1990).

Aluminum oxide particulates would also settle from the exhaust cloud. The Al_2O_3, however, is relatively insoluble at the ambient pH level (8.0 - 8.5) of the Banana River and Atlantic Ocean. It is also nontoxic to most aquatic organisms. Moreover, tidal flushing and mixing from prevailing and storm-related winds, in both the river and the ocean, would prevent substantial quantities of aluminum from accumulating (USAF 1988b).

Titan IV vehicle stages that do not go into orbit have trajectories designed for ocean impact. Once in the water, the vehicle hardware will corrode and metal ions will be released into the ocean environment. Any contamination that results, however, would be minor, because of the slow rate of corrosion and the large amount of water available for dilution (USAF 1986). If the liquid fuel stages of the core vehicle rupture upon impact with the ocean, any residual propellants (i.e., Aerozine-50 and NTO) would be released quickly. The amount of this release will probably be small because the fuel stages will be virtually empty when they are jettisoned from the Titan IV launch vehicle. Any residual solid propellant in the SRMUs will be held within a rubbery binder substance and will be slowly released to the environment. Consequently, the release of residual Titan IV propellants will not substantially impact the quality of the surface water environment (USAF 1986).

Surface water impacts associated with launch of Cassini onboard an SRM-equipped Titan IV would be similar to those described for an SRMU-equipped vehicle. Given that HCl concentrations in the SRM exhaust cloud would be about the same as those in an SRMU cloud but slightly less in total volume (see Section 4.1.2.2), the temporary acidification effects should, in turn, be slightly less. Aluminum oxide particulate concentrations and quantities deposited in surface waters would also be less for an SRM-equipped Titan IV. Expended SRMs landing in the ocean would also, by virtue of their smaller size, be expected to have even less impact than the SRMUs on water quality from the slow dissolution of residual fuel.

The launch of Cassini along with additional launches of Titan IV (SRMU or SRM) vehicles from Launch Complex 40 or 41 would probably not have any substantial cumulative impact on the surface water bodies—the Banana River and the Atlantic Ocean—adjacent to the launch site. The buffering capacities of these waters would offset any pH decreases that would occur from HCl deposition. No localized fish kills in the Banana River would be expected from Al_2O_3 deposition because of its nontoxic characteristics (USAF 1990).

Groundwater

Nonindustrial wastewaters (i.e., sanitary wastewaters) are generated during launch activities. Sanitary wastes from these activities are treated using secondary treatment methods, with the resulting effluents released to percolation ponds, in accordance with State of Florida permit requirements (USAF 1986, USAF 1988b, USAF 1990). Releases to percolation ponds should not significantly affect the quality of the surficial aquifer or the quantity of flow in the aquifer.

The primary source of potential groundwater contamination at the launch complex will be the nearly 1,510,000 l (400,000 gal) of water used as deluge, noise and fire suppressant, and launch pad washdown water during and after each launch of a Titan IV. This water would be supplied from municipal sources. The deluge/fire/noise suppression water will contain exhaust products from the SRMUs, principally dissolved HCl and particulate Al_2O_3, paint chips, and other debris from the launch pad. This wastewater will be acidic because of the dissolved HCl from the exhaust gases. About 20 percent (300,000 l; 80,000 gal) will be either vaporized by the heat of the SRMU exhaust and dispersed into the atmosphere and/or is blown by the exhaust on to the areas surrounding Launch Complex 40 or 41 (USAF 1990). The vaporized portion will contribute to the exhaust cloud, affecting ambient air quality. The portion blown on to the surrounding areas will either evaporate after deposition on the land surface or infiltrate the ground, where it may eventually reach the groundwater of the surficial aquifer.

The bulk of the deluge, noise, fire suppressant and washdown water (about 80 percent or 1,200,000 l [320,000 gal] will be collected in the flame bucket (launch duct sump) at the launch pad. This wastewater, as well as about 165,000 l (44,000 gal) of coolant water from the OVSS, will be sampled, and if found to be within the permit criteria (Florida drinking water standards), will be discharged to three nearby percolation ponds, in accordance with State of Florida industrial discharge permits. Once in the percolation ponds, these waters will infiltrate the permeable soils beneath the ponds and reach the groundwater of the surficial aquifer. These waters will mix with and will be diluted by the groundwater. Thus, the launch of the Cassini mission would not be expected to adversely affect the quality of the surficial aquifer at CCAS, although it would contribute dissolved contaminants (principally exhaust products from the SRMUs) to the underlying surficial aquifer. The USAF estimated the elevation or mounding of the groundwater under the east side of Launch Complex 41 will rise slightly with each Titan IV launch. The mounding, estimated at about 10 cm (0.3 ft) at Launch Complex 41, using conservative assumptions, will dissipate rapidly following a launch, given the highly permeable nature of the soils in this area (USAF 1990). Because of the relative isolation of the secondary semi-confined aquifers and the impermeable layer overlaying the much deeper Floridan Aquifer, it is very unlikely that the launch of Cassini would impact either of these deep aquifers.

The impacts of an SRM-equipped Titan IV launch would be expected to be similar to those described for an SRMU-equipped vehicle, but of somewhat lower magnitude due to the slightly smaller amount of HCl in the SRM exhaust cloud. The deluge/fire/noise suppression waters contained by the flame bucket would be similar in volume, as would the amount contained in the exhaust cloud. The amount of contaminants scrubbed from the SRM exhaust would be slightly less, however. Thus, effects on groundwater quality from release of deluge waters and deposition from the exhaust cloud would be similar, but slightly less in magnitude. Mounding effects at Launch Complex 41 would be the same as described previously because the volume of water released from the launch complex would be the same, regardless of the type of solid rocket motor used on the Titan IV.

The USAF recognizes that the potential exists, over time, for multiple Titan IV (SRMU or SRM) launches to adversely affect the quality of the surficial aquifer at Launch Complex 41, as well as at Launch Complex 40 (each complex is scheduled for three launches per year through at least 1995) (USAF 1990). Combined with multiple launches over time, Cassini may, therefore, contribute to increased contaminant input to the surficial aquifer. To provide early indications of an adverse effect on the groundwater, five monitoring wells have been installed in the surficial aquifer at each of the complexes as discussed in Section 3.1.5.4. All wells are monitored quarterly, and the USAF has committed to a mitigation plan in case contaminants reach levels above those approved by the State of Florida.

4.1.2.7 Impacts on Biological Resources

Floodplains and Wetlands

Launch Complexes 40 and 41 are located above the 500-yr floodplain (NASA 1994). No short- or long-term impacts to the floodplain are anticipated as a result of the Proposed Action.

Depending on the prevailing meteorological conditions (i.e., no offshore land breeze, only prevailing seasonal winds) during the launch of the Cassini spacecraft at CCAS, deposition of HCl and Al_2O_3 from the exhaust cloud could affect the biota and the water quality in the floodplains and wetlands west of the launch sites. The pH of the water could decrease as a result of HCl deposition; organisms in the upper 0.5 m to 1 m (1.6 ft to 3.3 ft) of the wetland area could be affected (USAF 1990). However, the natural buffering capacity of the waters should increase the pH to normal levels within a few hours after HCl deposition. The Al_2O_3 deposits should be minimal and nontoxic; Al_2O_3 is insoluble at the normal pH of the receiving waters (USAF 1990). The potential for deposition is greatest during the time of the 1997 primary launch opportunity (October) and the 1999 backup opportunity (March). At the time of the 1997 secondary opportunity (December), winds tend to blow toward the southeast. In this event, the buoyant exhaust cloud could be pushed either toward the ocean or toward a marsh area located about 0.75 km (0.5 mi) south of Launch Complex 40 (Figure 3-13). Because the cloud would likely be somewhat more dispersed upon passing over this marsh area, acidification of the marsh waters would probably be somewhat less than experienced in the areas to the west of the launch complexes.

Due to the somewhat smaller size of the SRM, a launch of the Cassini spacecraft with this motor would be expected to result in similar but slightly lower magnitude impacts to nearby wetlands as compared with an SRMU-equipped Titan IV.

Given the relatively infrequent schedule of Titan IV (SRMU or SRM) launches, cumulative impacts to floodplains and wetlands from the exhaust emissions are not anticipated. The groundwater monitoring program (Section 4.1.2.6) will enable the Air Force to detect any substantial groundwater contamination that feeds into the floodplains and wetlands near the launch complex.

Terrestrial Resources

The USAF addressed the impacts of Titan IV (SRMU) launches on the terrestrial environment (USAF 1990). Terrestrial vegetation, consisting of grass, located in undeveloped areas within about 20 m (66 ft) of the launch pad perimeter will probably be singed by the heat of the SRMU exhaust. The USAF has noted that vegetation singed by the exhaust heat has not been permanently affected (USAF 1990). The USAF has occasionally experienced brush fires with a launch event; these fires have been contained successfully. Because the exhaust ducts at both Launch Complexes 40 and 41 direct the exhaust to the east toward the Atlantic Ocean, the exhaust heat will most likely affect the vegetated areas immediately east of the exhaust port.

The exhaust from the SRMUs will contain large amounts of HCl (in solid, aerosol, and droplet form), which will interact with a portion (about 20 percent) of the deluge/fire/noise suppression water released during liftoff, as well as with moisture in the ambient air, to form hydrochloric acid. The acid formed could settle out from the exhaust cloud as wet deposition. Wet deposition of HCl can damage or kill vegetation, depending on the sensitivity of the vegetation and the amount and acidity of the wet deposition. The other major exhaust product from the SRMUs will be particulate aluminum oxide, which will also settle out of the exhaust cloud. These particulates, which are chemically inert, will probably not adversely affect vegetation. USAF observations of a Titan IV conventional SRM launch in 1989 found no evidence of wet deposition outside the perimeter fence at Launch Complex 41. The perimeter fence is 183 m (600 ft) from the launch complex, defining a "high-risk zone" for terrestrial wildlife (USAF 1990). The 1989 launch used the conventional 7-segment SRM. Although the SRMU is larger than the conventional SRM, the amount of fuel burned in the first 10 seconds after ignition would be about the same for both motors. In addition, only slightly less HCl would be produced in the SRM exhaust cloud (Section 4.1.2.2). Thus, impacts from the two motors would be about the same in the "high-risk" zone. Coastal scrub in these areas is characterized by short trees and shrubs (see Section 3.1.6.2). Some leaf spotting and possibly some defoliation could occur similar to that documented for Shuttle launches at KSC (NASA 1994). The relatively narrow bands of coastal strand and coastal dune vegetation (largely grasses) are further east of Launch Complexes 40 and 41. Should sufficient wet deposition occur in these areas, leaf spotting with possibly some defoliation in the coastal strand could occur, with similar impacts to some dune grasses. Other dune grasses would not be affected. Similar impacts were noted for three Shuttle launches in recent years where the exhaust cloud drifted over the dunes east of the Shuttle launch pad (NASA 1994). Should the exhaust cloud from the launch of the Cassini spacecraft drift over the coastal strand and dune areas, it probably would yield less impact to the vegetation than the Shuttle exhaust cloud because the exhaust from the Titan IV (SRMU) is drier than the exhaust from the Shuttle. Unlike the Shuttle, the Titan's main liquid-fueled engines will not be used for liftoff; therefore, the Titan IV exhaust cloud will not have any additional water output from liquid engine exhaust to contribute to HCl droplet formation.

Marsh vegetation could be adversely affected by wet deposition if the winds blow the exhaust cloud over the marsh area to the west of either launch complex (Figure 3-13). The USAF estimated that an area extending into the marsh 61 m (200 ft) from its closest point to Launch Complex 41 could receive wet deposition (USAF 1986), and some marsh vegetation in the area of cloud passage could be lost. The potential for transport of the buoyant exhaust cloud by seasonal winds over the marsh areas west of the two launch complexes is greatest during the time of the primary (October) and backup (March) launch opportunities. Winds during the secondary opportunity would tend to be toward the southeast to south and would tend to push the cloud either out over the ocean or to the south. If toward the south, some wet deposition could occur in the marsh area located about 0.75 km (0.5 mi) from Launch Complex 40 (Figure 3-13). Because the exhaust cloud would probably be somewhat more dispersed upon reaching this marsh area, vegetation impacts should be less.

Because the exhaust cloud would be transported and dispersed by existing winds as it would rise, HCl and particulate deposition could occur in areas beyond the "high-risk zone." This would most likely occur in an area within 5 km (3.1 mi) of the launch pad. As noted earlier, USAF modeling estimates that at this distance the HCl levels in the exhaust cloud would likely have been reduced to about 18.2 mg/m^3 (12 ppm). By way of comparison, Shuttle launches have resulted in secondary acidic and particulate deposition from the exhaust cloud in areas up to 14 km (9 mi) down wind (NASA 1994). Far-field effects, generally leaf-spotting, experienced from Shuttle launches have not had adverse long-term effects on vegetation receiving wet HCl deposition. The Titan IV SRMUs are about 60 percent the size of the Shuttle's solid rocket boosters, and the Titan IV SRMU exhaust contains less moisture (i.e., a lower HCl content). Therefore, if the exhaust cloud were driven over land areas near CCAS by the wind, less particulate and wet HCl deposition of acid would probably occur, with even less impact on far-field vegetation than would be experienced with a Shuttle launch.

Terrestrial wildlife that enters the fenced-in area would also be affected by the heat and noise overpressures of the launch of Cassini. Any wildlife within about 20 m (66 ft) of the exhaust trench would die from the heat of the exhaust (USAF 1990). Between the trench and the perimeter fence (i.e., within the "high-risk zone") extending to about 183 m (600 ft) from the launch pad, wildlife not fleeing the area could be injured by both the heat and noise overpressure from the SRMU exhaust; some wildlife could die. Post-launch inspections of the areas around the launch complexes have shown low mortality of wildlife, however. This is probably because the undeveloped areas near Launch Complexes 40 and 41 are grassed and located within an industrial setting (the launch complex) and unlikely to support large numbers or a variety of wildlife.

Noise levels exceeding 95 dBA may cause a temporary hearing loss in exposed terrestrial wildlife, leaving them more susceptible to predation until hearing is recovered (USAF 1990). The 95 dBA noise level could extend as far as 24 km (15 mi) from the launch complex. Sonic boom noise could cause a startle effect, but no adverse impacts are anticipated. Given that the noise levels from a launch will be experienced for only a short period (1 to 2 minutes) per launch event and, at present, only six Titan IV (SRMU) launches per year are planned at CCAS, it is unlikely that significant cumulative impacts to hearing will be experienced by wildlife from Titan IV (SRMU) launches alone. When considering other launches from CCAS and nearby KSC, the noise impact zones may overlap, and sensitive species residing in the areas of overlap could experience prolonged or permanent hearing loss.

An SRM-equipped Titan IV launch vehicle would be expected to result in similar but somewhat lower magnitude impacts than those of a Titan IV equipped with the larger SRMU. The "high-risk zone" for wildlife would be about the same, extending to the launch complex perimeter fence 183 m (600 ft) from the complex. Wet deposition of exhaust products, especially HCl, would not be expected to extend beyond the perimeter fence, as noted above. Aluminum oxide (Al_2O_3) particulate deposition would be expected to be less than that associated with an SRMU-equipped vehicle (Section 4.1.2.2). Noise effects on wildlife in the vicinity of the launch complex would be similar to those noted for the SRMU-equipped vehicle.

Launch of the Cassini spacecraft would be one of an average of six Titan IV (SRMU) launches per year scheduled from CCAS. Therefore, launch of Cassini would contribute to cumulative effects experienced from multiple Titan IV launches and others. The cumulative effects (i.e., possibly a reduction in the number of vegetative species in the near field) from the presently planned launch rate are not expected to be substantial.

Aquatic Biota

The exhaust cloud formed by ignition of the SRMUs that contains aluminum oxide particulates and HCl in dry and wet forms, and the deluge water and washdown water contained in the flame bucket after launch would be the two principal sources of potential impact to aquatic biota. The aluminum oxide particulates that settle out of the exhaust cloud over nearby water bodies (e.g., the Atlantic Ocean or the Banana River) would not be expected to adversely affect aquatic biota. The aluminum oxide is largely insoluble, particularly at the relatively high ambient pH of the nearby water bodies (pH = 8 or more) (USAF 1990).

The prevailing winds during the primary and backup launch opportunities would push the exhaust cloud back over land, thereby potentially affecting the Banana River. The prevailing winds during the secondary opportunity would push the exhaust cloud southeast to south, thereby largely avoiding the Banana River.

The HCl droplets in the exhaust cloud that could settle out over the nearby water bodies could cause a temporary decrease in pH. If this occurred over the Atlantic Ocean or the Banana River, the relatively high buffering capacity of these waters would quickly neutralize the acid input from the exhaust cloud, resulting in only a short-term decrease in pH. It is unlikely that biota in these two water bodies would be adversely affected. Acidic deposition in the marsh area to the west of the launch complexes could adversely affect fish and other aquatic fauna in the areas of greatest deposition (estimated to consist of an area about 61 m [200 ft] into the marsh from its closest point to the launch complex) (USAF 1986). Some fish and other biota could die until the marsh waters recovered to a normal pH. The marsh area located about 0.75 km (0.5 mi) to the south of Launch Complex 40 could be affected during the secondary opportunity with transport of the exhaust cloud over that area. Impacts would probably be somewhat less, because the cloud would likely be more dispersed in this area.

The deluge/fire/noise suppression and washdown water released from the launch complex to the percolation ponds would eventually reach the Banana River and the marsh area to the west of the launch complexes. The USAF has estimated that, given the porosity of the soils in this area, it would take 11 years for these waters to reach the marsh to the west (USAF 1990). The discharge of these waters from the launch site would not affect the marsh or Banana River. The groundwater monitoring program (see Section 4.1.2.6) will provide the USAF with advance warning if contaminants from the planned series of Titan IV (SRMU or SRM) launches, including Cassini, reach the groundwater and eventually the marsh and the Banana River and result in individual launch or cumulative impacts.

Marine biota could be impacted by jettisoned Titan IV components that fall into the ocean. Small amounts of ammonium perchlorate in the binding agent (HTPB for the SRMU PBAN for the SRM) could remain in the motor cases, and small amounts of Aerozine-50 and/or NTO could remain in Titan IV stages jettisoned into the ocean. Corrosion products from vehicle hardware would also enter the ocean water over time. It is highly unlikely that the corrosion of the vehicle hardware would occur at a rate fast enough to produce toxic concentrations of metal ions in the ocean or in other surface waters. However, Aerozine-50 and NTO could create adverse impacts. Both compounds, which are soluble in water, could reach toxic levels in a very small area near the spent fuel stage(s). Impacts are not expected to be substantial because of the large dilution volumes available in the ocean. The release of ammonium perchlorate from its binder would be very slow with little potential for adverse impact to biota (USAF 1988b).

Although the SRM is 15 percent smaller than the SRMU, the quantities of combustion products in the exhaust cloud and impacts to aquatic biota from an SRM-equipped Titan IV launch would be similar but somewhat lower in magnitude (see Section 4.1.2.2). Potential impacts associated with jettisoned vehicle components that fall into the ocean would also be somewhat less with respect to the SRM motor cases, which would have less residual fuel than the SRMU cases.

Because the currently planned number of Titan IV (SRMU or SRM) launches from CCAS is relatively few, it is very unlikely that the exhaust clouds from these launches would have any cumulative effects on aquatic biota.

Threatened and Endangered Species

The USAF and the U.S. Fish and Wildlife Service (FWS) extensively examined two principal potential sources of impacts to threatened or endangered species (USAF 1990). The first potential source was the security and operations lighting used at Launch Complexes 40 and 41 during launch events. These lights illuminate the landward horizon at both launch complexes. When the landward horizon is brighter than the seaward horizon, occasionally adult sea turtles and hatchling turtles can be disoriented. This causes them to move inland instead of to the ocean. Mortality, as a result, might be increased. As a consequence, the USAF, in consultation with the FWS, developed a light management plan to reduce the threat to the sea turtles during the nesting season. Compliance with the FWS-approved light management plan is required.

The second potential source of impacts was on two species—the Florida scrub jay (*Aphelocoma coerulescens coerulescens*) and the southeastern beach mouse (*Peromyscus polionotus niveiventris*)—most likely to reside near the two launch complexes. The impacts of concern were direct mortality from the exhaust heat, noise, and gases from the SRMUs and destruction of species habitat. Examination of the potential mortality from the exhaust led the FWS to conclude that the continued existence of the Florida scrub jay and the southeastern beach mouse will not be jeopardized by the planned Titan IV (SRMU) launches at CCAS (USAF 1990). Noise at levels above 95 dBA could induce short-term hearing loss in those species, making them more subject to predation.

The Air Force concluded that the exhaust heat and gases (specifically hydrogen chloride) will injure or destroy habitat near the launch pad and along the path of the exhaust cloud but that the populations of Florida scrub jay and southeastern beach mouse will not be threatened by these losses (USAF 1990). A high-risk zone will exist between the launch pad and the perimeter fence, which is 183 m (600 ft) away, where exhaust heat and sound overpressures will be intense.

West Indian manatee (*Trichechus manatus latirostris*) in the Banana River Manatee Refuge, about 14 km (9 mi) south of Launch Complex 41, would not be adversely impacted by the Cassini launch. Industrial wastewater effluents would not be directly discharged into the river from the Titan IV operations, all discharges are treated and then released to percolation ponds. The exhaust cloud could cause short-term depression of the pH of the Banana River near the launch complex, but the pH would be expected to return to normal quickly because of the relatively high buffering capacity of the river water (USAF 1990).

Birds, including those listed as threatened or endangered, should not be adversely affected; however, birds tend to exhibit a startle response to launches. Birds from a former wood stork (*Mycteria americana*) rookery abandoned in 1991, approximately 4 km (2.5 mi) northwest of Launch Complex 41, flew away during a Shuttle launch at Launch Complex 39A and returned within about 2 minutes after the liftoff (NASA 1994). Bald eagle (*Haliaeetus leucocephalus*) inhabiting and nesting in the vicinity of CCAS would probably not be disturbed by the launch of the Cassini spacecraft; the nearest nest is about 11 km (7 mi) to the north of Launch Complex 41. Osprey, located about 5 km (3.1 mi) south of Launch Complex 41, should not be affected by a normal Titan IV (SRMU) launch of the Cassini spacecraft.

Launch of Cassini would have similar effects on protected species near the launch complex. The FWS-approved lighting plan would be observed regardless of the type of solid rocket motor used. Exhaust gases from the firing of the SRMs would have somewhat less effect on nearby species due to the smaller size of the SRM compared with the SRMU.

Studies to date indicate that there are no significant adverse short-term or cumulative effects on threatened or endangered species or critical habitat from launches at CCAS and KSC.

4.1.2.8 Impacts on Socioeconomic Resources

The launch of the Cassini spacecraft aboard the Titan IV (SRMU)/Centaur from CCAS should have no substantial adverse effects on the socioeconomic environment surrounding CCAS. Instead, the launch could have a short-term beneficial effect on the local Cape Canaveral economy, if tourists from around the United States and Europe arrive to witness the launch. In addition to local socioeconomic benefits, implementation of the Cassini mission has a number of broader socioeconomic benefits, as noted in Section 1.4, including developing technology spinoffs, maintaining our leadership role in deep space exploration, and fostering future international cooperative efforts in space exploration.

Socioeconomic impacts would not be expected to differ with use of an SRM-equipped Titan IV.

4.1.2.9 Historical or Archaeological Resources

The launch of Cassini at CCAS would not be expected to have any significant impact on any known or unknown historical or archaeological sites near the launch site (USAF 1990). The nearest historical sites are Launch Pads 39A and 39B, which are located at KSC, about 6.4 km (4 mi) to the north of the launch complexes. There would be no anticipated impacts on these launch pads.

Use of an SRM-equipped Titan IV would not be expected to impact historical or archaeological resources near the launch complexes.

4.1.3 Environmental Impacts of Balance of Mission

The Cassini spacecraft once injected into its interplanetary VVEJGA trajectory (or a VEEGA for the secondary or backup contingency launch opportunities), would have no adverse impact on the human environment, given a normal trajectory. The Cassini Saturnian tour and delivery of the Huygens Probe would also have no impact on the Earth's environment.

Use of an SRM-equipped Titan IV and the associated VVEJGA or VEEGA spacecraft trajectories would, similarly, have no impacts on the human environment.

NASA's policy for conducting solar system exploration gives serious consideration to the concern for possible life forms on other planets and bodies. This policy takes into account the most recent scientific findings and recommendations of the Space Science Board (currently Space Studies Board) of the National Research Council. The Board's Committee on Planetary Biology and Chemical Evolution assessed the likelihood of Saturn and Titan being able to sustain Earth-type life as essentially nil. Nevertheless, the Huygens Probe would be assembled under prescribed conditions which would reduce biological burden (JPL 1990).

4.1.4 Nonradiological Impacts of Titan IV (SRMU)/Centaur Launch Accidents

The nonradiological impacts of Titan IV accidents addressed in the Titan IV Environmental Assessments (USAF 1986, USAF 1988a, USAF 1990) are fundamentally similar to the potential nonradiological Shuttle accident impacts addressed in the Shuttle program EIS (NASA 1978), the Tier 1 Galileo and Ulysses missions EIS (NASA 1988b), and the Tier 2 EISs for the Galileo (NASA 1989b) and Ulysses (NASA 1990) missions. Accidents either on the launch pad or in the first few seconds of flight present the most direct threat to people, most specifically the launch complex work force. On- and near-pad accidents were relatively common during the early development of the space program. Subsequently, facilities and launch procedures were developed to protect both launch-site workers and the public from the energy and debris associated with a vehicle explosion. As a result, these accidents have decreased, although they still occur occasionally. These procedures generally fall under the purview of Range Safety. After ignition, if a problem occurs that could threaten the public and property, the Flight Control Officer is responsible for transmitting a signal (i.e., command shutdown and destruct [CSD]) to the vehicle that intentionally ignites strategically-placed explosive charges on the vehicle and destroys it. All personnel, including workers and the public, not in specially designed bunkers would be sufficiently far away from the launch site not to be affected by the debris and other direct impacts of such an accident.

There are, however, potential short-term impacts on the environment from launch-related accidents. These include the localized effects of the fireball, fragments from the explosion, and the release of the propellants (some unburned) and their combustion products to the environment. These accidents would not present any substantial long-term impacts to the environment.

The accidents of concern range from propellant loading emergencies prior to launch, to a performance anomaly resulting in a CSD of the Titan IV (SRMU)/Centaur near the launch complex, to an explosion during ascent of the vehicle (USAF 1986, USAF 1988a, USAF 1988b). During a fueling emergency (e.g., a leak occurs or a part of the fueling system ruptures), both fuel and oxidizer could escape directly to the atmosphere. The fueling system uses redundant flow meters and redundant automatic shutoff devices to reduce the potential of such an event occurring. In addition, propellant loading operations are prohibited when meteorological conditions are such that an inadvertent release of nitrogen tetroxide from the fueling operation could concentrate at unsafe levels in downwind areas. If an accidental propellant spill occurs during the fueling operation, the unvaporized liquid would be retained either in the impervious lined holding areas surrounding the fuel tanks or in the flame bucket beneath the launch vehicle. Spills would be removed and disposed of at an appropriate offsite hazardous waste facility (USAF 1986); therefore, surface water resources and associated biota would not be affected.

In the event of a CSD action, the liquid propellant tanks and solid rocket motors would be ruptured (USAF 1986). Most of the hypergolic liquid propellants would ignite and burn. The SRMs are designed so that most of the solid propellant fires would be extinguished by the sudden reduction in chamber pressure (USAF 1986). The air emissions from such an event would be similar to those produced during launch (Table 4-1) and would consist of Al_2O_3 particulates, HCl, CO and NO_x from the SRMU fuel, and N_2, water, and CO_2 from the hypergolic fuels. The amount of dilution at ground level would depend on that distance and existing meteorological conditions. Because the SRMU fuel would probably extinguish with rupture of the motor casings, it is unlikely that air emissions would reach levels much higher than experienced in the exhaust cloud from a normal launch. Wet HCl levels could be somewhat higher due to the water vapor resulting from burning of the hypergols.

Some uncombusted solid and liquid propellant could enter nearby surface waters (i.e., Banana River or Atlantic Ocean). Depending on the amount of fuel reaching the surface waters, aquatic biota in the receiving area could be subjected to short-term impacts. In the case of a release to the ocean, aquatic biota could die from exposure to hydrazine (from the Aerozine-50 fuel) or from the nitrogen tetroxide. The USAF (USAF 1986) estimated that impacts to water quality and biota could be significant in the near-shore area of the Atlantic Ocean extending for a distance of up to 2,438 m (8,000 ft) from the ocean impact point. This assumes entry of a large amount of uncombusted fuels into the ocean. Given the volume of the receiving waters offshore CCAS, the impacts would be localized and short-term in nature. Entry of the propellant into the Banana River could result in relatively more impacts, 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.

Until the launch vehicle's instantaneous impact point clears land and is over the ocean, a vehicle destruct could also affect the terrestrial environment through fire and fragment impacts. Fire would affect the environment near the launch pad. Plants and animals near the launch pad would probably die in the fire. Some biota could also die from fragment impacts. The workforce in the launch exclusion area could also be affected, although impacts should be relatively minor because of the protective measures normally taken during a launch (e.g., shelters and protective clothing).

With a vehicular breakup or destruct further into the mission, the ocean could be affected. Some amount of liquid propellant could enter the ocean, depending on the amount of time after liftoff before the accident occurs. Between the liftoff and the separation of the solid rocket motors (about 146 seconds into the flight), the potential for liquid propellant entering the ocean would diminish with increasing altitude. The liquid propellant that could reach the ocean in concentrated quantities would decrease because of the dispersing effects from the released propellant falling through the air. Beyond 135 seconds for an SRMU and 118 seconds for an SRM-equipped vehicle (when ignition of the liquid propellant Titan IV engines occurs), the amount of liquid propellant available to contaminate ocean waters would decrease rapidly with continued firing of the main liquid-fueled rocket engines. Almost all of the liquid propellant would be consumed after 562 seconds into the mission for the SRMU-equipped vehicle, and 543 seconds for the SRM-equipped vehicle, leaving a small residual in the engine.

Accidents that occur in the stratosphere or above would result in the spacecraft and the remaining components breaking up during reentry through the Earth's atmosphere. Most of the spacecraft would be expected to burn up. The GPHS modules from the RTGs, as well as the RHUs, however, have been designed to survive this type of reentry and would reach the Earth's surface intact. The consequences associated with GPHS modules and RHUs impacting the Earth's surface are addressed in Section 4.1.5. Some of the debris from the broken-up spacecraft could also survive reentry. The GPHS modules, the RHUs, and any surviving spacecraft debris could impact an area of the Earth's surface tens of thousands of square kilometers (0.003 percent of the Earth's surface). Given that the Earth's surface is about three-fourths ocean, impacts would most likely occur there. Debris impacting on land areas could potentially strike persons inflicting injury or death, or destruction of property. The likelihood of this occurring is small, however, when worldwide population densities and worldwide water-land distributions are considered.

Nonradiological consequences of accidents involving an SRM-equipped Titan IV would be similar to those described for the Titan IV (SRMU). Given the smaller inventory of solid rocket motor fuel in the SRMs and differences in fuel formulation, impacts would probably be somewhat less in magnitude.

4.1.5 Radiological Accident Assessment

4.1.5.1 Safety Analysis Process

NASA, DOE, and their contractors (DOE 1989b, DOE 1990a), as well as Interagency Nuclear Safety Review Panels (INSRPs) (INSRP 1989a, INSRP 1990), have conducted extensive safety analyses of launching and operating RTG-powered spacecraft. With respect to the Cassini mission, NASA and DOE are, therefore, building on an extensive experience base that involves the following activities:

- Testing the RTGs, RHUs, GPHS modules, and fueled clads under simulated launch accident environments
- Evaluating the probability of launch-related accidents
- Modeling the behavior of the parts of the launch vehicle in different accident scenarios to determine whether fragments from the vehicle, upper stage, launch vehicle adapter, or other components will strike and damage the RTGs
- Estimating the outcomes of the RTG response to the launch accident environments.

Before approval for the launch of the Cassini spacecraft, DOE will conduct a detailed analysis of the risk associated with the use of the radioisotope systems (specifically, the RTGs and RHUs) for the mission and document the analyses in Final Safety Analysis Reports (FSARs). Similar analyses were performed for the Voyager missions in the 1970s and for the Galileo and Ulysses missions in 1989 and 1990. Although the FSARs (in support of the launch approval process) for the Cassini mission will not be completed until 1996, many tests and analyses performed for the Galileo (DOE 1988b, DOE 1989b) and Ulysses (DOE 1990a) missions were used as a baseline of safety information and analytical techniques for the Cassini mission.

The safety analysis for each specific mission begins with NASA's identification of the accident scenarios and associated adverse conditions (called RTG accident environments) that may challenge the RTGs, along with the probability of the accident occurring (i.e., the initiating accident probability). Then DOE determines the response of the RTGs to the accident environments using the extensive data base on RTG materials and performance characteristics that DOE has gathered from its RTG testing and analyses during the past 12 years. If the accident environments are severe enough, a release of radioactive material from a RTG can occur. This release is called a source term. The response of the RTG to the accident environment is described in part by the estimated source term (measured in becquerels [Bq] or curies [Ci]), the particle size distribution of the material released, and the location of the release, as well as by the probability that the accident environment will cause a release (i.e., the conditional probability). The product of the initiating probability and the conditional probability is the total probability that a release of radioactive material could occur in a given accident scenario. A further analysis of the release is then performed to estimate the potential health and environmental impacts.

In addition, NASA, DOE, and their contractors evaluated representative accident scenarios associated with the Cassini mission specifically for this EIS. These analyses (DOE 1995, Martin Marietta 1992, Martin Marietta Astro Space 1993, JPL 1993f, Halliburton NUS 1994a) form the basis for the radiological accident assessments. The planned FSARs for the Cassini mission are expected to provide more comprehensive analyses than are available for this EIS and will provide a much more detailed evaluation of the full range of accidents and environments that could occur during the Cassini mission.

Moreover, under Section 9 of Presidential Directive, National Security Council Memorandum #25 (PD/NSC-25), a separate nuclear launch safety review is conducted of DOE's safety analysis by an ad hoc INSRP formed for the Cassini mission. The panel is composed of members from the Department of Defense (DOD), DOE, and NASA, supported by experts from other government agencies, national laboratories, and universities. INSRP will review the DOE FSARs and will evaluate the nuclear risks associated with the mission, and document its evaluation in a Safety Evaluation Report (SER). The SER is a pre-decisional document which is submitted to NASA, the White House Office of Science and Technology Policy (OSTP), DOE, and DOD for use in the Presidential decision-making process. The Presidential decision-making process is invoked after the NASA Administrator requests nuclear launch safety approval through the Director of OSTP. The nuclear launch safety of the mission may be approved by the Director of OSTP, or, if the Director deems it advisable, the matter will be forwarded to the President for decision.

This EIS for the Cassini mission occurs early during the overall safety analysis process. The safety review and evaluation for this EIS is based on the best currently available information. For the Proposed Action, four representative launch accident scenarios and their associated accident environments were investigated for Phases 1 through 6 (i.e., ignition through Earth escape). The details of the Titan IV (SRMU)/Centaur, a summary of the potential failure modes, the environments that could result from the accidents, and the initiating probabilities of the accidents are presented in the *Titan IV CRAF/Cassini EIS Databook* (Martin Marietta 1992).

In support of this EIS, Martin Marietta Astro Space (formally the Astro Space Division of the General Electric Company) used the *Titan IV CRAF/Cassini EIS Databook* (Martin Marietta 1992) to estimate the response of the RTGs to the representative accident scenarios and environments based on test data and previous analyses for the Ulysses and Galileo missions. In addition, the potential source terms for each of the four major representative accident scenarios for Phases 1 through 6 identified by NASA were estimated. The details of the RTG response and the source terms that could result from the analyzed accidents for the Titan IV (SRMU)/Centaur are given in the *RTG Safety Assessment* (Martin Marietta Astro Space 1993) for Phases 1 through 6.

In addition, NASA and DOE reviewed possible accidents and failures that could occur during the interplanetary cruise of the spacecraft on its trajectory to Saturn and estimated both the probability and consequences of failures that could result in an inadvertent reentry into the Earth's atmosphere by the spacecraft (JPL 1993f, Halliburton NUS 1994a). All launch opportunities using the Titan IV (SRM) involving an Earth-Gravity-Assist (EGA) would be identical to those using the Titan IV (SRMU)/Centaur. Accordingly, the EGA inadvertent reentry conditions and associated risks, as described in *Preliminary Risk Analysis for the Cassini Mission* (Halliburton NUS 1994a), would be identical for the Titan IV (SRM)/Centaur.

Consequence and risk analyses (Martin Marietta Astro Space 1993, Halliburton NUS 1994a) for this EIS were performed using basic assumptions, models, and techniques similar to those reported in the Ulysses EIS (NASA 1990) and developed for the Ulysses FSAR (DOE 1990a). Expectation and maximum case radiological consequences and expectation risk were estimated for the launch accident scenarios identified in this EIS.

The Cassini FSARs, currently scheduled for completion in 1996, are expected to expand the accident analyses in several areas. Monte Carlo analyses of the potential fuel release scenarios for each of the launch accidents are planned using a Cassini-specific Launch Accident Scenario Evaluation Program (LASEP), similar to the analyses performed for FSARs for the Galileo and Ulysses missions (DOE 1989b, DOE 1990a). These analyses should indicate the conditional probability of a fuel release and the amount of damage to the fueled clads once the initiating failure has occurred. Additional work is also expected on the response of the RTG modules to the aerodynamic and thermal conditions expected during an inadvertent reentry associated with an Earth swingby. The Cassini FSARs are also expected to include an uncertainty analysis.

4.1.5.2 Accident Scenarios and Environments

This section briefly discusses the four representative accident scenarios and their associated RTG environments for the launch phases (Phases 1 through 6) of the Cassini mission. In addition, the environment associated with an inadvertent reentry during interplanetary cruise of the spacecraft is also addressed. More detailed information about Phases 1 through 6 accident scenarios and environments is provided in several references (Martin Marietta 1992, Martin Marietta Astro Space 1993, Halliburton NUS 1994a).

The Titan IV (SRMU)/Centaur for the Cassini mission is extensively described in the *Titan IV CRAF/Cassini EIS Databook* (Martin Marietta 1992). This databook also summarizes the potential failure modes for each of the major elements of the Titan IV (SRMU)/Centaur launch system that could result in accident environments posing potential threats to the RTGs on the Cassini spacecraft during Phases 1 through 6.

Four specific accident scenarios were identified as representative of failures that could potentially occur during launch of the Cassini spacecraft:

- Command Shutdown and Destruct
- Titan IV (SRMU) Fail-to-Ignite
- Centaur Tank Failure/Collapse
- Inadvertent Reentry From Earth Orbit.

These scenarios were chosen based on the collective expert judgment that the resulting environments represent the range of credible severe situations and the majority of failures likely to occur result in one of these four scenarios (Martin Marietta 1992). Accidents of concern were then arrayed by the mission launch phase in which they could occur. (See Section 2.2.7 for a discussion of mission launch phases.)

The environments for each of the potential accident scenarios (see Table 4-5) were then analyzed in terms of blast overpressures, fragments, impacts, fire and/or reentry conditions that could threaten the RTGs. The blast overpressures and fires result from the explosion or detonation of the liquid and solid propellants on the launch vehicle. Fragments are generated from the breakup of various launch vehicle components. The reentry conditions refer to the angles of reentry orientation, velocities, and heating environment of the GPHS modules following breakup of the spacecraft.

In addition to the Phases 1 through 6 accident scenarios identified, NASA reviewed the potential accidents and failures that could occur during the interplanetary cruise of the spacecraft on its trajectory to Saturn, and identified two accident scenarios that could lead to an inadvertent reentry of the spacecraft into the Earth's atmosphere. The short-term inadvertent reentry involves an accident/failure occurring during the Earth swingby process that results in an uncontrollable spacecraft being placed on an Earth-impacting trajectory. The long-term inadvertent reentry involves losing spacecraft control prior to the final gravity-assist for that trajectory. The long-term inadvertent reentry would also require the spacecraft to enter an orbit that crosses the Earth's orbital path and additionally reenter the Earth's atmosphere. The *Cassini Earth Swingby Plan* (JPL 1993f) evaluates the proposed VVEJGA and VEEGA trajectories and presents the results of a failure mode analysis for the spacecraft, navigation, and operations during the interplanetary cruise portion of the mission.

The following paragraphs briefly describe each of the postulated accident scenarios for Phases 1 through 6 and the two inadvertent reentry scenarios for the interplanetary cruise portion of the mission.

Command Shutdown and Destruct

At any time during Phases 1 through 5, the Flight Control Officer could elect to activate the command shutdown and destruct system (CSDS) and destroy the launch vehicle. The CSDS is initiated only when the trajectory of the launch vehicle threatens land or populations. Destruct mechanisms would be in place on the launch vehicle, including the core vehicle, the Centaur, and the SRMUs. These destruct mechanisms would ensure that the propellant tanks and/or the solid rocket motor cases split, thrust terminates and propellants disperse, depending on the vehicle configuration at the time when the CSDS is activated.

The most significant environments threatening the RTGs from a CSD scenario would be the blast overpressures (shock waves) from the explosion of the liquid propellants and fragments generated by the breakup of the Cassini spacecraft, the Centaur, and the SRMUs. The *RTG Safety Assessment* (Martin Marietta Astro Space 1993) indicates that in a Phase 1 CSD scenario, the RTGs will be damaged and will either

TABLE 4-5. RTG ENVIRONMENT MATRIX FOR THE TITAN IV (SRMU)/CENTAUR

Accident Scenario	Mission Phase/Mission Elapsed Time[a]					
	1 0 to 11 s	2 11 to 23 s	3 23 to 56 s	4 56 to 246 s	5 246 to 688 s	6 688 to 5,576 s
Command Shutdown and Destruct (CSD)	←Fireball/Thermal— ←—— ←——	—— Blast—— ——Fragment	——→ —— ——	 ——→ ——	 ——→	N/A
Titan IV (SRMU) Fail-to-Ignite	←Fireball/Thermal→ ←Blast→ ←Fragment→	N/A	N/A	N/A	N/A	N/A
Centaur Tank Failure/Collapse	←Fireball/Thermal— ←Blast— ←Fragment—	—— —— ——	——→ —— ——	 ——→ ——→	←Reentry Thermal/	Aerodynamic Forces→
Inadvertent Reentry From Earth Orbit	N/A	N/A	N/A	N/A	N/A	←Reentry→ Thermal/ Aerodynamic Forces

Source: adapted from Martin Marietta 1992

N/A = Environment is not applicable for accident scenario or mission phase.

a. Nominal mission phase elapsed time. Some differences could exist in the exact timing for the primary and the contingency opportunities. Shaded areas indicate the phase when fuel release at ground level could potentially occur.

fall to the launch pad, ground, or ocean surface. The blast overpressures alone are not expected to be sufficient to seriously threaten the integrity of the GPHS modules. However, a secondary impact of the damaged RTG on a hard surface could result in a fuel release. While most fragments would not be expected to have sufficient momentum to severely threaten the RTGs, two types of SRMU fragments, the staging rockets and igniter assemblies, could have sufficient momentum to release the GPHS modules as free objects to impact the ground surfaces. The resulting distortions to the fueled clads from the fragment environment and hard surface impact could result in small fuel releases (Martin Marietta Astro Space 1993).

The physical location of the RTGs near the top of the launch stack would offer protection to the RTGs from most of the fragments that would be generated from the destruction of the launch vehicle.

The surface impact velocity threshold for damage to the RTGs that results in a fuel release is approximately the terminal velocity (55.8 m/s [183 ft/s]) of a tumbling RTG. The RTGs would not be expected to have velocities in this range unless the CSD occurs after T + 6 seconds in Phase 1. If the CSD occurs earlier in Phase 1, the impact velocity of the RTGs on the concrete pad or similar hard surface would not be expected to result in a fuel release.

Should a CSD occur during Phase 5, reentry heating would remove the RTG converter housings leaving GPHS modules to reenter individually by design. If this occurred during the 8 seconds when the Instantaneous Impact Point (IIP) is over Africa, individual reentering GPHS modules could impact rock surfaces with fueled clad failure possible. For other portions of Phase 5, as well as for Phases 2-4, a CSD would result in the RTGs and/or modules impacting the ocean waters and sinking with no release expected (DOE 1990a).

Titan IV (SRMU) Fail-to-Ignite

The failure of one SRMU to ignite at T=0 (Phase 1) would cause the Titan IV with the Centaur and spacecraft to fall in the vicinity of the launch pad (Martin Marietta 1992). If such a failure occurred, the entire launch vehicle would probably begin a rigid body tipover. At about 4 seconds, the vehicle would have tipped to between 25 and 29 degrees from the vertical, and the nonignited SRMU would physically separate from the rest of the launch vehicle. At about 6 seconds, the aft end of the motor would contact the ground first, with the rest of the vehicle then rolling over and crashing. The ground impact would cause the Cassini spacecraft, Centaur, and core vehicle propellant tanks to rupture, and the propellants would mix and explode. The payload fairing would be blown apart by the explosion.

The shock wave from the explosion of the Centaur propellants would completely remove the RTG converter and possibly the graphite components of the RTG, thereby releasing bare-fueled clads. Even if the bare clads were subsequently struck by fragments, only one type of fragment; i.e., SRMU nose cone fragments, could be sufficiently energetic to cause a breach. The maximum velocity of the upper portion of the vehicle at the time of ground impact would not be sufficient to cause the clads to breach, even if they impacted concrete. Thus, only the bare-fueled clads struck by the most energetic SRMU nose cone fragments could possibly fail and release fuel to the environment (Martin Marietta Astro Space 1993).

Centaur Tank Failure/Collapse

The Centaur propellant tanks could fail or collapse during the period while the RTGs are being installed and the propellant tanks filled until immediately after the end of the second Centaur main engine burn when the spacecraft escapes Earth (Martin Marietta 1992). Equipment failures, exceedance of operating or processing requirements, and software or human error could cause the Centaur tank failure/collapse. The Centaur tank assembly could rupture in three ways, resulting in mixing the liquid hydrogen and oxygen propellants: the liquid oxygen tank could rupture to the external surroundings, the liquid hydrogen tank could rupture to external surroundings, or the intermediate bulkhead between the oxygen and hydrogen tanks could fail resulting immediately in rupture to external surroundings. These failures could result in an explosion of the Centaur propellants.

The predicted overpressures (shock waves) from the explosion of the Centaur propellants that would follow a Centaur tank failure/collapse are not expected to result in a release of plutonium fuel. The predicted overpressures and static impulses would be substantially lower than those found necessary in experimental tests to strip the converter shell from the RTG. The momentum of the resulting fragments would also be substantially below the threshold at which incipient breaching of the fueled clads was observed in experimental tests (Martin Marietta Astro Space 1993). Because the RTGs are expected to remain essentially intact after a Centaur propellant explosion, RTG fuel could be released only if the RTGs struck a hard surface end-on with sufficient velocity. Similarly, as for the CSD scenario, the RTGs would not be expected to have impact velocities leading to a release unless the Centaur Tank Failure/Collapse scenario occurred after T + 6 seconds in Phase 1. If the Centaur Tank Failure/Collapse occurs earlier in Phase 1, the impact velocity of the RTGs on the hard surface would not be expected to result in a fuel release.

In Phase 5, a Centaur tank failure/collapse would probably result in the breakup of the spacecraft. Upon atmospheric reentry, the RTG aluminum casing would melt by design releasing the GPHS modules, which would reenter as discrete bodies. It should be noted that there is only an 8-second period during Phase 5 in which the modules could impact limited portions of the African continent under the vehicle flight path. During the balance of Phase 5, the modules would impact in the ocean. Only those GPHS modules which impact a rock surface on the African continent could release fuel.

Inadvertent Reentry From Earth Orbit

Some potential failures associated with Phase 6 could result in the breakup of the spacecraft and the RTGs, with the GPHS modules independently reentering the Earth's atmosphere intact and impacting the surface of the Earth. Failures leading to reentry during Phase 6 include the failure of the Centaur to ignite for its second burn, mechanical and electronic failures, and guidance malfunctions. The types of trajectories that could result from such failures include escape from Earth orbit, gradual orbit decay, reentry, and a powered reentry. Escape from Earth orbit is not considered a type of reentry, but a type of unplanned trajectory with the spacecraft exiting from the Earth's gravitational pull. Most inadvertent reentries in Phase 6 would result from orbital decay with reentry velocities of about 7.8 km/s (25,592 ft/s). Powered reentries could have reentry velocities of up to about 11 km/s (36,091 ft/s). Every failure would not lead to a reentry trajectory. However, for those yielding a reentry, the Cassini spacecraft (including the RTGs) would undergo thermal and mechanical breakup. In some cases, only the Cassini spacecraft would reenter; for others, both the Centaur and Cassini spacecraft would reenter together.

The response of the Cassini RTGs to reentry from Earth orbit (Phase 6) would be considered essentially the same as that for the Ulysses mission (NASA 1990). The RTGs are designed so that the GPHS modules will survive reentry from Earth orbit without fuel release unless they strike a hard surface. The graphite (carbon-carbon composite) aeroshell serves as a heat shield to directly contain the reentry thermal and structural environments while the graphite materials thermally insulate the fueled clad from the aeroshell's resulting high temperatures. Given the predicted reentry latitude bands based on the analyses done for the Ulysses FSAR (DOE 1990a), an average of three GPHS modules are predicted to strike a rock surface with an accompanying fuel release. Impact on soil or water is not expected to result in a fuel release.

Accident Scenarios and Environments with the SRM-Equipped Titan IV

If the Titan IV (SRMU)/Centaur were not available for the Proposed Action launch opportunities, the Titan IV (SRM)/Centaur would be used. The accident scenarios and environments were reviewed relative to the Titan IV (SRMU)/Centaur. Analysis of the Titan 34D-9 launch accident, which occurred April 1986, was also considered. It was estimated that the only threat to the RTGs from the SRMs would arise from the fragments generated in the breakup of the nose cone and possibly the forward closure of the forward SRM segment. Only these fragments travel on a path that could possibly intersect the RTGs (Martin Marietta Astro Space 1994c). The effect of employing SRMs on a Titan IV vehicle for the Cassini mission would be expected potentially to present a somewhat increased fragment hazard (from the hazard level associated with use of the SRMUs) to the RTGs in the event of a vehicle accident.

Short-Term Inadvertent Reentry During Earth Swingby

The short-term reentry scenario involves problems that could occur prior to the Earth swingbys of the VVEJGA and VEEGA trajectories. If an accident or failure (environmental, internal, or ground-induced) resulted in the loss of control of the spacecraft prior to an Earth swingby, the spacecraft could conceivably be placed on an Earth-impacting trajectory. (Earth impact is defined as the spacecraft reentering the Earth's atmosphere.)

NASA will take specific actions to ensure the probability of Earth reentry will be below 1 in a million. These actions include spacecraft and mission design elements, such as extra micrometeoroid protection, raising of the minimum Earth swingby altitude from 300 km (990,000 ft) to 500 km (1,600,000 ft), additional biasing away from the Earth for the trajectory, and mandating special policies regarding uplinking real-time commands and proscribing uplinking real-time commands during parts of the swingby.

During the VVEJGA trajectory of the primary launch opportunity, the spacecraft would fly past the Earth at an altitude of 500 km (1,600,000 ft) and at a velocity of 19.1 km/s (62,700 ft/s) (JPL 1993f). During the VEEGA trajectories of the secondary and backup launch opportunities, the spacecraft would fly past the Earth at altitudes and velocities ranging from 1,500 to 500 km (4,900,000 to 1,600,000 ft) and 16.5 to 17.3 km/s (54,000 to 56,800 ft/s) for the first and second Earth swingbys, respectively.

NASA and DOE have conducted preliminary analyses of the Cassini spacecraft's response to a postulated accidental reentry scenario during the Earth swingby phase of the mission (McRonald 1992a, McRonald 1992b, Foils Engineering 1993, Martin Marietta Astro Space 1994a). The primary factor influencing the spacecraft's response is its reentry angle (i.e., the spacecraft's flight path relative to the surface of the Earth directly below the point of entry). If the spacecraft's flight path angle is very shallow (i.e., less than 7 degrees), the spacecraft is predicted to skip out of Earth's atmosphere without impacting the Earth. Shallow angle reentries were defined as those between 7 and 20 degrees, where steep angle reentries were defined as those between 20 to 90 degrees. Both shallow and steep reentries would subject the spacecraft to severe thermal and mechanical stresses, resulting in the breakup of the spacecraft. Steep reentry angles will subject the GPHS modules to large heating rates and thereby subject the aeroshell to maximum mechanical and thermal stresses. Release of the GPHS modules could occur at altitudes ranging from 67 to 93 km (220,000 to 305,000 ft), depending on the reentry angle. The GPHS modules would then be subjected to severe aerodynamic drag and resulting thermal and mechanical stresses caused by rapid deceleration from the approximately 16.5 to 19 km/s (54,000 to 62,300 ft/s) initial reentry velocities to their terminal velocity (approximately 50.3 m/s [165 ft/s]).

Long-Term Inadvertent Reentry From Interplanetary Cruise

During the non-swingby or interplanetary cruise portions of the gravity-assist trajectories prior to the final gravity-assist, a failure could result in a loss of spacecraft control. If control of the spacecraft was lost and could not be reestablished, the spacecraft could drift in its orbit around the Sun and potentially impact the Earth a decade to centuries later. If the spacecraft fails to enter orbit about Saturn, the resulting trajectories (if altered at all) would tend to be ones that either eject the spacecraft from the solar system or do not cross the Earth's orbital path.

The response of the spacecraft to a long-term reentry would be assumed to be similar to the short-term inadvertent reentry cases. Breakup at high altitude and release of the GPHS modules would be expected. Preliminary analysis indicates a distribution of possible reentry angles, reentry velocities, and reentry latitudes (JPL 1993f). Although these predictions are uncertain, they would generally fall within the range of the short-term reentry analyses for the VVEJGA and VEEGA trajectories. The atmospheric reentry conditions affecting the GPHS modules on a long-term reentry were assumed to be no worse than those predicted for the VVEJGA short-term inadvertent reentry.

4.1.5.3 Probabilities for the Initiating Accidents

This section summarizes the launch system failure probability analysis. A detailed explanation of the analysis can be found in Chapter 10 of the *Titan IV CRAF/Cassini EIS Databook* (Martin Marietta 1992).

Phases 1 Through 6 Accidents

The *Titan IV CRAF/Cassini EIS Databook* (Martin Marietta 1992) presents estimates of the launch failure probabilities with uncertainties for each of four representative accident scenarios that could occur in Phases 1 through 6.

The probability analysis examined the Titan, Centaur, and the Cassini spacecraft separately and then combined the three vehicle analyses at the end of the process, using a Monte Carlo technique, to arrive at a total launch stack probability. The analysis used for the spacecraft implemented a top-down system-level approach that relied extensively on expert engineering judgment for the estimation of credible intervals for the probabilities of spacecraft-induced accident scenarios.

The methodology used for both the Titan IV and the Centaur combined analytical data and failure rate predictions with actual flight history data using an approach facilitated by Bayes Theorem. The theorem allows analytical evaluations (e.g., failure rate analyses and predictions) to be combined mathematically with observed evidence (actual Titan and Centaur flight experience; Centaur ground test data) to develop the probability of failure during a single launch. The analytical evaluations or failure rate predictions were generated using Failure Mode Effects and Analysis (FMEA) data bases. The observed evidence or flight history information included the flight history of all Titan (excluding Intercontinental Ballistic Missile flights) and Centaur vehicles through mid-July 1992 to support publication of the initiating accident probabilities for Chapter 10 of the *Titan IV CRAF/Cassini EIS Databook* in September 1992. The Bayesian technique accounted for changes in the configuration of both the Titan and the Centaur due to design evolution over the years.

The flight history data that was utilized extended over a 30-year period for both the Titan and the Centaur. By the time data gathering for the *Titan IV CRAF/Cassini EIS Databook* was completed, the Titan family of launch vehicles had been used for over 320 launches. Titans have launched spacecraft carrying RTGs five times, and have carried astronauts aloft 10 times. The Centaur at the time the EIS Databook in September 1992 was completed had been involved in 82 launches, 70 of which were successful; six of the 70 were also carrying RTGs. Since June 1989, the Titan IV (SRM) has been involved in eleven successful launches; one launch in August 1993 failed due to a malfunction in one of the solid rocket motors.

In addition, there have been twelve Centaur flights since mid-July 1992 involving eight Atlas/Centaur launches and four Titan IV (SRM)/Centaur launches. One Centaur failed during an Atlas I launch in August 1992 in which one of the two Centaur main engines failed to start. Although the Atlas launch vehicle carrying a Centaur also failed in

March 1993, the Centaur separated and performed as expected. The four Titan IV (SRM)/Centaur launches were all successful.

Because inherent uncertainties are associated with predicted future events, the probability distribution for the accident scenarios, by mission phase, were reported at the 5-percent, 50-percent, mean, and 95-percent levels. Although the historical flight data have not been updated to include all similarly designed launch vehicles and spacecraft launched subsequent to completion of the EIS Databook, the uncertainties as expressed by the probability distributions would encompass most identifiable failure modes and/or accidents. It is unlikely, therefore, that any new information would substantially change the estimated overall initiating failure or accident probabilities. The Titan IV and Centaur flight history, as of September 1992 (date of the completion of the EIS Databook), will be updated in subsequent probability analyses to support the FSAR process. The EIS Databook estimates only represent the probability of the initiating accident, not the overall probability that the RTG would be damaged and that fuel would be released.

It should be noted that in the initial flight design for Phase 6, the spacecraft would be in a low Earth parking orbit for up to 1 day. This short time period would not allow recovery from some failure modes, such as failure of the Centaur engine to restart, and resulted in an estimated mean initiating probability of inadvertent reentry from Earth orbit of 2.0×10^{-2} or about 1 in 50 (Martin Marietta 1992). To reduce the probability of reentry from low Earth parking orbit, new project requirements were added in 1994 to use a 10-day parking orbit. Upon successful Centaur/spacecraft separation, the spacecraft propulsion system would be used to achieve a long-lived orbit. This would result in a mean initiating probability of inadvertent reentry from Earth orbit of 2.0×10^{-3} or about 1 in 500 (Bream 1994).

Table 4-6 presents the full range of initiating accident probability (i.e., per mission accident scenario frequency) estimates for the representative accident scenarios in Phases 1 through 6 (Martin Marietta 1992, Bream 1994). The initiating accident probability is the probability of a specific initiating accident scenario occurring. Even though an initiating accident occurs, fuel is not always released to the environment. Therefore, an additional probability, called a conditional probability, is also considered.

The conditional probability is the probability that the RTGs will sustain sufficient damage to result in a release of plutonium dioxide fuel once a specific type of accident (initiating accident) occurs. Therefore, the total probability of release for a given accident scenario is the product of the probability of the initiating accident occurring and the conditional probability of a plutonium dioxide release. Conditional and total probabilities will be discussed in Section 4.1.5.4.

Initiating Accident Probabilities Associated with the Titan IV (SRM)/Centaur

Initiating accident probabilities for the SRMU-equipped Titan IV were generated based on previously developed hardware failure rate data for the SRM. This was considered conservative because the SRMU is an upgraded or enhanced version of the SRM. Although updated initiating accident probabilities for the Titan IV (SRM)/Centaur are not currently available, these failure probabilities for the SRM are not expected to differ

TABLE 4-6. INITIATING ACCIDENT SCENARIO PROBABILITIES FOR PHASES 1 THROUGH 6 FOR THE TITAN IV (SRMU)/CENTAUR

Initiating Accident Scenario		Mission Launch Phase[a]						Mission Launch Phase Totals by Scenario
		1 0 to 11 s	2 11 to 23 s	3 23 to 56 s	4 56 to 246 s	5 246 to 688 s	6 688 to 5,576 s	
Command Shutdown and Destruct (CSD)	5%	4.9×10^{-5}	5.3×10^{-5}	3.7×10^{-5}	1.6×10^{-3}	1.1×10^{-2}	Not Applicable	1.9×10^{-2}
	Median	2.4×10^{-4}	2.6×10^{-4}	2.5×10^{-4}	8.3×10^{-3}	2.8×10^{-2}		4.1×10^{-2}
	Mean	4.4×10^{-4}	4.6×10^{-4}	5.9×10^{-4}	1.1×10^{-2}	3.2×10^{-2}		4.5×10^{-2}
	95%	1.3×10^{-3}	1.5×10^{-3}	2.3×10^{-3}	3.0×10^{-2}	6.6×10^{-2}		8.3×10^{-2}
Titan IV (SRMU) *Fail-to-Ignite*	5%	2.2×10^{-5}	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	2.2×10^{-5}
	Median	4.5×10^{-4}						4.5×10^{-4}
	Mean	1.4×10^{-3}						1.4×10^{-3}
	95%	5.8×10^{-3}						5.8×10^{-3}
Centaur Tank Failure/Collapse[b] (excluding Earth escape)	5%	1.2×10^{-5}	4.6×10^{-6}	1.3×10^{-5}	3.0×10^{-4}	1.7×10^{-4}	1.5×10^{-5}	1.2×10^{-3}
	Median	5.1×10^{-5}	4.4×10^{-5}	1.2×10^{-4}	9.5×10^{-4}	1.3×10^{-3}	1.1×10^{-4}	3.7×10^{-3}
	Mean	1.1×10^{-4}	1.1×10^{-4}	2.9×10^{-4}	1.8×10^{-3}	2.6×10^{-3}	2.6×10^{-4}	5.2×10^{-3}
	95%	3.9×10^{-4}	4.1×10^{-4}	1.2×10^{-3}	6.5×10^{-3}	9.7×10^{-3}	9.0×10^{-4}	1.5×10^{-2}
Inadvertent Reentry From Earth Orbit[b] (excluding Earth escape)	5%	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	3.4×10^{-4}	3.4×10^{-4}
	Median						1.2×10^{-3}	1.2×10^{-3}
	Mean						1.7×10^{-3}	1.7×10^{-3}
	95%						4.6×10^{-3}	4.6×10^{-3}
Scenario Totals By Mission Phase[c]	5%	2.6×10^{-4}	1.0×10^{-4}	1.1×10^{-4}	2.7×10^{-3}	1.3×10^{-2}	4.5×10^{-4}	Not Applicable
	Median	1.0×10^{-3}	3.6×10^{-4}	5.0×10^{-4}	1.0×10^{-2}	3.1×10^{-2}	1.5×10^{-3}	
	Mean	1.9×10^{-3}	5.7×10^{-4}	8.8×10^{-4}	1.3×10^{-2}	3.4×10^{-2}	2.0×10^{-3}	
	95%	6.9×10^{-3}	1.8×10^{-3}	3.1×10^{-3}	3.3×10^{-2}	7.0×10^{-2}	4.8×10^{-3}	

Sources: Martin Marietta 1992, Bream 1994

[a] Mission phase timeframes are subject to change.

[b] *Probability estimates for Phase 6 reflect new 1994 project requirements (Bream 1994) that require the spacecraft to be placed in a higher Earth parking orbit than initially assumed (Martin Marietta 1992).* With the spacecraft in the higher orbit, the mean initiating probability of an inadvertent reentry is reduced by nearly a factor of 10.

[c] The probability estimate for the 5%, median, mean, and 95% scenario totals by mission phase were obtained by a Monte Carlo summation process.

significantly from those for the SRMU. Therefore, it was assumed that the initiating probabilities for the SRM would approximate those estimated for the SRMU.

Design Requirements Regarding Inadvertent Reentry

Mission and spacecraft design precautions must be taken to ensure that an inadvertent reentry into Earth's atmosphere with a resulting impact upon the Earth's surface does not occur during the Earth swingby(s) of the Proposed Action trajectories. Moreover, design precautions must also be taken to prevent a loss of spacecraft control during the interplanetary cruise to preclude a potential Earth impact years later.

To this end, a Cassini formal design requirement was imposed to ensure the expected probability of Earth impact does not exceed 10^{-6} (i.e., 1 in a million) (JPL 1993f):

> Following injection, the probability of Earth impact by the spacecraft shall not exceed 10^{-6} taking into account potential failures.

To verify that this requirement can be satisfied during the mission, an assessment of the Earth impact probability was performed by JPL (JPL 1993f). The JPL study was conducted to determine the necessary actions in spacecraft, ground system, and navigation to ensure that the probability of Earth impact would satisfy the design requirement. The study also included a quantitative assessment of the probability of Earth impact, including evaluation of the uncertainties in the assessment process. Additional details of that study can be found in Appendix B. JPL has performed the necessary actions in spacecraft, ground system and navigational design to ensure that the Cassini mission complies with the 10^{-6} design requirement (JPL 1993f). Some of the design changes included additional micrometeoroid protection, raising of the minimum Earth swingby altitude from 300 km to 500 km (9.9×10^5 to 1.6×10^6 ft), additional biasing away from the Earth for the trajectory, and mandating special policies regarding uplinking real-time commands during parts of the swingby. Additionally, an independent review panel found the approach taken by JPL to assess the probability of inadvertent reentry to be sound and reported that JPL's results are reasonable (Cassini Swingby Independent Review Panel 1995).

Short-Term Inadvertent Reentry Probability Assessment

The short-term Earth-impact component is the contribution resulting from the navigation of the planned Earth swingbys for a given trajectory (VVEJGA or VEEGA). Calculating the short-term probability of Earth impact required evaluating three factors: the failure probabilities and associated anomalous velocity changes, the uncertainties in the navigation process, and the characteristics of the spacecraft trajectory.

To keep the short-term inadvertent reentry probability low, a trajectory-biasing strategy is used. During most of Cassini's inner solar system journey, the spacecraft is on a trajectory that, without further maneuvers, would miss the Earth by tens of thousands of kilometers. The spacecraft would not be placed on a trajectory passing through the actual Earth swingby point, as close as 500 km (1.6×10^6 ft), until 10 days prior to the Earth swingby for the VVEJGA, and 7 days prior to each of the two Earth swingbys for the VEEGA.

An extensive failure mode analysis of the spacecraft and ground support systems was performed (JPL 1993f) to identify failures that could result in sufficient spacecraft directional and velocity changes to place the spacecraft on an Earth-impacting trajectory. Three general categories of failures were evaluated: environmentally-induced failures, such as micrometeoroid impacts; internal failures, such as stuck thruster valve and electronic failures; and ground-induced failures, such as incorrect navigation commands. Unless the failure completely incapacitates the spacecraft, the normal course of action is to accurately determine the spacecraft trajectory and, if required, command a recovery sequence to modify the trajectory and avoid Earth reentry.

For most of the failures identified, redundant backup systems and adequate time exists to correct any problems and avoid Earth impact. Of all the failure modes identified, only micrometeoroid-induced propellant tank ruptures contribute significantly to the short-term impact probability. The contribution of all other environmental, internal and external failures is small, principally because either they do not change the spacecraft's trajectory enough to place the spacecraft on an Earth-impact trajectory or adequate time or backup systems exist to correct the problem.

The navigation plan is to utilize a trajectory biasing strategy which breaks the overall trajectory, from leaving Earth's gravitational field after launch to the Earth swingby, into segments. The final aimpoint at Earth needed to satisfy the required swingby conditions is not imposed until the final segment. Before the final segment, the spacecraft trajectory remains biased away from Earth so that the potential changes in the trajectory caused by any problems will not result in the spacecraft reentering the Earth's atmosphere. This is accomplished by predicting how much each type of failure could change the spacecraft's trajectory and ensuring that the navigation plan keeps it far enough away from Earth so that any changes caused by a failure would not change the course toward an Earth intercept.

The probability of Earth impact is presented as a probability density function (PDF) over the model uncertainties. To calculate a PDF for the short-term Earth impact probability, it was necessary to perform a Monte Carlo simulation for both the 1997 primary and 1999 backup trajectories. The mean values for the resulting distributions are 7.6×10^{-7} and 4.7×10^{-7}, respectively (JPL 1993f). For the backup trajectory, the first Earth swingby has a probability of 1.9×10^{-7} while the second Earth swingby has a probability of 2.8×10^{-7}. Because the trajectories for the secondary and backup launch opportunities are similar, the Earth impact probability for the secondary is expected to be similar to the backup. The contribution to short-term Earth impact probability, however, is expected to be less for the secondary mission because the first Earth swingby altitude is much higher than that of the backup mission. In general, the Earth impact probability decreases as the swingby altitude increases. Appendix B of this EIS presents further details.

Long-Term Inadvertent Reentry Probability Assessment

The long-term Earth-impact component is the contribution from a failure during interplanetary cruise that leads to a disabled spacecraft drifting into an Earth crossing orbit so that it reencounters the Earth sometime beyond the nominal Saturn encounter date. For this analysis, the possibility of impact during the first 100 years was considered. The significant spacecraft failure mode for the long-term component is internal failure of a spacecraft system (JPL 1993f). The probability of long-term inadvertent Earth reentry given a failure is influenced by the trajectory characteristics of the spacecraft at the time of failure. Failures on legs targeted to Venus or Earth swingbys tend to result in trajectories that remain in the vicinity of Earth's orbit. Failures on legs targeted to Jupiter or Saturn tend to result in trajectories that never return to the vicinity of Earth's orbit. The gravity-assists by the massive outer planets virtually ensure that failures during the last 73 percent of the primary and last 44 percent of the backup interplanetary cruise do not result in the possibility of an Earth reentry (JPL 1993f).

The long-term reentry analysis computes the probability of Earth impact of a non-targeted swingby from the time of spacecraft failure to 100 years beyond the planned SOI. This computation encompasses the long-term probability of Earth impact, projected spacecraft failure probabilities, associated anomalous spacecraft velocity changes, the uncertainties in the navigation process, and the long-term motion of the spacecraft. Only failures that would cause the spacecraft to become uncommandable with no chance of recovery were considered in the long-term inadvertent reentry probability assessment.

Using existing theory on Earth-crossing asteroids, a Monte Carlo analysis identified the number of crossings of the spacecraft through the path of the Earth. The spacecraft must cross the Earth's orbital path, and, at the time of the crossing, the Earth must be in a position for an impact to occur. An uncertainty analysis was performed to yield the probability distributions for both the number of orbital crossings per case and the probability of Earth impact given that a crossing occurs. These distributions were combined with the spacecraft failure distribution to yield a PDF for the long-term Earth impact probability.

The mean long-term impact probability over 100 years is 6.0×10^{-8} for the primary mission and 4.0×10^{-7} for the backup mission (JPL 1993f). The impact probability is larger for the backup mission due to the longer cruise duration and the different interplanetary trajectory characteristics. It is reasonable to assume that the long-term probability associated with the secondary launch opportunity would be similar to or less than that for the backup opportunity. In nearly all cases, an important result of the analysis is that for failures occurring during the latter half of the interplanetary cruise for both launch opportunities, the spacecraft would be quickly ejected from the solar system by a strong Saturn gravity-assist, thereby precluding any possibility of Earth impact.

4.1.5.4 Potential Accident Source Terms

The expectation and maximum case source terms were developed in the *RTG Safety Assessment* (Martin Marietta Astro Space 1993) for the Titan IV (SRMU)/Centaur and subsequently supplemented (Owings 1994a) based on an evaluation of the response of the RTGs to accident environments with consideration given to RTG component safety test data and accident analyses performed for the Ulysses mission (DOE 1990a). The expectation source terms for a given accident scenario represent a probability-weighted source term, based on a range of release conditions considered in the analysis. The maximum case source terms correspond either to the upper limit deemed credible for the scenario based on consideration of supporting analyses and safety test data, or to a total probability greater than or equal to a probability cutoff of 1.0 x 10^{-7}. In either case, the estimates are nominal in that no uncertainties are considered. The uncertainties are expected to be addressed in the Cassini FSARs. Larger source terms with correspondingly lower probabilities may ultimately be predicted for the Cassini FSARs.

Since the publication of the DEIS, ongoing analyses of the potential accident scenarios and environments and testing of the spacecraft hypergol fuels indicated that the launch vehicle configuration for the Proposed Action would not require a Space Vehicle Destruct System (SVDS) for the Cassini spacecraft. The analyses concluded that without the SVDS, the resulting environments would not present increased hazards to the RTGs (DOE 1995). Therefore, the estimated source terms and consequences presented in the EIS (Sections 4.1.5.4 and 4.1.6) do not change.

As part of the nuclear launch safety approval process, DOE will prepare a more in-depth evaluation of the potential consequences in the Cassini FSARs. NASA will review the FSARs, when they become available, and will evaluate the information presented for differences, if any, in the estimates of the potential consequences.

Phases 1 Through 6 Accident Scenarios

The *RTG Safety Assessment* contains a detailed development of the source terms estimated for each of the four representative accident scenarios identified for Phases 1 through 6 (Martin Marietta Astro Space 1993). The approach used for this safety assessment was to estimate the response of the RTG to each of the accident scenarios on the basis of the similarity of the associated accident environments to those analyzed in detail for the Ulysses mission (DOE 1990a). The Ulysses mission FSAR was used because it has the most recent analyses conducted and includes both the latest analytical techniques and test data. In the inadvertent reentry from the Earth orbit scenario, the conditions that the RTG would be exposed to in the Cassini mission are essentially identical to those in the Ulysses scenario; therefore, many of the evaluations performed for the Ulysses mission are applicable to the Cassini mission.

Table 4-5, given previously, provides the associated RTG accident environments applicable to each scenario by phase. Table 4-7 summarizes the source terms resulting from the accident scenarios in Phases 1 through 6 and their total probabilities (initiating accident probability times conditional release probability). In the first three accident scenarios (Command Shutdown and Destruct, Titan IV (SRMU) Fail-to-Ignite, and Centaur Tank Failure/Collapse), none of the initial explosions that could occur are predicted to result in a release of plutonium dioxide fuel. An SRMU nose fragment impact on bare fueled clads occurring as a result of a Titan IV (SRMU) Fail-to-Ignite accident scenario could result in a fuel release. The other releases of radioactive fuel predicted to occur from these scenarios would result from the impact of the RTGs, GPHS modules, or fueled clads on hard ground surfaces. These ground impacts were assumed to occur on concrete surfaces in the launch pad area during Phase 1 and on rock in Phase 5 during the portion of the trajectory when the instantaneous impact point of the launch vehicle is over Africa. Inadvertent reentry during Phase 6 could result in a fuel release for any GPHS modules impacting rock surfaces. No source terms have been identified for Phases 2, 3, and 4 (Martin Marietta Astro Space 1993). Should the SRM-equipped Titan IV be used, the RTG damage is expected to be nearly the same as for the Titan IV (SRMU)/Centaur (Martin Marietta Astro Space 1994c).

TABLE 4-7. SUMMARY OF LAUNCH PHASES 1 THROUGH 6 ACCIDENT SCENARIO SOURCE TERMS AND PROBABILITIES FOR THE TITAN IV (SRMU)/CENTAUR[a]

Mission Phase	Accident Scenario Description		Mean Initiating Probability[a]	Conditional Probability	Total Probability	Source Term Bq (Ci)[b]	Release Location
1	Command Shutdown and Destruct (RTG end-on and GPHS modules impacts on concrete, with and without fragment impacts)	Exp. Case[c] Max. Case[d,e]	4.4×10^{-4}	3.84×10^{-1} 5.00×10^{-3}	1.69×10^{-4} 2.20×10^{-6}	2.97×10^{11} (8.02) 1.06×10^{12} (28.7)	CCAS-Ground
1	Titan IV (SRMU) Fail-to-Ignite (Bare fueled clads impacted by SRMU nose cone fragments)	Exp. Case[c] Max. Case[d]	1.4×10^{-3}	6.52×10^{-1} 9.29×10^{-5}	9.13×10^{-4} 1.30×10^{-7}	1.38×10^{11} (3.72) 5.96×10^{11} (16.1)	CCAS-Ground
1	Centaur Tank Failure/Collapse (RTG end-on impact on concrete, with/without fragment impacts)	Exp. Case[c] Max. Case[d]	1.1×10^{-4}	3.83×10^{-1} 5.00×10^{-3}	4.21×10^{-5} 5.50×10^{-7}	2.98×10^{11} (8.06) 1.06×10^{12} (28.7)	CCAS-Ground
5	Command Shutdown and Destruct (GPHS module impacts on rock, Africa)	Exp. Case[c] Max. Case[d]	3.2×10^{-2}	1.44×10^{-2} 6.25×10^{-6}	4.61×10^{-4} 2.00×10^{-7}	5.44×10^{10} (1.47) 2.77×10^{11} (7.49)	Africa-Ground
5	Centaur Tank Failure/Collapse (GPHS module impacts on rock, Africa)	Exp. Case[c] Max. Case[d]	2.6×10^{-3}	1.44×10^{-2} 5.77×10^{-5}	3.74×10^{-5} 1.50×10^{-7}	5.44×10^{10} (1.47) 2.35×10^{11} (6.34)	Africa-Ground
6	Inadvertent Reentry from Earth Orbit (GPHS module impacts on rock)	Exp. Case[c] Max. Case[d]	2.0×10^{-3}	2.18×10^{-1} 5.00×10^{-5}	4.36×10^{-4} 1.00×10^{-7}	5.55×10^{10} (1.50) 2.77×10^{11} (7.49)	Unspecified locations worldwide-Ground

Sources: Martin Marietta 1992, Martin Marietta Astro Space 1993, Halliburton NUS 1994a, Bream 1994

a. Initiating probability estimates have been reported from the *Titan IV CRAF/Cassini EIS Databook* (Martin Marietta 1992). Phase 6 initiating probabilities have been modified in accordance with new project requirements (Bream 1994).

b. All source terms occur effectively at ground level as opposed to releases at altitudes above ground level. All source terms in Phase 1 are influenced by the fireball. The fireball would tend to vaporize a fraction of the fuel released and increase the number of respirable particles. No source terms were identified for Phases 0, 2, 3, and 4.

c. The expectation values represent a probability-weighted average source term based on a range of release conditions for a given scenario (Halliburton NUS 1994a).

d. A maximum case corresponds to either the upper limit deemed credible for a given scenario based on consideration of supporting analyses and the safety test data, or that corresponding to a total probability greater than or equal to a probability cutoff of 1.0×10^{-7}. Larger source terms with correspondingly lower conditional probabilities may be ultimately predicted for the Cassini FSARs (Halliburton NUS 1994a).

e. The total probability of the maximum case is the sum of the total probabilities for those paths leading to the highest source term of 1.06×10^{12} (28.7 Ci) (Halliburton NUS 1994a).

Short-Term Inadvertent Reentry During Earth Swingby

A detailed development of the expected source terms for the inadvertent reentries associated with the VVEJGA and VEEGA trajectories is reported in *Preliminary Risk Analysis of the Cassini Mission* (Halliburton NUS 1994a). This report summarizes the expected probability distributions for reentry angle and reentry latitude, RTG breakup and GPHS module release altitude versus reentry angle, aerodynamic and thermal behavior of the GPHS modules on reentering, ablation of the GPHS modules under thermal stresses, and reentry response of fuel particles as a function of reentry conditions. Additional details can be found in Appendix B. Since swingby reentry conditions are independent of the specific launch vehicle, radiological consequences associated with the Cassini spacecraft on a VVEJGA trajectory are assumed to be the same for an SRMU- and SRM-equipped Titan IV launch vehicle.

Based on reentry analyses, it was concluded that for both shallow (7-20 degrees) and steep (20-90 degrees) reentry angles, the 54 GPHS modules (i.e., 18 modules per RTG) would reenter independently and that the response of each GPHS module to the thermal and mechanical stresses of deceleration during reentry could vary significantly, depending on the reentry angle and motion of the GPHS during reentry. The preliminary modeling indicated that complete burn-through of the graphite aeroshell could occur if the GPHS module reentered in a broadside stable orientation. This could lead to the release of the graphite impact shells (GISs) and possibly the release of fuel particles at high altitude. If the GPHS modules exhibit any significant tumbling motion during reentry, significant ablation (about 60 percent of the aeroshell wall thickness) could occur, but burn-through is not predicted.

Thus, the mechanical and thermal stresses resulting from the reentry heating at high altitude is expected to result in the failure of the RTG housing and release of the 54 GPHS modules. The variations in the reentry conditions that these 54 GPHS modules experience is predicted to result in a range of fuel end states, including damaged and undamaged GPHS aeroshell modules, GISs, fuel chunks, and fuel particles and vapor.

Based on the best available information, evaluations determined that these fuel end states were possible for both shallow and steep reentry angles. DOE staff and contractors with expertise in RTG-reentry and RTG-safety developed probability estimates of the range of potential fuel end states using Failure/Abort Sequence Trees (FASTs). The conditional probability of the various fuel end states was based on the available analyses. This approach allowed the estimation of the "expected" or probability-weighted fuel end states predicted for the VVEJGA and VEEGA reentry cases evaluated. For each swingby case, the expectation source term for both the shallow and steep reentry cases was estimated.

Table 4-8 summarizes the expectation source terms for the VVEJGA and VEEGA swingby inadvertent reentry accidents as presented in the *Preliminary Risk Analysis of the Cassini Mission* (Halliburton NUS 1994a). Four basic fuel end states were selected as representative of the possible combinations:

- Intact GPHS Modules—The modules that survive reentry intact decelerate to their terminal velocities, 50.3 m/s (165 ft/s), before they strike the Earth's surface. The release of fuel from the fueled clad is not expected unless the

TABLE 4-8. SUMMARY OF AVERAGE (EXPECTATION) CASE SOURCE TERMS FOR INADVERTENT REENTRIES DURING EARTH SWINGBY[a]

Fuel End State	Primary: VVEJGA		Backup: VEEGA-E1[b]		Backup: VEEGA-E2[b]	
	Number of Components	Expectation Source Term[c] Bq (Ci)	Number of Components	Expectation Source Term[c] Bq (Ci)	Number of Components	Expectation Source Term[c] Bq (Ci)
Intact Module (54 total)	20.4		19.3		22.8	
Rock Impact	0.82	5.59×10^{13} (1.51×10^{3})	0.92	6.25×10^{13} (1.69×10^{3})	0.56	3.77×10^{13} (1.02×10^{3})
Soil Impact	4.3	—	4.3	—	5.5	—
Water Impact	15.3	—	14.1	—	16.7	—
Intact Module (54 total) (damaged/GIS intact)	5.7		5.8		5.6	
Rock Impact	0.23	6.29×10^{13} (1.70×10^{3})	0.28	7.55×10^{13} (2.04×10^{3})	0.13	3.77×10^{13} (1.02×10^{3})
Soil Impact	1.2	8.29×10^{13} (2.24×10^{3})	1.3	8.88×10^{13} (2.40×10^{3})	1.3	9.29×10^{13} (2.51×10^{3})
Water Impact	4.3	—	4.2	—	4.2	—
Intact GISs (108 total)	20.4		22.8		15.6	
Rock Impact	0.81	1.13×10^{14} (3.06×10^{3})	1.1	1.48×10^{14} (4.00×10^{3})	0.38	5.18×10^{13} (1.40×10^{3})
Soil Impact	4.3	2.08×10^{14} (5.62×10^{3})	5.1	1.75×10^{14} (4.73×10^{3})	3.7	1.28×10^{14} (3.46×10^{3})
Water Impact	15.3	—	16.6	—	11.5	—
Fraction of Fuel Released at High Altitude[d]	0.327 of total	4.88×10^{15} (1.32×10^{5})	0.325 of total	4.88×10^{15} (1.32×10^{5})	0.330 of total	$4.96\ 10^{15}$ (1.34×10^{5})

Source: Halliburton NUS 1994a

a. The average (expectation) source terms for inadvertent reentries during an Earth swingby would be the same for the Titan IV (SRMU or SRM)/Centaur configuration.

b. E1 and E2 represent the first and second targeted Earth swingby for the VEEGA trajectory.

c. The expectation source terms are probability-weighted source terms using the conditional probabilities for the shallow or steep reentries. For the primary VVEJGA case, the expectation case values = 0.25 x (Shallow Values) + 0.75 x (Steep Values). For the VEEGA trajectory the conditional probabilities (weighting factors) for shallow and steep reentries are 0.11 and 0.89, respectively, for the E1 case. The corresponding values for the E2 case are 0.54 and 0.46.

d. Fraction of the total plutonium fuel inventory released.

GPHS modules strike a hard surface, such as rock. For rock impacts, the assumed release fraction is 25 percent. For the shallow and steep VVEJGA and VEEGA reentry cases studied, an average of 34 (steep reentries) to 49 percent (shallow reentries) of the GPHS modules from the 3 RTGs are expected to survive reentry intact.

- Intact But Damaged GPHS Modules With Intact GISs—The post-reentry heating conditions are assumed to degrade the modules and GISs to the point that the total release of fuel is assumed to occur from any GIS impacting rock surfaces and a release of 25 percent is assumed if they strike soil. No release is predicted from water impacts. For the reentry cases studied, an average of 10 to 11 percent of the GPHS modules are expected to survive reentry with damaged but intact modules.

- Intact GISs—The GISs that survive reentry decelerate to their terminal velocities, 61 m/s (200 ft/s), before they strike the Earth's surface. The GISs would probably degrade to the point that the total release of fuel from the fueled clads is assumed if they strike rock, and a release fraction of 25 percent is assumed if they strike soil. No release is predicted from water impacts. For the reentry cases studied, an average of 7.3 (shallow reentries) to 23 percent (steep reentries) of the GISs are expected to be released from the GPHS modules at high altitude and to survive reentry.

- Fuel Particle and Vapor—For all the reentry cases studied, about 32 to 34 percent of the fuel from the three RTGs is expected to be released at high altitude. An evaluation was performed (Foils Engineering 1993) to determine the reentry response of fuel particles as a function of reentry conditions. Based on this analysis and the expected initial particle size distribution of the fuel, the particle size distribution of the fuel released during reentry was calculated as a function of the reentry angle. The fraction of the fuel particles released during reentry estimated to be reduced to vapor or respirable particles less than 10 microns (μm) ranges from 66 percent for very shallow reentries (8 degrees) to about 20 percent for steep (90 degree) reentries. The remainder of the fuel is released in particulate form, with about 4 to 7 percent in the 10 to 6,000 μm (0.004 to 0.24 in.) size range and the remainder in large pieces greater than 6,000 μm (0.24 in.) in diameter.

The footprints for debris following spacecraft breakup for a range of reentry conditions, including orbital decay, shallow- and steep-angle reentries, and VEEGA inadvertent reentry conditions, were examined for the Galileo mission (McRonald 1988, INSRP 1989b). The size and shape of the footprint of the debris (GPHS modules, GISs, and larger fuel particles) following the breakup of the spacecraft during an inadvertent swingby reentry are expected to vary considerably with the reentry angle. For Galileo, using a VEEGA trajectory, a shallow angle reentry footprint could have had a length of 280 km (174 mi) or more, and a steep-angle reentry could have had a footprint of 50 km (31 mi) long. For 90-degree (directly overhead) reentries, the footprint was predicted to cover nominally 10 km^2 (4 mi^2) (Halliburton NUS 1994a).

Further analysis of the fallout footprint was done as a function of reentry angle. When the reentry angles are probability weighted according to each Earth-Gravity-Assist reentry type, the resulting footprint areas were estimated (see Table 4-9).

TABLE 4-9. ESTIMATED FOOTPRINT AREAS FOR REENTRY TYPES

Reentry Type	Shallow Reentry km^2 (mi^2)	Steep Reentry km^2 (mi^2)
VVEJGA	27,600 (10,656)	4,800 (1,853)
VEEGA (E1)[a]	26,700 (10,309)	4,100 (1,583)
VEEGA (E2)[a]	28,200 (10,888)	7,200 (2,780)

Source: Halliburton NUS 1994a

a. E1 and E2 represent the first and second Earth swingbys for the VEEGA trajectory identified for the secondary and backup launch opportunities.

Long-Term Inadvertent Reentry From Interplanetary Cruise

The response of the spacecraft to a long-term reentry is expected to be similar in character to the short-term Earth swingby reentry case with breakup at high altitude and release of the GPHS modules. Preliminary analyses of the long-term reentry indicate that the distribution of possible reentry angles, reentry velocities, and reentry latitudes generally fall within the range of the short-term reentry analyses for the VVEJGA and VEEGA trajectories (JPL 1993f). The atmospheric reentry conditions affecting the GPHS modules on a long-term reentry were assumed to be no worse than those predicted for the VVEJGA inadvertent swingby reentry.

There are uncertainties related to the amount of potential fuel release from a long-term inadvertent reentry. These uncertainties would include timing of the reentry, which has bearing on the composition of the plutonium dioxide fuel. The amount of fuel released (i.e., source term) in a long-term reentry would be expected to be similar to that predicted for the VVEJGA and VEEGA inadvertent swingby reentries and its radioactivity could be less because of decay of the plutonium-238. The dominant radiological component of the fuel, plutonium-238, has a half life of 87.75 years. Because of radioactive decay and accounting for all the plutonium isotopes in the original fuel, the amount of plutonium remaining after 100 years is 45 percent, after 500 years is 2 percent, after 1,000 years is 0.13 percent, and after 5,000 years is 0.08 percent. In addition, there are other uncertainties related to the aging of the RTG components and the total world population and its distribution at the time of reentry.

4.1.6 Environmental Consequences and Impacts of Radiological Accidents

The following sections discuss the methodologies and radiological consequences associated with a mission accident. Section 4.1.6.1 describes the methodologies that lead to the radiological consequences (Section 4.1.6.2). Section 4.1.6.3 describes the impacts to the affected environment determined by the CCAS regional area and global area. It should be noted that the radiological methodologies and consequences of an inadvertent reentry during the interplanetary cruise portion of either the VVEJGA or VEEGA are associated with the short-term inadvertent reentry only.

4.1.6.1 Radiological Consequences Methodology

This section describes the methodologies and criteria available to assess the radiological consequences (Section 4.1.6.2) from a postulated representative accident.

The potential radiological consequences of the representative accident scenarios have been estimated using the methods described in the Ulysses FSAR (DOE 1990a) and Final EIS (FEIS) (NASA 1990). In developing the radiological consequences, the results presented in the Galileo FSAR (DOE 1989a) and FEIS (NASA 1989b) were also considered. Details on the dose calculation methodology are presented in Appendix A of the Ulysses FEIS (NASA 1990), as well as in Volume III, Books 1 and 2 of the *Final Safety Analysis Report* for the Ulysses Mission (DOE 1990b).

All the source terms of interest involve releases in the atmosphere, either near ground level or at high altitudes. The atmospheric transport and dispersion of such releases is modeled to determine the time-integrated airborne and ground concentrations with respect to population and surface feature (land/water) distributions and other environmental media (e.g., vegetation, soil, and water). Generally, this methodology entails the use of three models: EMERGE, LOPAR, and HIPAR. EMERGE is used for releases in the troposphere (up to about 10 km [6 mi]); LOPAR and HIPAR are used for higher altitude releases of small particles and vapor (less than 10 microns in physical diameter) and large particles (greater than 10 microns in physical diameter), respectively. Key features of these models are given below:

- EMERGE, a three-dimensional Gaussian puff-trajectory model that treats time- and space-varying meteorological conditions, accounts for the vertical plume configuration; particle-size-dependent transport, deposition, and plume depletion; and sea-breeze recirculation in the vicinity of the launch site.

- LOPAR, an empirical model derived for small particles from weapons testing data, accounts for worldwide circulation patterns and delayed fallout as a function of latitude band.

- HIPAR, a large-particle trajectory model, accounts for the altitudinal variation in atmospheric properties and the rotation of the Earth. HIPAR uses a wind field that is a function of the latitude, longitude, and altitude.

The EMERGE model interfaces with a demographic and surface feature data base for the CCAS/KSC regional area. Both LOPAR and HIPAR interface with a worldwide demographic data base to facilitate the estimation of radiological impacts.

After modeling the atmospheric transport and dispersion of the releases with one or more of these models, the radiation doses to the general population from exposure to the radioactive material concentrations in the environment are determined by considering the following exposure pathways:

- Direct inhalation of released material
- Inhalation of resuspended material previously deposited on the ground
- Ingestion of contaminated food (vegetables and seafood)
- External exposure to ground-deposited material.

The exposure pathway parameters and the internal dose conversion factors used in this analysis are identical to, or updated from, those used in the Ulysses FSAR (DOE 1990a, Halliburton NUS 1994a).

Individual and Collective Radiological Dose

Exposure to plutonium dioxide from an accident could occur in several ways. Following an accident, exposure could result from inhalation of respirable particles of plutonium dioxide in the immediate vicinity of the accident. While there could be some direct exposure (neutron and gamma exposure) within a few feet of the GPHS modules or large particles, the principal radiological health concern would be inhalation of very small respirable size particles (approximately 3 μm or less). The very small respirable particles would be the principal hazard because they can remain in the body for many years if inhaled; larger particles can be expelled.

These small particles or vapor could also present an exposure hazard downwind of the accident when the radioactively contaminated plume passes. This is a concern for both Phase 1 launch pad accidents and Phases 5 and 6, and Earth swingby accidents where the GPHS modules could impact rock. For an inadvertent Earth swingby accident, exposure could also result from inhalation of plutonium dioxide vapor and small particle fallout from a high altitude release. Most of the vapor released at high altitude would be expected to fall back to the Earth's surface within 5 years. Because most of the plutonium dioxide inhaled would reside in the body for a long time, the body would be continuously exposed as long as the plutonium remained. Therefore, the radiological dose values reported are "50-year dose commitments" (i.e., the total dose that could be received by an individual during the 50-year period following initial exposure).

In addition, exposure to plutonium dioxide deposited in the environment after an accident could be possible, either from inhalation of resuspended small plutonium-bearing particles or from ingestion of contaminated food. Inhalation of resuspended particles is the dominant long-term exposure pathway. The concentration of ground-deposited resuspendable radioactive particles would tend to decrease rapidly with time, because of natural processes, such as wind and percolation into the soil with rainfall. For ground-level releases from impacts on hard surfaces, most of the long-term dose commitment would occur during the first 2 years after release. Ground-deposited radioactive particles caused by resuspension of contaminated soil available to the inhalation pathway decreases dramatically during the first 2 years. Long-term dose estimates for the populations outside CCAS boundaries and worldwide include dose contributions from inhalation of resuspended material and ingestion of contaminated food products over a 50-year period following the accident.

Collective dose, expressed in units of person-Sievert (person-Sv or person-rem), is simply the sum of all individual doses received in a given population as a result of exposure to a radiation source. Collective dose is also referred to as "population dose."

In discussing the impacts of radiation doses, the concept of de minimis has been used to indicate a collective dose level at which the risks to human health are considered negligible. De minimis, as a concept in determining the risk from exposure to ionizing radiation, remains a controversial topic within the regulatory and scientific communities. Both the EPA and the U.S. Nuclear Regulatory Commission (NRC) have considered and supported the concept of a de minimis level but have not yet adopted regulations or standards for individual dose or collective doses. The National Council on Radiation Protection and Measurement (NCRP) in 1987 established a "Negligible Individual Risk Level" of 1 in 10 million annual risk, which corresponds to a dose rate of 1.0×10^{-5} Sv/yr (1.0×10^{-3} rem/yr) (NCRP 1987). For the purpose of this EIS, the de minimis dose is 1 1.0×10^{-5} Sv/yr (1.0×10^{-3} rem/yr). No position is taken in this document regarding de minimis, except that health effects calculated with and without de minimis applied are considered equally valid in light of the uncertainties in its application to collective doses. The collective doses are reported both with and without de minimis values.

In calculating radiological consequences for Phases 5 and 6 and for the short-term inadvertent reentries involving worldwide locations, average population densities were used based on a probability-weighting over reentry conditions of the latitude-dependent population density distribution. In calculating maximum individual doses due to releases from intact components impacting Earth surfaces, the location of the maximally exposed individual relative to a given ground-level release was determined by considering the average area associated with an individual corresponding to the applicable population density. Due to uncertainties, there is actually some probability distribution over the dose to the maximally exposed individual, and the reported results represent expectation values of such distributions (Halliburton NUS 1994b).

Health Effects

Health effects are defined as the number of excess latent cancer fatalities (above the normally observed cancer fatalities) that could occur in the exposed population as a result of exposure to released radioactive fuel. Health effects are calculated on the basis of the collective (population) dose multiplied by a health effects factor (number of cancer fatalities per person-Sv [per person-rem] of exposure). For purposes of this EIS, the health effects estimator used in converting radiation doses to health effects in the exposed population is 3.5×10^{-2} fatalities per person-Sv (3.5×10^{-4} fatalities per person-rem), which was developed for Pu-238 in the Ulysses FSAR (DOE 1990a). The health effects are reported both with and without de minimis. For those results with a de minimis dose level applied, the collective dose involving individuals receiving less than 1.0×10^{-5} Sv/yr (1.0×10^{-3} rem/yr) are excluded from the health effects calculation.

Land Area Contamination

Estimates of land areas potentially contaminated are based on depositions of plutonium above a screening level of 7.4×10^{3} Bq/m^{2} (0.2 μCi/m^{2}). EPA proposed this level as a screening level above which the need for cleanup should be evaluated (EPA 1990). It should be noted that the estimates presented in this EIS are for illustrative purposes and are not intended to reflect a definitive statement with respect to specific areas around CCAS or globally that could potentially be contaminated. Should an accident occur, a site-specific screening level would be established.

4.1.6.2 Radiological Consequences

This section presents estimates of the potential radiological consequences of accidents utilizing the assumptions and methodology for dose calculation techniques used for the Ulysses mission EIS (NASA 1990) and the Ulysses FSAR (DOE 1990a). Estimates are reported for the four representative accident scenarios for Phases 1 through 6 of the Cassini mission and for the potential Earth swingby accidents occurring during the VVEJGA or VEEGA trajectories. These radiological consequences are reported in more detail in *Preliminary Risk Analysis of the Cassini Mission* (Halliburton NUS 1994a). It should be noted that in calculating the radiological consequences, no credit was taken for mitigation measures that could occur in case of an accident. Contingency planning will be an important activity in preparation for the Cassini mission launch (see Section 4.1.9).

Radiological consequences of the source terms described in Section 4.1.5.4, are measured in terms of collective dose and health effects (both with and without de minimis), maximum individual dose, and land area contamination. The doses are expressed as 50-year committed effective dose equivalents. The collective dose includes each exposed person and the level of each person's exposure. Health effects are expressed as excess latent cancer fatalities that may occur in the exposed population, above those that would be expected to normally occur over a 50-year period following initial exposure. Estimates of land area contamination are based on a screening level established by U.S. EPA of 7.4×10^3 Bq/m^2 (0.2μCi/m^2) (EPA 1990).

Tables 4-10 and 4-11 summarize the results of the radiological consequence analyses for launch Phases 1 through 6 based on the expectation case and maximum case source terms reported in Table 4-7. Tables 4-12 and Table 4-13 summarize the results of the radiological consequence analysis of the VVEJGA and VEEGA inadvertent reentry cases.

Potential Consequences for Phases 1 through 6 Accidents

For accident scenarios with a fuel release occurring near CCAS, the collective dose and health effects would be small. For the Phase 1 expectation source term (Table 4-10), the collective dose would be about 2×10^{-2} person-Sv (2×10^0 person-rem). For the maximum case Phase 1 scenario (Table 4-11), the collective dose would be about 7×10^{-2} person-Sv (7×10^0 person-rem). Less than one health effect (based on either the expectation or maximum cases) was estimated for any of the representative accidents occurring near CCAS. When de minimis is considered, no health effects would be predicted. An offsite individual (member of the general public) at least 16 km (10 mi) away could receive a maximum individual dose of up to about 1×10^{-6} Sv (1×10^{-4} rem) from expectation case source terms. With the maximum case release of about 1.1×10^{12} Bq (28.7 Ci) for a Phase 1 accident, this offsite individual could receive a dose of about 3.6×10^{-6} Sv (3.6×10^{-4} rem). Looking at Table 4-14 and comparing the Cassini accident doses with individual doses received from natural background radiation (about

TABLE 4-10. RADIOLOGICAL CONSEQUENCES FOR PHASES 1 THROUGH 6 (Expectation Case Source Terms)[a,b,c]

Mission Phase	Accident Scenario	Collective Dose,[d] person-Sv (person-rem)		Health Effects[e]		Maximum Individual Dose Sv (rem)	Land Area, km^2 (mi^2) Above 7.4×10^3 Bq/m^2 ($0.2\ \mu Ci/m^2$)
		Without De Minimis	With De Minimis	Without De Minimis	With De Minimis		
1	Command Shutdown & Destruct	2.07×10^{-2} (2.07×10^{0})	– –	7.24×10^{-4}	– –	1.02×10^{-6} (1.02×10^{-4})	4.02×10^{-1} (1.55×10^{-1})
	Titan IV (SRMU) Fail-to-Ignite	9.59×10^{-3} (9.59×10^{-1})	– –	3.36×10^{-4}	– –	4.73×10^{-7} (4.73×10^{-5})	1.86×10^{-1} (7.18×10^{-2})
	Centaur Tank Failure/Collapse	2.08×10^{-2} (2.08×10^{0})	– –	7.28×10^{-4}	– –	1.03×10^{-6} (1.03×10^{-4})	4.01×10^{-1} (1.55×10^{-1})
5	Command Shutdown & Destruct	4.32×10^{-3} (4.32×10^{-1})	1.25×10^{-3} (1.25×10^{-1})	1.51×10^{-4}	4.38×10^{-5}	1.24×10^{-4} (1.24×10^{-2})	2.17×10^{-2} (8.38×10^{-3})
	Centaur Tank Failure/Collapse	4.32×10^{-3} (4.32×10^{-1})	1.25×10^{-3} (1.25×10^{-1})	1.51×10^{-4}	4.38×10^{-5}	1.24×10^{-4} (1.24×10^{-2})	2.17×10^{-2} (8.38×10^{-3})
6	Inadvertent Reentry From Earth Orbit	1.97×10^{-2} (1.97×10^{0})	5.68×10^{-3} (5.68×10^{-1})	6.90×10^{-4}	1.99×10^{-4}	5.43×10^{-4} (5.43×10^{-2})	2.22×10^{-2} (8.57×10^{-3})

Source: Halliburton NUS 1994a

[a] The radiological consequences associated with the expectation case source terms for launch phase accidents are assumed to be the same for the Titan IV (SRMU or SRM)/Centaur configuration.

[b] No source terms were identified in Phases 0, 2, 3, and 4.

[c] The expectation values represent a probability-weighted average source term based on a range of release conditions for a given scenario.

[d] The de minimis dose level for the purpose of this EIS is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year. The collective dose "with de minimis" is the total dose to members of the exposed population receiving more than 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year; i.e., the collective dose does not include de minimis level.

[e] Excess latent cancer fatalities.

TABLE 4-11. RADIOLOGICAL CONSEQUENCES FOR PHASES 1 THROUGH 6 (Maximum Case Source Terms)[a,b,c]

Mission Phase	Accident Scenario	Collective Dose,[d] person-Sv (person-rem)		Health Effects[e]		Maximum Individual Dose Sv (rem)	Land Area, km^2 (mi^2) Above 7.4×10^3 Bq/m^2 (0.2 μCi/m^2)
		Without De Minimis	With De Minimis	Without De Minimis	With De Minimis		
1	Command Shutdown & Destruct	7.04×10^{-2} (7.04×10^{0})	– –	2.59×10^{-3}	– –	3.64×10^{-6} (3.64×10^{-4})	1.43×10^{0} (5.52×10^{-1})
	Titan IV (SRMU) Fail-to-Ignite	4.15×10^{-2} (4.15×10^{0})	– –	1.45×10^{-3}	– –	2.05×10^{-6} (2.05×10^{-4})	8.00×10^{-1} (3.09×10^{-1})
	Centaur Tank Failure/Collapse	7.04×10^{-2} (7.04×10^{0})	– –	2.59×10^{-3}	– –	3.64×10^{-6} (3.64×10^{-4})	1.43×10^{0} (5.52×10^{-1})
5	Command Shutdown & Destruct	2.21×10^{-2} (2.21×10^{0})	6.36×10^{-3} (6.36×10^{-1})	7.73×10^{-4}	2.23×10^{-4}	2.38×10^{-4} (2.38×10^{-2})	1.11×10^{-1} (4.28×10^{-2})
	Centaur Tank Failure/Collapse	1.86×10^{-2} (1.86×10^{0})	5.38×10^{-3} (5.38×10^{-1})	6.51×10^{-4}	1.88×10^{-4}	2.30×10^{-4} (2.30×10^{-2})	9.36×10^{-2} (3.61×10^{-2})
6	Inadvertent Reentry From Earth Orbit	9.81×10^{-2} (9.81×10^{0})	2.83×10^{-2} (2.83×10^{0})	3.43×10^{-3}	9.90×10^{-4}	1.06×10^{-3} (1.06×10^{-1})	1.11×10^{-1} (4.28×10^{-2})

Source: Halliburton NUS 1994a

a. The radiological consequences associated with the maximum case source terms for launch phase accidents are assumed to be the same for the Titan IV (SRMU or SRM)/Centaur configuration.

b. No source terms have been identified for Phases 0, 2, 3, and 4.

c. A maximum case corresponds to either the upper limit deemed credible for a given scenario based on consideration of supporting analyses and the safety test data, or that corresponding to a total probability greater than or equal to a probability cutoff of 1.0×10^{-7} (Halliburton NUS 1994a).

d. The de minimis dose level for the purpose of this EIS is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year. The collective dose "with de minimis" is the total dose to members of the exposed population receiving more than 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year; i.e., the collective dose does not include de minimis level.

e. Excess latent cancer fatalities.

TABLE 4-12. RADIOLOGICAL CONSEQUENCES FOR AN INADVERTENT REENTRY DURING AN EARTH SWINGBY ASSOCIATED WITH THE VVEJGA[a]

Reentry Case	Collective Dose,[b] person-Sv (person-rem)		Health Effects[c]		Maximum Individual Dose, Sv (rem)	Land Area, km^2 (mi^2) Above 7.4 x 10^3 Bq/m^2 (0.2 μCi/m^2)
	Without De Minimis	With De Minimis	Without De Minimis	With De Minimis		
Shallow[d]	9.93 x 10^4 (9.93 x 10^6)	2.08 x 10^2 (2.08 x 10^4)	3.48 x 10^3	7.28 x 10^0	2.14 x 10^{-1} (2.14 x 10^1)	5.34 x 10^3 (2.06 x 10^3)
Steep[e]	5.46 x 10^4 (5.46 x 10^6)	3.04 x 10^2 (3.04 x 10^4)	1.91 x 10^3	1.06 x 10^1	3.37 x 10^{-1} (3.37 x 10^1)	1.60 x 10^3 (6.17 x 10^2)
Expectation[f]	6.58 x 10^4 (6.58 x 10^6)	2.80 x 10^2 (2.80 x 10^4)	2.30 x 10^3	9.77 x 10^0	3.06 x 10^{-1} (3.06 x 10^1)	2.04 x 10^3 (7.88 x 10^2)

Source: Halliburton NUS 1994a

a. The radiological consequences for inadvertent reentry during an Earth swingby would be assumed to be the same for the Titan IV (SRMU or SRM)/Centaur on a VVEJGA trajectory.

b. The de minimis dose level for the purpose of this EIS is 1.0 x 10^{-5} Sv (1.0 x 10^{-3} rem) per year. The collective dose "with de minimis" is the total dose to members of the exposed population receiving more than 1.0 x 10^{-5} Sv (1.0 x 10^{-3} rem) per year.

c. Health effects, or excess latent cancer fatalities, for the short-term inadvertent reentry accident are evaluated based on collective exposure of approximately 5 billion persons worldwide. Most of the persons exposed would receive an individual radiation dose of less than 1.0 x 10^{-5} Sv (1.0 x 10^{-3} rem) per year (the de minimis dose level). If only those individuals worldwide receiving higher than de minimis dose level were considered, the estimated health effects would be approximately 10 (excess latent cancer fatalities) with the VVEJGA, and 15 with either the VEEGA E1 or E2.

d. Conditional probability given an inadvertent reentry: 0.25. This branch is identified as the "Maximum Case" for a VVEJGA inadvertent reentry.

e. Conditional probability given an inadvertent reentry: 0.75.

f. This is the "Expectation Case" with probability-weighted consequences given an inadvertent reentry determined by:

Expectation Values = 0.25 (Shallow Values) + 0.75 (Steep Values).

TABLE 4-13. RADIOLOGICAL CONSEQUENCES FOR INADVERTENT REENTRIES DURING AN EARTH SWINGBY ASSOCIATED WITH THE BACKUP VEEGA E1 AND E2[a]

Reentry Case	Collective Dose,[b] person-Sv (person-rem)		Health Effects[c]		Maximum Individual Dose, Sv (rem)	Land Area, km^2 (mi^2) Above 7.4×10^3 Bq/m^2 (0.2 μCi/m^2)
	Without De Minimis	With De Minimis	Without De Minimis	With De Minimis		
Shallow—E1[d]	1.25×10^5 (1.25×10^7)	2.92×10^2 (2.92×10^4)	4.38×10^3	1.02×10^1	2.61×10^{-1} (2.61×10^1)	5.71×10^3 (2.20×10^3)
Shallow—E2[e]	1.53×10^5 (1.53×10^7)	3.64×10^2 (3.64×10^4)	5.36×10^3	1.27×10^1	3.25×10^{-1} (3.25×10^1)	5.73×10^3 (2.21×10^3)
Steep—E1[f]	6.40×10^4 (6.40×10^6)	4.34×10^2 (4.34×10^4)	2.24×10^3	1.52×10^1	5.03×10^{-1} (5.03×10^1)	1.54×10^3 (5.95×10^2)
Steep—E2[g]	1.03×10^5 (1.03×10^7)	4.83×10^2 (4.83×10^4)	3.60×10^3	1.69×10^1	3.90×10^{-1} (3.90×10^1)	2.26×10^3 (8.73×10^2)
Expectation—E1[h]	7.07×10^4 (7.07×10^6)	4.18×10^2 (4.18×10^4)	2.48×10^3	1.46×10^1	4.76×10^{-1} (4.76×10^1)	2.00×10^3 (7.72×10^2)
Expectation—E2[i]	1.30×10^5 (1.30×10^7)	4.19×10^2 (4.19×10^4)	4.56×10^3	1.47×10^1	3.55×10^{-1} (3.55×10^1)	4.13×10^3 (1.59×10^3)

Source: Halliburton NUS 1994a

a. The radiological consequences for an inadvertent reentry during an Earth swingby would be assumed to be the same for the Titan IV (SRMU or SRM)/Centaur on a VEEGA trajectory.

b. The de minimis dose level for the purpose of this EIS is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year. The collective dose "with de minimis" is the total dose to members of the exposed population receiving more than 1.0×10^{-5} Sv (1.0×10^{-3} rem).

c. Health effects, or excess latent cancer fatalities, for the short-term inadvertent reentry accident are evaluated based on collective exposure of approximately 5 billion persons worldwide. Most of the persons exposed would receive an individual radiation dose of less than 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year (the de minimis dose level). If only those individuals worldwide receiving higher than de minimis dose level were considered, the estimated health effects would be approximately 10 (excess latent cancer fatalities) with the VVEJGA, and 15 with either the VEEGA E1 or E2.

d. Conditional probability given an inadvertent reentry: 0.11. This branch is identified as the "Maximum Case" for a backup E1 inadvertent reentry.

e. Conditional probability given an inadvertent reentry: 0.54. This branch is identified as the "Maximum Case" for a backup E2 inadvertent reentry.

f. Conditional probability given an inadvertent reentry: 0.89.

g. Conditional probability given an inadvertent reentry: 0.46.

h. This is the "Expectation Case" with probability-weighted consequences given an inadvertent reentry determined by:
Expectation Values = 0.11 (Shallow Values) + 0.89 (Steep Values).

i. This is the "Expectation Case" with probability-weighted consequences given an inadvertent reentry determined by:
Expectation Values = 0.54 (Shallow Values) + 0.46 (Steep Values).

TABLE 4-14. AVERAGE ANNUAL EFFECTIVE DOSE EQUIVALENT OF IONIZING RADIATION TO A MEMBER OF THE U.S. POPULATION

Source	Effective Dose Equivalent[a]	
	Sv/yr (rem/yr)	Percent of Total
Natural		
Radon[b]	2.0×10^{-3} (0.2)	55
Cosmic	2.7×10^{-4} (0.027)	8
Terrestrial	2.8×10^{-4} (0.028)	8
Internal	3.9×10^{-4} (0.039)	11
Subtotal - Natural	3.0×10^{-3} (0.3)	82
Manmade		
Medical		
X-ray diagnosis	3.9×10^{-4} (0.039)	11
Nuclear medicine	1.4×10^{-4} (0.014)	4
Consumer products	1.0×10^{-4} (0.010)	3
Other		
Occupational	$<1.0 \times 10^{-5}$ (<0.001)	<0.03
Nuclear fuel cycle	$<1.0 \times 10^{-5}$ (<0.001)	<0.03
Fallout	$<1.0 \times 10^{-5}$ (<0.001)	<0.03
Miscellaneous[c]	$<1.0 \times 10^{-5}$ (<0.001)	<0.03
Subtotal - Manmade	6.4×10^{-4} (0.064)	18
Total Natural and Manmade[d]	3.64×10^{-3} (0.364)	100

Source: National Research Council 1990

a. Effective dose equivalent is proportional to incremental risk in cancer.

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

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

d. The 50-year effective dose commitment is 50 yr x 3.64×10^{-3} Sv/yr (3.64×10^{-1} rem/yr) or 1.82×10^{-1} Sv (1.82×10^{1} rem).

3×10^{-3} Sv/yr [3×10^{-1} rem/yr]) and from manmade sources (on the order of 6.4×10^{-4} Sv/yr [6.4×10^{-2} rem/yr] for a total 50-year effective dose commitment of about 1.82×10^{-1} Sv [1.82×10^{1} rem) (National Research Council 1990), the Cassini accident doses would be considered not detectable. Land area contamination for an accident occurring near CCAS would potentially contaminate less than 1.5 km^2 (0.58 mi^2) above the screening level.

During the 8-second period of Phase 5, the GPHS modules could impact land areas in Africa with a resultant fuel release. The collective dose associated with the expectation source terms (Table 4-10) would be about 4.3×10^{-3} person-Sv (4.3×10^{-1} person-rem). Similarly, for the maximum source term case (Table 4-11), the collective dose would be about 2.2×10^{-2} person-Sv (2.2×10^{0} person-rem). Less than one health effect over a 50-year period (based on either the expectation or maximum case, with and without de minimis) was estimated for a Phase 5 accident. For the expectation case, the maximum individual dose would be about 1.2×10^{-4} Sv (1.2×10^{-2} rem). For the maximum source term case, the maximum individual dose would be about 2.4×10^{-4} Sv (2.4×10^{-2} rem). Again, the maximum individual dose for either source term case would be well below that experienced from natural and manmade background radiation by the average U.S. citizen. Anticipated land contamination above the screening level would be less than 1 km^2 (0.39 mi^2) for either the expectation or maximum source term cases.

For a Phase 6 accident (as with a Phase 5 accident), the radiological consequences would be limited to the immediate vicinity of the individual GPHS impact sites. While 54 modules would be expected to independently reenter the Earth's atmosphere, an average of three modules would be expected to impact on a hard surface and release plutonium dioxide fuel. For impacts onto a hard surface for a Phase 6 accident, the expectation release (source term) would be about 5.6×10^{10} Bq (1.5 Ci) and would result in a 50-year collective dose of about 1.97×10^{-2} person-Sv (1.97×10^{0} person-rem). Less than one health effect over the 50-year period would be anticipated, with or without de minimis. The maximum individual dose, ignoring de minimis, would be about 5.4×10^{-4} Sv (5.4×10^{-2} rem), substantially less than the 50-year effective dose commitment received as background by an average U.S. citizen (Table 4-14). For the maximum source term case, the collective dose would be about 9.8×10^{-2} person-Sv (9.8×10^{0} person-rem) which would equate to less than one health effect. Considering de minimis, the resulting health effects drop by about a factor of 3. The maximum individual dose would be 1.06×10^{-3} Sv (1.06×10^{-1} rem). Land area contamination could be less than 1 km^2 (0.39 mi^2) with either the expectation or maximum case.

Potential Consequences for a Short-Term Inadvertent Reentry During Earth Swingby (VVEJGA)

For inadvertent swingby reentry accidents, a combination of fuel end states (i.e., intact or damaged GPHS modules, GISs, particles of fuel, and vapor) would be expected to occur. The type and degree of radiological consequences could vary significantly, depending on the fuel end state and the reentry angle. Appendix B in this EIS summarizes the methodologies used in estimating the consequences for the short-term inadvertent reentry during an Earth swingby accident.

Most of the larger components (e.g. GPHS modules, GISs) and large fuel particles would be expected to fall within the reentry footprint which could vary considerably in size. For the most shallow of reentry angles (7 degrees), the footprint was assumed to be nominally 50,000 km^2 (19,305 mi^2). For the steepest reentry angle [90 degrees], a nominal footprint of 10 km^2 (3.9 mi^2) was assumed. Table 4-9, presented previously, gives the resulting footprint areas when the reentry angles are probability-weighted according to each EGA reentry. The remainder of the fuel, the small particles and vapor, collectively about one third of the total fuel release for the scenarios modeled, would temporarily remain at high altitude and would spread around the world during the several years that it takes to return to the Earth's surface.

The collective dose to the population due to ground impacts within the footprint area and worldwide from high altitude releases is about 5.46 x 10^4 person-Sv (5.46 x 10^6 person-rem) for a steep angle reentry, and about 9.93 x 10^4 person-Sv (9.93 x 10^6 person-rem) for a shallow reentry. The expectation collective dose would be about 6.58 x 10^4 person-Sv (6.58 x 10^6 person-rem). This dose, however, would be spread over a significant fraction of the estimated world population or about 5 billion of the total 7 to 8 billion person population, such that on average, the incremental dose over background would likely be indistinguishable. The annual collective dose to the same population from natural background radiation (see Table 4-14 for the average annual effective dose equivalent for a member of the United States public) would be on the order of 10^7 person-Sv (10^9 person-rem).

The collective doses for the steep and shallow reentry cases, and for the expectation case, would be derived largely from inhalation of the vapor component and the small particulate component of the source term, specifically the small plutonium dioxide particles 10 microns or smaller in size, released at high altitude and dispersed worldwide. The estimated excess health effects that could occur over a 50-year period associated with each case were estimated to range from about 11 with de minimis to about 1,910 without de minimis for the steep reentry; about 7 to 3,480 (with and without de minimis, respectively) for the shallow reentry; and about 10 to 2,300 (with and without de minimis, respectively) for the expectation case. In contrast, within this same exposed population, approximately 1 billion people (i.e., 20 percent or 1/5 of the population) would be expected over time to die of cancer due to other causes. The additionally estimated cancer fatalities associated with the expectation case analysis for an inadvertent reentry during an Earth swingby (see Table 4-13) could be a 0.0005 percent increase above the normally observed 1 billion cancer fatalities. Since the observed cancer death rates vary by more than +/-50 percent among the larger countries (American Cancer Society 1994), this increase would not be statistically observable.

The estimated contaminated land area above the U.S. EPA screening level from an inadvertent reentry during an Earth swingby accident could be large, ranging from 1,600 to 5,340 km^2 (618 to 2,062 mi^2) with an expectation value of 2,040 km^2 (788 mi^2) (Halliburton NUS 1994a).

Potential Consequences for a Short-Term Inadvertent Reentry During Earth Swingby (VEEGA)

The results of the radiological consequence analyses of the backup VEEGA E1 and E2 inadvertent reentries are presented in Table 4-13. (E1 and E2 represent the first and second targeted Earth swingbys in the VEEGA trajectory.) For VEEGA inadvertent reentries, the reentry velocity for E1 and E2 would be approximately 16.5 km/s (54,000 ft/s) and 17.3 km/s (56,800 ft/s), respectively. However, for this EIS and based on conservatism, the radiological consequences for the VEEGA inadvertent reentry were estimated based on the VVEJGA reentry velocity (i.e. 19.1 km/s [62,700 ft/s]) (Halliburton NUS 1994a).

In comparing Table 4-13 with Table 4-12, it can be noted that the consequences (doses, health effects, and land area contamination) associated with the VEEGA E1 and E2 swingbys are generally somewhat greater than those estimated for the VVEJGA swingby reentry accident. This is because the VEEGA E1 and E2 swingby reentries would most likely occur within more northern latitude bands than would the VVEJGA. Population densities in the more northern bands are greater than those in the more southern bands where the VVEJGA Earth impact would tend to occur (44.7 and 55.6 persons/km^2 for the VEEGA E1 and E2 swingbys, vs. 36.5 persons/km^2 for the VVEJGA Earth impact) (Halliburton NUS 1994a). In addition, the probability of RTG components striking rock, at least in the E1 swingby reentry, is greater than that associated with the VVEJGA ($P = 0.0476$ for the E1 reentry vs. 0.040 for the VVEJGA reentry). Other factors affecting the differences between the VVEJGA and VEEGA consequences include growth in the worldwide population between the time of the VVEJGA Earth swingby scheduled for 1999, and the E1 and E2 swingbys of the VEEGA trajectory (2001 and 2004, respectively). In comparing the expectation consequences across the VVEJGA and the VEEGA E1 and E2 estimates, one will also see a reflection of differences in the probability-weighting used to derive the expectation values (see footnote "e" in Tables 4-12 and 4-13). The probability-weighting factor for shallow versus steep reentry is most noticeable in the E2 expectation consequences (a 0.54 weighting factor for shallow reentry) where the estimated collective dose is an order of magnitude higher (1.30×10^5 person-Sv [1.30×10^7 person-rem]) than that of either the VEEGA E1 reentry or the VVEJGA (7.07×10^4 person-Sv [7.07×10^6 person-rem] and 6.58×10^4 person-Sv [6.58×10^6 person-rem], respectively). (Shallow reentry results in a greater vapor fraction for the plutonium dioxide fuel, hence a greater potential for worldwide exposure.)

As with the estimated consequences for the VVEJGA reentry, the collective dose is spread over much of the worldwide population. In general, the resulting health effects would probably be undetectable in the population as a whole because of the high (approximately 20 percent [American Cancer Society 1994]) incidence of cancer fatalities from other causes. Aside from the VEEGA E2 expectation case and steep reentry case collective doses which are both an order of magnitude higher than their VEEGA E1 and VVEJGA counterparts, the balance of the consequence estimates do not vary greatly from each other. Additional details of these analyses can be found in Appendix B.

Potential Consequences of a Long-Term Inadvertent Reentry from Interplanetary Cruise

Section 4.1.5.2 describes the potential for a long-term Earth impact by the Cassini spacecraft. Should such an event occur, it is reasonable to assume that the spacecraft would break up in much the same manner as the short-term reentry scenarios (see Section 4.1.5.4). Latitude distributions for long-term reentry would be about the same as those estimated for the VVEJGA and VEEGA short-term reentry (JPL 1993f). The long-term analysis evaluated the probability for such an event over a period extending for 100 years beyond the nominal SOI date for the trajectory involved (VVEJGA or VEEGA). It is reasonable to assume that the radiological releases and, in turn, the consequences (health effects and land contamination) could be similar (i.e., same order of magnitude) to the short-term inadvertent reentry.

4.1.6.3 Impacts of the Radiological Consequences on the Environment

This section presents the environmental impacts of the representative Cassini accident scenarios in which plutonium dioxide RTG fuel could be released to the environment resulting in land and/or surface water contamination. The health and environmental risks associated with plutonium (mainly Pu-238) dioxide are addressed in the Galileo and Ulysses EISs (NASA 1989b, NASA 1990) and in Appendix C of this EIS. The affected environment, described in Section 3 of this EIS, has been divided into two areas (i.e., regional and global). The regional area would be where Phase 1 accident impacts could occur. The global area relates to limited portions of Africa where a Phase 5 accident could result in land impacts or to indeterminate areas worldwide where a Phase 6 accident and an inadvertent reentry during a swingby could lead to land and/or atmospheric impacts.

It should be emphasized that the following discussion is provided for illustrative purposes and is not intended to reflect a definitive statement regarding specific areas that would be contaminated in the event of an accident involving a release of plutonium dioxide fuel. In the unlikely event that an accident occurred, the amount of contamination and the specific affected areas would be determined and appropriate mitigation actions taken. When determining the necessary level of mitigation, the characteristics of the material deposited would be considered. Plutonium dioxide has extremely low solubility in water and has a low bioaccumulation rate within the food chain; its alpha emissions are short range, and the primary radiological health concern is inhalation of respirable particles.

The impacts on the environment of the potential accident scenarios associated with the Cassini mission are assessed according to the potential areal extent of the contamination (i.e., land surface area and/or water bodies). The first step is the identification of areas where deposition could exceed a specified screening level of 7.4×10^3 Bq/m^2 (0.2 μCi/m^2) by mission phase (see Tables 4-10, and 4-11, for Phases 1 through 6 and Table 4-12 and 4-13 for an inadvertent reentry during swingby). The screening level chosen is based on EPA guidance (EPA 1990) for contamination of soil by unspecified transuranic elements, including plutonium. EPA suggests that areas contaminated above the 7.4×10^3 Bq/m^2 (0.2 μCi/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 fatality to less than one chance in one million (< 1 in 10^6). Based on this guidance, contamination below the screening level is judged to have minimal or no impacts on populations of plant and animal species. For purposes of this discussion, therefore, areas that do not exceed the 7.4×10^3 Bq/m^2 (0.2 μCi/m^2) screening level are considered to have negligible potential for substantial environmental impact and are not analyzed.

The last step in the environmental assessment methodology is the identification of the nature and magnitude of the potential impacts in the affected areas. In addition to the effects caused by exposure to plutonium dioxide in the environment, decontamination and mitigation activities employed to reduce plutonium dioxide concentrations and exposure could affect natural habitats and human land uses.

Because the deposition of plutonium dioxide partially depends on the distribution of plutonium dioxide particles released during an accident, two fundamental assumptions were made. The particles of released plutonium dioxide would be distributed, so that the majority of the large particles would be deposited closer to the accident/impact site, with the size of the deposited particles decreasing with distance. The highest concentrations of released radioactive material would, therefore, be closer to the release point and concentrations would tend to decrease with distance.

Potential Radiological Impacts to the CCAS Regional Area

Accidents occurring during Phase 1 would result primarily in plutonium dioxide deposition on the controlled land areas of CCAS/KSC. After Phase 1 of the mission, the launch vehicle and Cassini spacecraft would have gained enough altitude and down-range distance from the CCAS region that none of the representative Titan IV launch accidents scenarios would result in fuel release unless the RTGs (or GPHSs or bare fueled clads) hit a hard surface. No source terms are postulated for Phases 2, 3, and 4; therefore, no radiological impacts would be expected.

Areas of land cover (e.g., buildings, roads, crop areas, ornamental vegetation, and grassy areas) contaminated above the 7.4×10^3 Bq/m^2 (0.2 μCi/m^2) level would be evaluated to determine if decontamination or mitigation actions would be necessary. The results of the radiological consequence analyses show that up to 1.43 km^2 (0.55 mi^2) of dry land area could be contaminated above the screening level (see Table 4-11). Therefore, only small areas of cleanup would be necessary.

The amount of plutonium dioxide resuspended in the air in natural areas determines if plutonium dioxide concentrations may pose inhalation health hazards to humans. If levels were determined to pose inhalation health hazards, access to the area could be restricted until monitoring indicated that plutonium dioxide concentrations would no longer pose a potential health hazard.

Although plutonium dioxide could affect the human use of these land covers, there would be no initial impact on soil chemistry, and most of the plutonium dioxide deposited on the water bodies would be insoluble and would deposit in the sediments. No substantial impacts to flora and fauna are expected from surface contamination and skin contact with the plutonium dioxide, except where particle concentration and/or size is great enough to overheat the contaminated surface.

In the unlikely event of a Phase 1 accident, especially in view of the extremely low level of health effects that would be expected and the composition of the population in the region (See Section 3.1.7), it is highly unlikely that any given racial, ethnic, or socioeconomic group of the population would bear a disproportionate share of the consequences.

Potential Radiological Impacts to the Global Area

For the representative accidents that could occur during the launch of the Cassini spacecraft, only the scenarios occurring in Phases 5 and 6 could result in limited land contamination in Africa (for Phase 5 accidents) or in indeterminate locations within the global area for inadvertent reentry accidents from Earth orbit (Phase 6). In addition, impacts could occur from the inadvertent reentry during an Earth swingby.

The contamination from a release occurring during Phases 5 and 6 would result from accidents in which GPHS modules impact rock. Each of the GPHS modules hitting rock would release plutonium dioxide at a different location separated by distances ranging from a few kilometers to hundreds of kilometers. Using the maximum case source terms in Table 4-11, the total amount of land contaminated at levels above the screening level following a Phase 5 or 6 accident could be about 0.11 km^2 (.04 mi^2) or less. Thus, given that there would likely be several GPHS impact locations, the area of contamination at each rock impact site would probably be relatively small and localized.

Should an accident result in a release in territories outside the jurisdiction of the United States, the Federal Government would respond if requested with the technical assistance and support needed to clean up and remediate affected areas and to recover the plutonium fuel if possible.

In inadvertent swingby reentry accidents, a combination of intact or damaged GPHS modules, GISs, particles of fuel, or vapor from a high-altitude release would be expected to occur, with the modules, GISs, and large particles impacting within a footprint tens to thousands of square kilometers in area, depending on the reentry angle. The vapor fraction, as well as some of the very small particulates (10 μm or less in size) would remain in the atmosphere for several years. Since about 3/4 of the Earth's surface in the reentry latitudes is ocean, many of these large pieces could strike water and settle to the ocean floor. The large pieces would be expected to quickly become buried in the sea-floor sediment or encrusted and present a negligible hazard to ocean life.

As provided in Table 4-12, land areas contaminated above the EPA screening level were estimated at 1,600 and 5,340 km^2 (618 and 2,062 mi^2) for the steep and shallow VVEJGA Earth inadvertent reentry, respectively, with an expectation value of 2,040 km^2 (788 mi^2) (Halliburton NUS 1994a). Similar ranges of land contamination for the backup VEEGA E1 and E2 reentry accidents could occur (see Table 4-13). The type and degree of contamination could vary significantly, depending on the fuel end state and the reentry angle. The highest level of contamination would likely be at an impact site and decrease rapidly with distance from the impact site. The contaminated area would likely not be circular but more oval reflecting the wind dispersion pattern at the time of the impact.

The remainder of the contamination from fuel particles greater than 10 microns released at high altitude would be expected to quickly return to Earth, with the larger particles settling to the surface within a matter of hours to days after the accident. Much of this contamination would be expected to fall within, or downwind of the reentry footprint.

For the scenarios modeled, most of the land contamination results from the non-respirable particles released at high altitude. Most of these radioactive particles, because of their size, would have an activity level greater than 7.4×10^3 Bq (0.2 μCi) such that the land surrounding the impact site would be considered contaminated above the EPA screening level. Thus, most of the area within the reentry footprint could potentially have sufficient radioactivity to be considered contaminated.

In addition to land contamination, a radiological accident could increase worldwide plutonium levels. Plutonium dioxide already exists in the environment as a result of nuclear weapons testing and the SNAP-9A accident (refer to Table 3-8). Should an accident occur with a release of plutonium dioxide, the contribution to ionizing radiation would increase.

4.1.7 Economic Impacts

Due to the uncertainty in defining the exact magnitude of economic costs associated with the radiological impacts, a range of mitigation costs was used to assess the costs that could result from mission accidents. The minimum economic impact is based on the estimated cost of a radiological monitoring program. Table 4-15 lists the minimum cost estimates for such a program. This estimate represents the costs of equipment and personnel needed to develop and implement a comprehensive long-term monitoring program, which would probably be based on the following activities:

- Measurement of ground concentrations to characterize the nature and extent of contamination
- Airborne measurements of the amount and characteristics of the release
- Atmospheric modeling estimates of the amount and location of material deposited, using meteorological data in effect at the time of release.

A large percentage of the costs associated with this monitoring program would occur in the first year or two when the program plan would be developed, equipment purchased, and personnel hired and, if necessary, trained. After the program has been initiated and an evaluation period completed, costs would probably decrease to a maintenance level necessary to run the program in the succeeding years.

The maximum economic impact is defined as the comprehensive mitigation actions (such as decontamination, cleanup, and disposal) undertaken on all areas contaminated above a screening level of 7.4×10^3 Bq/m^2 (0.2 μCi/m^2). Only economic impacts associated with the effects of radioactive deposition are estimated in this analysis.

TABLE 4-15. MINIMUM MONITORING PROGRAM COST ESTIMATES[a] (FY 1994)

Period	Activity	Cost (FY 1994 $)
Year one	Transition from launch monitoring activity, plan development, supplemental equipment purchases, hiring of personnel	$1,240,000
Year two	Testing and shakedown of program methods and monitoring network, monitoring of mitigation actions	$620,000
Year three	Transition to long-term monitoring of impacts and mitigation actions	$310,000
Year four and each succeeding year	Program maintenance	$124,000

Source: Updated from NASA 1989b

a. Minimum monitoring cost could escalate for multiple monitoring sites.

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

- Location—The location can affect the ease of access to the deposition (e.g., a steep hillslope could be more expensive to clean up than a level field), as can access to the site location and necessary decontamination resources, such as heavy equipment, water, and clean soil.
- Land Cover Type—The characteristics of some kinds of land covers make them more difficult and, therefore, more expensive to decontaminate (e.g., plowing and restoration of a natural vegetation area could be more costly than using the same technique in an agricultural area).
- Initial Contamination Level—Higher levels of initial contamination could require more sophisticated and more costly decontamination techniques to meet a particular cleanup standard than a lower level of initial contamination.
- Decontamination Method—More sophisticated decontamination methods (e.g., wetland restoration, soil stripping, or contaminant immobilization techniques) are generally much more expensive than simple actions, such as flushing surfaces with water.
- Disposal of Contaminated Materials—The disposal of contaminated vegetation and soils onsite could be much more cost effective than the transportation and disposal of these same materials to a distant repository.
- Cleanup Standard—The applicable cleanup standard may be site specific and may be higher or lower than the proposed EPA screening level.

The need for mitigation and the cost involved, however, would be based on actual conditions, as characterized by the monitoring program that would be initiated following the release of radioactive material. EPA has estimated cleanup costs (EPA 1990), which have been escalated to 1994 dollars. The EPA report indicated that cleanup (remediation) costs for contaminated soils in the United States could range from approximately $250 thousand to $5 million per square kilometer ($1 thousand to $20 thousand per acre), if removal and disposal were not required. Removal and disposal of contaminated soil at a near-surface facility could cost from approximately $37 million to $50 million per square kilometer ($150 thousand to $200 thousand per acre). In addition, a decontamination cost, derived by DOE from historical data, of $200 million per square kilometer ($800 thousand per acre) includes the cost of cleanup and disposal of contaminated material, reclamation costs, costs associated with relocation of residents, and long-term surveillance.

In addition, significant secondary costs could be associated with these mitigation activities:

- Temporary or long-term loss of employment
- Destruction or quarantine of agricultural products
- Restriction or bans on commercial fishing
- Land use restrictions, which could affect real estate values and tourism activity
- Public health effects and medical care.

An assessment of the potential economic cost of accidents at commercial nuclear power plants found that decontamination costs would probably account for approximately 20 percent of the total economic cost of an accident (NRC 1975). Although the types of radioactive contamination resulting from a potential nuclear reactor accident are quite different from the contamination that could result from an RTG accident, this discussion of the secondary costs for decontamination and mitigation activities is a useful guide.

Table 4-16 lists the potential range of cleanup methods that could be used. Cleanup costs estimated in this EIS are solely for illustrative purposes. Actual post-accident mitigation activities would be based on detailed monitoring and assessments at that time.

Potential Economic Impacts to the CCAS Regional Area

Land contamination would occur in the CCAS regional area if an accident occurred in Phase 1 of the launch. Using the maximum source terms given in Table 4-11, the estimated amount of land contaminated at levels above the proposed EPA screening level would be about 1.43 km^2 (0.55 mi^2) or less for Phase 1 accidents. This area would be in the immediate vicinity of either launch site.

Using the upper end of the EPA cost estimates for remediation without removal and disposal (i.e., $5 million/$km^2$ [$20 thousand per acre]), the total cost for cleanup of the contaminated land potentially associated with the Phase 1 representative accident scenario would be about $7 million. Using the upper end figure of $50 million per square kilometer ($200 thousand per acre), the estimated cleanup costs (with removal and disposal) would be approximately $70 million.

Potential Economic Impacts to the Global Area

Land contamination could occur from accidents occurring during the 8-second portion when the vehicle's IIP is over Africa. Land contamination could also occur at multiple locations worldwide for reentry accidents from Earth orbit in Phase 6 or from Earth swingby reentry accidents. As shown in Table 4-11, the total estimate of land area contaminated above the EPA screening level for the maximum case would be about 0.11 km^2 (0.04 mi^2) or less for either a Phase 5 or Phase 6 accident. Once again, mitigation costs would be small.

For the short-term inadvertent Earth reentry accidents, if the reentry footprint occurred over land, the potential costs could be high. Since the estimated size of the

TABLE 4-16. RANGE OF DECONTAMINATION METHODS FOR VARIOUS LAND COVER TYPES

Land Cover Type	Low-Range Cost Decontamination/Mitigation Methods	High-Range Cost Decontamination/Mitigation Methods
Natural Vegetation	Locate and remove any detectable particles. Rinse vegetation with water. Impose recreational and other use restrictions.	Locate and remove any detectable particles. Remove and dispose all vegetation. Remove and dispose topsoil. Relocate animals. Restore habitat.
Urban	Locate and remove any detectable particles. Rinse building exteriors and hard surfaces. Rinse ornamental vegetation. Deeply irrigate lawns. Relocate affected population temporarily.	Locate and remove any detectable particles. Remove and dispose all vegetation. Impose land use restrictions. Demolish some or all structures. Relocate affected population permanently.
Agriculture	Locate and remove any detectable particles. Deeply irrigate cropland. Destroy first-year crop, including citrus crops. Rinse citrus and other growing stocks. Plow (shallow) pasture and grain crop areas.	Locate and remove any detectable particles. Destroy citrus and other perennial growing stocks. Ban future agricultural land uses.
Wetland	Locate and remove any detectable particles. Rinse emergent vegetation. Impose recreational and other use restrictions.	Locate and remove any detectable particles. Remove and dispose all vegetation. Dredge and dispose sediments. Restore habitat.
Inland Water	Locate and remove any detectable particles. Impose boating and recreational restrictions.	Locate and remove any detectable particles. Dredge and dispose of contaminated sediment. Impose commercial and recreational fishing restrictions.
Ocean	Locate and remove any detectable particles. Impose shoreline use restrictions.	Locate and remove any detectable particles. Dredge and dispose of contaminated sediment. Impose commercial and recreational fishing restrictions.

footprint could range up to about 50,000 km^2 (19,305 mi^2) for the shallowest reentry angles and could be greater than the 10 km^2 (3.9 mi^2) for even steep reentry angles, all of this land would require surveillance and monitoring to locate the detectable particles (e.g., larger components and the larger particles). Initial surveys would likely include low-altitude air overflights with sensitive radiation detectors. These would be expected to identify the hot spots (e.g., most of the GPHS modules and GISs and some of the larger particles) of surface plutonium contamination, if they are not shielded by soil or water. Initial costs of the surveys could easily be in the tens to hundreds of millions of dollars.

The activities that might occur after the initial survey would vary a great deal, depending on the extent of the contamination and the location. It is anticipated that efforts would then be made to perform more detailed ground surveys in the hot spots. Larger components would be recovered, to the extent practical. In some types of land areas, the environmental impacts of attempts to recover single particles might be much greater than leaving the particle in place. In the unlikely event such an accident occurred, it is reasonable to assume that not all particles would be detected and recovered.

4.1.8 Health Effects Risk Assessment

From a statistical perspective, the doses received from an accidental release of radioactive material are predicted to increase the number of latent cancer fatalities in the exposed population. These excess latent cancers fatalities, referred to as health effects, are calculated based on the collective (population) dose multiplied by a health effects factor (i.e., number of cancer fatalities per person-Sv [person-rem] of effective dose). Scientific opinions vary on the exact value of excess cancer fatalities per person-Sv (person-rem) effective dose. A value of 3.5×10^{-2} latent cancer fatalities (health effects) per person-Sv (3.5×10^{-4} latent cancer fatalities per person-rem) was used in the Ulysses EIS (NASA 1990) and is a representative value for radionuclides that emit predominantly alpha radiation, such as plutonium-238.

To put the estimates of potential health effects for the representative Cassini mission accidents into a perspective which can be compared with other human undertakings and events, it is useful to use the concept of risk. Risk is defined by multiplying the total probability of an event occurring with the consequences of the event. Risk, therefore, is the probability-weighted consequence of an event. In the case of potential Cassini mission accidents resulting in a release of plutonium dioxide, the total probability is obtained by multiplying the probability of the initiating accident by the conditional probability that a release will occur. Risk is then determined by multiplying this total probability for each accident scenario by the associated health effects (latent cancer fatalities) or consequences. The risk estimates for the Cassini mission have been developed from three perspectives: contribution by mission phase/scenario to mission risk (expressed as health effects) based upon the collective dose and health effects estimates; average individual risk developed by dividing the mission risk estimates by the population exposed; and finally, health effects risk to the maximally exposed individual based on the maximum individual dose estimates. The following paragraphs discuss the three perspectives of mission risk. However, it should be noted that when referring to total or overall mission risk, radiological consequences and/or contributions to risk from the low probability long-term inadvertent reentry scenario for either the VVEJGA or VEEGA cannot be estimated, and therefore are not included in any calculations.

It should be noted that the risks associated with launch phase accidents (Phases 1 to 6) that would potentially release plutonium dioxide fuel, are the same for each of the Proposed Action's three launch opportunities (primary, secondary and backup). The amount of fuel that could be released has been estimated for each applicable launch phase accident scenario as very low (Table 4-7), resulting in essentially zero health effects (Table 4-10). The risks (short-term and long-term) associated with an inadvertent reentry during the VVEJGA Earth swingby are specific to the October 1997 opportunity, while those associated with the December 1997 secondary launch opportunity's VEEGA trajectory are the same as those for the March 1999 backup mission's VEEGA. Again, it should be noted that the amount of fuel released from an inadvertent reentry during Earth swingby, although substantially larger than releases from launch phases accidents, the probability of such an accident is extremely small (see Table 4-17) and less than 1 in one million.

Mission Risk

Table 4-17 presents the preliminary estimates of the contribution to total mission risk in terms of health effects for each representative accident scenario over the launch Phases 1, 5, and 6 based upon the expectation case. Since the accident scenarios, probabilities, consequences and risks are identical for the launch phases of the primary and backup launch opportunities, separate tables are not presented. Table 4-17 also provides the total probability, consequences, and estimated contributions to the overall or total mission risk for the primary VVEJGA Earth swingby, and for the two Earth swingbys (E1 and E2) of the secondary or backup VEEGA trajectory. Total health effects mission risk is the sum of the mission risk contributions from each launch phase and from the VVEJGA (primary opportunity) or VEEGA trajectory (backup opportunity) but does not include contributions to risk from the long-term reentry.

For the mission through Phase 6, Phase 1 provides the largest contribution to overall or total mission risk of 4.6×10^{-7} number of health effects (without de minimis). (This is obtained by adding the mission risk contribution calculated for each of the three representative accident scenarios applicable to Phase 1.) The population at risk from a Phase 1 accident involving a release of plutonium dioxide would be the population in the vicinity of CCAS, estimated to be on the order of 100,000 people (Halliburton NUS 1994a). When the concept of de minimis is applied, the health effects for Phase 1 would be considered negligible. In turn, the contribution to total mission risk from a Phase 1 accident would also be considered negligible.

For a Phase 5 accident with impact in Africa, the predicted health effects would be about 1.5×10^{-4} over an assumed reference population of about 1,000 people (Halliburton NUS 1994a). Since the overall probability of an accident occurring in Phase 5 is 5.0×10^{-4} (1 in 2,000), the mission risk contribution or expected number of health effects would be 7.5×10^{-8}. Factoring in de minimis, the predicted health effects would be reduced by a factor of 3.4, with the risk contribution dropping by a factor of about 3.

TABLE 4-17. PRELIMINARY HEALTH EFFECTS MISSION RISK ESTIMATES FOR THE PROPOSED ACTION USING THE TITAN IV (SRMU)/CENTAUR

Mission Phase	Accident Scenario	Total Probability	Radiological Consequences, Health Effects[a,b]		Mission Risks, Health Effects[a,c,d]	
			Without De Minimis	With De Minimis	Without De Minimis	With De Minimis
1	Command Shutdown & Destruct Titan IV (SRMU) Fail-To-Ignite Centaur Tank Failure/Collapse	1.7×10^{-4} 9.1×10^{-4} 4.2×10^{-5}	7.24×10^{-4} 3.36×10^{-4} 7.28×10^{-4}	- - -	1.2×10^{-7} 3.1×10^{-7} 3.1×10^{-8}	- - -
Mission Risk Contribution: Phase 1					4.6×10^{-7}	-
5	Command Shutdown & Destruct Centaur Tank Failure/Collapse	4.6×10^{-4} 3.7×10^{-5}	1.51×10^{-4} 1.51×10^{-4}	4.38×10^{-5} 4.38×10^{-5}	6.9×10^{-8} 5.6×10^{-9}	2.0×10^{-8} 1.6×10^{-9}
Mission Risk Contribution: Phase 5					7.5×10^{-8}	2.2×10^{-8}
6	Inadvertent Reentry from Orbit	4.4×10^{-4}	6.90×10^{-4}	1.99×10^{-4}	3.0×10^{-7}	8.8×10^{-8}
Total Mission Risk Contribution: Launch Phases					8.4×10^{-7}	1.1×10^{-7}
VVEJGA	Inadvertent Reentry-Swingby	7.6×10^{-7}	2.30×10^{3}	9.77×10^{0}	1.7×10^{-3}	7.4×10^{-6}
Total Mission Risk Contribution: Primary VVEJGA					1.7×10^{-3}	7.5×10^{-6}
VEEGA	Inadvertent Reentry E1 Inadvertent Reentry E2	1.9×10^{-7} 2.8×10^{-7}	2.48×10^{3} 4.56×10^{3}	1.46×10^{1} 1.47×10^{1}	4.7×10^{-4} 1.3×10^{-3}	2.8×10^{-6} 4.1×10^{-6}
Mission Risk Contribution: Backup VEEGA					1.8×10^{-3}	6.9×10^{-6}
Total Mission Risk Contribution: Backup VEEGA					1.8×10^{-3}	7.0×10^{-6}

Source: Halliburton NUS 1994a

a. Health effects are incremental latent cancer fatalities.

b. Health effects, or excess latent cancer fatalities, for the short-term inadvertent reentry accident are evaluated based on collective exposure of approximately 5 billion persons worldwide. Most of the persons exposed would receive an individual radiation dose of less than 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year (the de minimis dose level). If only those individuals worldwide receiving higher than de minimis dose level were considered, the estimated health effects would be approximately 10 (excess latent cancer fatalities) with the VVEJGA, and 15 with either the VEEGA E1 or E2.

c. Expectation of incremental latent cancer fatalities.

d. The mission risk contribution due to a given accident scenario (i) is: $(\text{Mission risk contribution})_i = (\text{Total Probability})_i \times (\text{Consequences})_i$

For a Phase 6 inadvertent reentry accident, assuming average world population densities in the latitude bands likely to be impacted by such an accident, the predicted number of health effects would be 6.9×10^{-4} over a reference population assumed to be about 5,000 people (Halliburton NUS 1994a). With much less than 1 latent cancer fatality in the reference population, this effect would be clearly indistinguishable from the normally observed cancer fatalities in that population. From a risk perspective, the mission risk contribution or expected number of health effects from a Phase 6 accident is 3.0×10^{-7}. Accounting for de minimis, the number of health effects and the contribution to total mission risk would be reduced by a factor of about 3.

For an inadvertent reentry from a VVEJGA or VEEGA Earth swingby(s), the potential health effects could occur in two distinct populations, the population within and near the reentry footprint and most of the world population within broad north to south latitude bands. Since the reentry footprints, and hence the potentially affected populations, could vary considerably with reentry angle and latitude, the predictions of radiological exposures and health effects have large uncertainties. Based on the estimated footprint areas in Table 4-9 and average population densities in the potentially affected latitude bands, the affected footprint population could be in the 10^5 to 10^6 range (specifically, 226,000 persons in the VVEJGA steep reentry footprint and 2,200,000 persons in the VEEGA E2 shallow reentry footprint). The health effects predicted for the population exposed to releases from the GPHS modules, GISs, and larger particles likely to impact this affected population range from 13 to 29. (See Appendix B, Tables B-5 and B-7; sum of health effects from "intact components" and "mostly particulates" for the VVEJGA shallow reentry and VEEGA E2 steep reentry cases.) These latent cancer fatalities would likely be indistinguishable from the normally observed cancer fatalities in the exposed population.

In the unlikely event that a VVEJGA or VEEGA inadvertent reentry occurred, approximately 5 billion of the estimated 7 to 8 billion world population at the time of the swingbys could receive 99 percent or more of the radiation exposure. Based on Table 4-17, 2,300 health effects could occur over a 50-year period in this exposed population following a VVEJGA inadvertent reentry, with 2,480 or 4,560 health effects potentially occurring for the backup VEEGA E1 or E2 inadvertent reentry, respectively. These numbers are likely to be statistically indistinguishable from normally observed cancer fatalities among the world population since approximately 1/5 or 1 billion people would die of cancer due to other causes. In addition, the probability of either a VVEJGA or VEEGA short-term inadvertent reentry is extremely low; on the order of 7.6 in 10 million for the VVEJGA; 2.8 out of 10 million for the VEEGA E2. From a risk perspective, the mission risk contribution or expected number of health effects from a VVEJGA reentry accident is 1.7×10^{-3}, and 1.8×10^{-3} for the VEEGA. The radiological consequences (health effects) and the contribution to total mission risk from the Earth-gravity-assist trajectories are reduced two to three orders of magnitude with de minimis.

The total or overall mission risk (i.e., the expected number of health effects due to the risk of radiological accidents associated with the overall mission) is dominated by Earth swingby reentry accidents for both the primary launch opportunity (VVEJGA) and the backup launch opportunity (VEEGA). The overall mission risk (without de minimis) is 1.7×10^{-3} for the primary launch opportunity, and for the backup is 1.8×10^{-3}. Applying the de minimis concept, the total mission risk for both the primary and backup launch opportunities would be reduced by two orders of magnitude.

These risks are clearly low when compared to the health risks from many large projects and the daily risks faced by individuals. For example, the expected number of fatalities during a major construction project often approaches 1.

Average Individual Risk

Although the predicted risks of health effects due to accidents during Phases 1 through 6 are clearly low, it is still useful to compare the health risks associated with the Cassini mission to risks encountered elsewhere. One measure of the risk associated with the release of plutonium fuel from a Cassini mission accident is to estimate the risk to the average exposed individual, or the average individual risk. This risk is the average risk of a health effect (latent cancer fatality) to a person in the exposed population. For launch phase accidents, the persons potentially affected are in the vicinity of the launch site. For other mission accidents, the persons exposed could be within the general vicinity of reentry footprints or worldwide, depending on the accident scenario. Using the basic techniques and assumptions in the Ulysses mission EIS and FSAR (NASA 1990, DOE 1990a), the average individual risk from each representative accident scenario can be calculated.

Table 4-18 presents the average individual risks estimated for launch Phases 1 through 6 for the primary and backup opportunities and for the associated VVEJGA and VEEGA trajectories (Halliburton NUS 1994a). The values provided in Table 4-18 were derived from the expectation case results presented in Tables 4-10, 4-12, and 4-13. Because launch Phases 1 through 6 and the four representative accident scenarios are common to all of the Titan IV launch opportunities (primary, secondary, backup, as well as for the 2001 alternative), the average individual risks for each phase are the same across all launch opportunities and are reported once in Table 4-18. The highest average individual risk for both the primary and backup opportunities would occur in Phase 5 of the launch, with the risk estimated at about 7.5×10^{-11}, or a chance of about 1 in 13 billion of the average exposed individual incurring a fatal cancer as a result of a Phase 5 accident (with release of RTG fuel). Applying the de minimis concept, the average individual risk from such a Phase 5 accident would be reduced by a factor of about three, to 2.2×10^{-11} health effects, or a chance of about 1 in 45 billion of the average exposed individual contracting fatal cancer as a result of an RTG fuel release in Phase 5.

With respect to the Earth gravity-assist trajectories and potential releases of plutonium fuel from an inadvertent reentry during swingby, the resulting exposed population would be essentially worldwide. On that basis, the average individual risk from an inadvertent reentry during the primary opportunity's VVEJGA Earth swingby would be 3.4×10^{-13}, or a chance of about 1 in 2.9 trillion of the average exposed individual incurring a fatal cancer as a result of a fuel release. Accounting for de minimis, the risk drops by about two orders of magnitude to 1.5×10^{-15} or a chance of 1 in 670 trillion of incurring a fatal cancer as a result of the accident.

TABLE 4-18. PRELIMINARY AVERAGE INDIVIDUAL RISK ESTIMATES FOR THE PROPOSED ACTION USING THE TITAN IV (SRMU)/CENTAUR

Mission Phase	Accident Scenario	Mission Risks, Health Effects[a,b]		Exposed Population at Risk[c]	Average Individual Risk[b,c,d]	
		Without De Minimis	With De Minimis		Without De Minimis	With De Minimis
1	Command Shutdown & Destruct	1.2×10^{-7}	–	1×10^5	1.2×10^{-12}	–
	Titan IV (SRMU) Fail-To-Ignite	3.1×10^{-7}	–	1×10^5	3.1×10^{-12}	–
	Centaur Tank Failure/Collapse	3.1×10^{-8}	–	1×10^5	3.1×10^{-13}	–
				Subtotal: Phase 1	4.7×10^{-12}	–
5	Command Shutdown & Destruct	6.9×10^{-8}	2.0×10^{-8}	1×10^3	6.9×10^{-11}	2.0×10^{-11}
	Centaur Tank Failure/Collapse	5.6×10^{-9}	1.6×10^{-9}	1×10^3	5.6×10^{-12}	1.6×10^{-12}
				Subtotal: Phase 5	7.5×10^{-11}	2.2×10^{-11}
6	Inadvertent Reentry from Orbit	3.0×10^{-7}	8.8×10^{-8}	5×10^3	6.0×10^{-11}	1.8×10^{-11}
VVEJGA	Inadvertent Reentry - Swingby	1.7×10^{-3}	7.4×10^{-6}	5×10^9	3.4×10^{-13}	1.5×10^{-15}
VEEGA	Inadvertent Reentry E1	4.7×10^{-4}	2.8×10^{-6}	5×10^9	9.4×10^{-14}	5.6×10^{-16}
	Inadvertent Reentry E2	1.3×10^{-3}	4.1×10^{-6}	5×10^9	2.6×10^{-13}	8.2×10^{-16}
				Subtotal: VEEGA	3.5×10^{-13}	1.4×10^{-15}

Source: Halliburton NUS 1994a

a. Expectation of incremental latent cancer fatalities.

b. The de minimis dose level for the purpose of this EIS is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year.

c. Population at risk is an order-of-magnitude estimate, representing the estimated number of persons that significantly accounted for most of the collective dose.

d. The average individual risk for a given accident scenario, (i), is:

$$(\text{Average individual risk})_i = (\text{Mission risk contribution})_i \,/\, (\text{Exposed population at risk})_i$$

TABLE 4-19. AVERAGE INDIVIDUAL RISK WITHIN THE FOOTPRINT OF EARTH-GRAVITY-ASSIST REENTRY ACCIDENTS

Reentry Type	Footprint Area, km^2 (mi^2)	Land Fraction	Population Density,[a] persons/km^2 persons/mi^2	Health Effects[b]		Conditional Probability	Short Term Total Probability	Average Individual Risk[c]	
				Without De Minimis	With De Minimis			Without De Minimis	With De Minimis
VVEJGA									
Expectation[d]	1.05×10^4 (4.05×10^3)	0.251	47.1 (122)	1.64×10^1	9.48×10^0	1.00	7.6×10^{-7}	1.0×10^{-10}	5.8×10^{-11}
VEEGA E1									
Expectation[d]	6.59×10^3 (2.54×10^3)	0.273	60.1 (156)	2.45×10^1	1.41×10^1	1.00	1.9×10^{-7}	4.3×10^{-11}	2.5×10^{-11}
VEEGA E2									
Expectation[d]	1.85×10^4 (7.14×10^3)	0.265	78.9 (204)	2.47×10^1	1.42×10^1	1.00	2.8×10^{-7}	1.8×10^{-11}	1.0×10^{-11}
						Overall VEEGA	4.7×10^{-7}	6.1×10^{-11}	3.5×10^{-11}

Source: adapted from Halliburton NUS 1994a

a. Population densities are adjusted as follows (Halliburton NUS 1994a):

Scaled population density = (1990 Population Density x World Population at Swingby Year Plus 5 Years)/1990 World Population)

Values for the 1990 population density applicable to various reentry types are presented in Appendix B (Table B-2).

b. The de minimis dose level for the purpose of this EIS is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year.

c. Method of calculation:

Average Individual Risk = (Health Effects x Total Probability)/(Footprint Area x Land Fraction x Population Density).

d. Expectation calculation:

Expectation Value = (P_1 x Shallow Value) + (P_2 x Steep Value)

where P_1, P_2 = Conditional probability of reentry type for EGA inadvertent reentry.

The average individual risks associated with the Earth swingbys would be somewhat greater for the people exposed within the footprint of intact modules and components impacting land. Within the footprint, individuals could receive exposure not just from the vaporized fuel in the air but also from releases associated with the impact on land (rock, soil) of intact modules and components that survived reentry. The average individual risks within the footprints are provided in Table 4-19 for the expectation cases. The average individual risk for exposed individuals within the footprint was developed from the following calculation:

> Average Individual Risk Within Footprint = (Health Effects x Total Probability)/(Footprint Area x Land Fraction x Population Density)

This calculation was made to account for population growth and the conditional probability that the affected individuals would be in the footprint. The footprint area first had to be adjusted for the amount of area within the footprint likely to be land (i.e., Footprint Area x Land Fraction). The population density within the footprint area had to be adjusted for population growth between 1990 (the census year for the basic population data used by Halliburton NUS) and the year when the exposure would be likely to occur. (For the purposes of this analysis, this was the year 2004 for the VVEJGA and 2006 [E1] and 2009 [E2] for the VEEGA. Because the collective dose due to vaporized fuel released at high altitude dominates collective dose from all source terms, all dates are 5 years beyond the actual swingby date, when exposure to vaporized fuel released at high altitude would tend to be a maximum.)

Looking at the primary launch opportunity VVEJGA Earth swingby, the average individual risk for an individual inside the footprint would be about 1.0×10^{-10} or a chance of 1 in 10 billion of developing fatal cancer as a result of exposure. Accounting for de minimis, the average individual risk would be about 5.8×10^{-11} or a chance of 1 in 17 billion. The overall average individual risk across the two Earth swingbys of the backup launch opportunity would be about 6.1×10^{-11} or a chance of about 1 in 16 billion of incurring a fatal cancer as a result of exposure from a VEEGA swingby reentry accident. With de minimis, the average individual risk drops to about 3.5×10^{-11} or a chance of 1 in 29 billion of a fatal cancer from a VEEGA accident exposure. The average individual risk within the footprint would be, nonetheless, extremely small.

These average individual risks identified in Table 4-18 are also quite small compared with the approximate commonly faced individual risks. Table 4-20 presents the calculated individual risk of fatality by various causes for people within the United States. From all causes, the individual risk is approximately 9 in 1,000 per year with disease, accidents, and suicide being the dominant contributors. The individual risk from launch of the Cassini spacecraft is estimated at less than 1 in ten billion (1×10^{-10}), which is insignificant when compared to these other everyday and unrelated risks.

On an absolute scale, the risk of latent cancer fatalities due to the accidents identified is quite small. The radiological risks to people living near the CCAS launch site are much lower than the Nuclear Regulatory Commission (NRC) quantitative safety objective for nuclear power plant operation:

TABLE 4-20. CALCULATED INDIVIDUAL RISK OF FATALITY BY VARIOUS CAUSES IN THE UNITED STATES

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

a. Based on 1991 data except where noted (National Safety Council 1992).
b. Based on 1990 data (Bair 1992).
c. Based on 1989 data (USBC 1992).

> The risk to the population in the area near a nuclear power plant (i.e., within 16 km [10 mi] of the plant site) of cancer fatalities that might result from nuclear power plant operation should not exceed one-tenth of one percent (0.1%) of the sum of all cancer fatality risks resulting from all other causes (51 FR 28044).

Risk to the Maximum Exposed Individual

Another perspective can be gained by looking at the risk to the maximum exposed individuals. This risk is calculated in the same manner as the mission (population) risk and the average individual risk, only using the maximum individual doses from Tables 4-10, 4-11, and 4-13. For Phase 1 launch accidents, the total offsite maximum individual risk of a latent cancer fatality due to radiological accidents would be 2.3×10^{-11} (1 in 43 billion). Cancer risks to most offsite people from launch accidents would be even lower, with the average CCAS area individual risk of a fatal cancer due to the Cassini launch being less than 4.7×10^{-12} (1 in 200 billion) (see Table 4-18). These risks are approximately a million times lower than that allowed for nuclear facilities with NRC safety objectives.

For the estimated exposures to the maximum exposed individuals within the general GPHS module impact areas for Phases 5 and 6 and the GPHS module, GIS, and/or large particle impact areas for Earth swingby accidents, the incremental cancer fatality risks to these maximum exposed individuals is estimated to be approximately 1×10^{-8} (1 in 100 million) for each of these accident cases. This is at least 10,000 times lower than that required by NRC safety objectives. Actual estimates of the maximum individual doses are presented in Tables 4-10, 4-12, and 4-13. Table 4-21 presents the estimated latent cancer fatality risks to individuals receiving the highest exposures in Cassini mission accidents. The average individual risk of health effects due to these accidents is expected to be less than 10^{-10} (1 in 10 billion) (see Table 4-18).

4.1.9 Emergency Response Planning

Prior to the launch of the Cassini spacecraft with RTGs and the RHUs onboard, a comprehensive radiological contingency plan would be developed in accordance with the Federal Radiological Emergency Response Plan. This contingency plan, similar to the ones developed for the Galileo (NASA 1989b) and Ulysses (NASA 1990) missions, would ensure that any accident, whether it involves a radiological release or not, could be met with a well-developed and tested response. The plan would be developed through the combined efforts of NASA, DOE, DOD, EPA, the Federal Emergency Management Agency, State of Florida, and local organizations involved in emergency response. Portions of the plan would be practiced to ensure that the various organizations were prepared to support the launch. NASA would be the Cognizant Federal Agency coordinating the Federal response for accidents occurring within U.S. jurisdiction.

In the event of a release, or in support of preplanned precautionary measures, the State of Florida and local governments would determine an appropriate course of action. As more detailed radiological measurements became available, State and local authorities would decide on the addition or rescission of precautions.

TABLE 4-21. ESTIMATED LATENT CANCER FATALITY RISKS TO INDIVIDUALS RECEIVING THE HIGHEST EXPOSURES IN CASSINI MISSION ACCIDENTS[a,b]

Mission Phase/ Accident Scenario	Total Probability	Maximum Individual Dose, Sv (rem)	Estimated Latent Cancer Fatalities Per Sv (rem) Exposure	Latent Cancer Fatality Risk
Phase 1: Command Shutdown & Destruct	1.7×10^{-4}	1.02×10^{-6} (1.02×10^{-4})	3.5×10^{-2} (3.5×10^{-4})	6.1×10^{-12}
Phase 1: Titan IV SRMU Fail-to-Ignite	9.1×10^{-4}	4.73×10^{-7} (4.73×10^{-5})	3.5×10^{-2} (3.5×10^{-4})	1.5×10^{-11}
Phase 1: Centaur Tank Failure/Collapse	4.2×10^{-5}	1.03×10^{-6} (1.03×10^{-4})	3.5×10^{-2} (3.5×10^{-4})	1.5×10^{-12}
			Subtotal: Phase 1	2.3×10^{-11}
Phase 5: Command Shutdown & Destruct	4.6×10^{-4}	1.24×10^{-4} (1.24×10^{-2})	3.5×10^{-2} (3.5×10^{-4})	2.0×10^{-9}
Phase 5: Centaur Tank Failure/Collapse	3.7×10^{-5}	1.24×10^{-4} (1.24×10^{-2})	3.5×10^{-2} (3.5×10^{-4})	1.6×10^{-10}
			Subtotal: Phase 5	2.2×10^{-9}
Phase 6: Inadvertent Reentry from Orbit	4.4×10^{-4}	5.43×10^{-4} (5.43×10^{-2})	3.5×10^{-2} (3.5×10^{-4})	8.4×10^{-9}
Earth Swingby: VVEJGA	7.6×10^{-7}	3.06×10^{-1} (3.06×10^{1})	3.5×10^{-2} (3.5×10^{-4})	8.1×10^{-9}
Earth Swingby: Backup Mission E1	1.9×10^{-7}	4.76×10^{-1} (4.76×10^{1})	3.5×10^{-2} (3.5×10^{-4})	3.2×10^{-9}
Earth Swingby: Backup Mission E2	2.8×10^{-7}	3.55×10^{-1} (3.55×10^{1})	3.5×10^{-2} (3.5×10^{-4})	3.5×10^{-9}
			Subtotal: VEEGA	6.7×10^{-9}

Source: Martin Marietta Astro Space 1993, JPL 1993f, Owings 1994a, adapted from Halliburton NUS 1994a

[a] The maximum individual dose is based on the individual being within the footprint.

[b] Based on expectation release values presented in Tables 4-10, 4-12, and 4-13.

The contingency plan would entail the following steps:

- Determining whether radioactive material was released
- Assessing and characterizing the extent of any release
- Predicting the propagation and dispersion of the released material
- Formulating and recommending protective and mitigating actions to protect people and property from the impacts of the release
- Minimizing the effects of a release by controlling the contaminated areas and containing radioactive materials
- Recovering and disposing of the radioactive material
- Decontaminating and recovering affected areas, facilities, equipment, and properties.

A specially equipped Radiological Control Center located at KSC would direct any emergency actions required during the pre-launch countdown or the early phases of the mission. These emergency actions could involve radiation monitoring and possibly precautionary sheltering or relocation of personnel. In the event of an accident, a nearby offsite location would be established by NASA, DOE, DOD, EPA, and the State of Florida which would conduct radiological monitoring and assess the accumulated data.

The response to launch accidents would also depend on the geographical locations involved. Accident sites within the continental United States and U.S. Territories would be supported initially by the nearest military or Federal installation possessing a radiological contingency response capability. Personnel from all supporting installations would be alerted to this potential requirement prior to launch. Additional support would be dispatched from the launch site support personnel or from other support agencies, as needed. For accidents occurring outside the continental United States or its territorial jurisdictions, the State Department and diplomatic channels would be employed in accordance with pre-arranged procedures and support elements would be dispatched as appropriate.

If an ocean or water impact occurs, NASA, DOE, and DOD would initiate security measures and search and retrieval operations. The recovery of the plutonium dioxide fuel would be based on the technological feasibility, the cost of the recovery operation, the health hazard presented to recovery personnel and the environment, and other pertinent factors.

4.2 ENVIRONMENTAL IMPACTS OF THE 1999 MISSION ALTERNATIVE

This mission alternative would entail dual Shuttle launches from KSC in which the first launch would predeploy an upper stage(s) into low Earth orbit, and a second launch, 21 to 51 days later, to deliver the Cassini spacecraft and the remaining upper stage(s) into low Earth orbit. An on-orbit mating of the upper stages and the spacecraft would be performed by astronauts, followed by the insertion of the spacecraft in March 1999 into its VEEGA trajectory to Saturn. The backup launch opportunity would occur about 19 months later in August 2000, should the March 1999 opportunity have to be canceled for technical or other reasons (e.g., weather). Additional details describing this alternative are presented in Section 2.3. The launch impacts described below (Section 4.2.2) for the March 1999 primary launch opportunity would also apply to the August 2000 backup launch opportunity.

4.2.1 Environmental Impacts of Preparing for Launch

The environmental impacts associated with this phase of the mission preparation would be similar to those described in Section 4.1.1. Spacecraft assembly and associated testing would still be completed at JPL. The spacecraft would be shipped to KSC, and the Huygens Probe would be shipped by ESA to KSC. The RTGs and RHU would be transported to KSC by DOE, and the remaining assembly and testing of the completed spacecraft (with Probe, RTGs, and RHUs) would be completed at KSC along with integration of the completed spacecraft to the partial upper stage and ultimately with the Shuttle.

The industrial operations and associated solid and liquid wastes that would be generated by Shuttle preparations would not occur at CCAS. Solid and liquid wastes generated by pre-launch processing at KSC would be handled and disposed of in accordance with KSC procedures and permits. Fueling of the Shuttle external tank would involve liquid hydrogen and liquid oxygen fuels; therefore, the emissions associated with the use of Aerozine-50 and nitrogen tetroxide for the Titan IV would be absent.

Radiation exposure of occupational personnel handling the RTGs and RHUs and the public prior to launch were also addressed in prior NASA NEPA documentation (NASA 1989b, NASA 1990). Although two Shuttles would be launched, the potential for radiation exposure would not double. Occupational exposures would occur during integration and testing of the RHUs and RTGs with the spacecraft (and Probe) prior to launch of the second Shuttle, and during final integration of the RTGs with the spacecraft just prior to the second launch. The general public would not be allowed near the RTGs or RHUs at any time; therefore, no exposure of the public would occur.

None of the activities associated with preparation for launch using the two Shuttle launch vehicles would have any significant environmental impacts. A more complete description of these activities and impacts for a single Shuttle launch is given in the Galileo and Ulysses Tier 2 EISs (NASA 1989b, NASA 1990). The principal difference is that under this alternative, the vehicle pre-launch activities would occur twice, separated by 21 to 51 days. It is not anticipated that implementation of this alternative would cause NASA's planned Shuttle launches per year to be increased; therefore, the contribution of the Cassini mission to the pre-launch impacts experienced from the normally planned Shuttle launches per year would not be increased.

4.2.2 Environmental Impacts of a Normal Launch of the Cassini Spacecraft by the Dual Shuttle Launches

The environmental impacts of this alternative would be the same as those addressed in the Galileo and Ulysses mission Tier 2 EISs (NASA 1989b, NASA 1990) and in the KSC *Environmental Resources Document* (NASA 1994). The only difference is that the impacts associated with this alternative would occur twice, as expected with two Shuttle launches. The impacts from the two launches would occur between 21 to 51 days apart.

The KSC Environmental Resources Document (NASA 1994) generally updated the impact description in the Galileo and Ulysses (NASA 1989b, NASA 1990) Tier 2 EISs. The updated information is summarized below and in Table 2-6, given previously.

The Shuttle would utilize both its liquid fueled main engines (liquid hydrogen and liquid oxygen fuel) and two solid rocket boosters (SRBs) to lift the vehicle and its cargo off the launch pad and to reach the desired parking orbit. The SRBs would use a solid rocket fuel similar to that in the Titan IV SRMs, and the exhaust emissions from the two SRBs would be the primary source of impact associated with a Shuttle launch. Each of the SRBs is about two times the size of an SRMU. The total fuel inventory of the Shuttle's two SRBs would be about 1,010,000 kg (2,220,000 lb). The mission timeline (see Section 2.3.7) for a Shuttle is similar to that of a Titan IV (SRMU): the Shuttle ascends through the troposphere (sea level to about 10 km [32,808 ft]) in about 60 seconds and transits the stratosphere in about 236 seconds (altitude about 50 km [164,050 ft]).

Exhaust products in the exhaust cloud are typically dispersed within about 14 km (9 mi) of the launch complex (Pad 39A or 39B), with the heaviest deposition of Al_2O_3 particulates and HCl droplets and aerosols occurring within about 1 km (0.6 mi) of the launch pad. Within this 1-km (0.6-mi) area, chlorides have been measured at levels of up to 127 g/m^2 (0.026 lb/ft^2) and Al_2O_3 particulates at levels up to 246 g/m^2 (0.050 lb/ft^2). Under certain meteorological conditions, up to 7,100 kg (15,653 lb) of particulates and 3,400 kg (7,496 lb) of HCl can be deposited within 1 km (0.6 mi) of the pad (NASA 1994).

The ground cloud from a Shuttle launch has high concentrations of solid rocket motor exhaust products, specifically particulates (Al_2O_3) and HCl near the launch pad, similar to a Titan IV (SRMU) launch. As the Shuttle is launched, about 3,300,000 l (863,000 gal) of deluge and washwater is used. An unknown amount of the 1,938,000 l (510,000 gal) of deluge water discharged to the flame trench is vaporized in the Shuttle exhaust, contributing to the formation of HCl droplets in the exhaust cloud. The water (1,238,800 l [326,000 gal]) used to wash down the launch facility about 10 minutes after launch also scrubs HCl from the exhaust cloud. The washwater is collected in tanks connected to the flame trench and would be neutralized prior to release to the ground surface in the vicinity of the launch complex (Pad 39A or 39B) (NASA 1994).

Elevated levels of metals (e.g., aluminum, iron, zinc) have been observed in nearby surface waters immediately after launch in areas of heavy exhaust deposition, as reflected in substantially reduced acidity in the affected water bodies. Levels of these metals within a few hours of launch return to normal after the acidity of the affected water bodies normalizes.

Groundwater studies at Shuttle Launch Pads 39A and 39B have concluded that while minor elevations of heavy metals have been detected, there is no clear evidence of accumulation in the surficial aquifer, nor is there any demonstrated relationship to Shuttle launches (NASA 1994).

Changes in the biological environment have been documented for Shuttle launches. Short-term changes include acidification of nearby surface water impoundments, alteration of water chemistry (elevation of metals as noted above), and fish kills in shallow impoundments north of the launch complex. Over time, as launches have continued, the vegetative community structure and the species composition have been altered and the vegetative cover has been reduced. These effects have been largely limited to a small area of about 15 ha (37 acres) near the launch pads. This would be the area of heaviest deposition of exhaust products from a Shuttle launch (NASA 1994).

At distances beyond 1 km (0.6 mi) from the launch pad, exhaust product deposition varies with movement of the exhaust cloud. Some vegetation damage (e.g., leaf spotting) has been observed.

There have been no known significant adverse impacts on threatened or endangered species associated with Shuttle launches from KSC.

4.2.3 Environmental Impacts of Balance of Mission

Implementation of a normal VEEGA trajectory would have no adverse impact on the human environment, nor would completion of the Saturnian tour by the Cassini Orbiter or delivery of the Huygens Probe.

As noted in Section 4.1.3, Cassini mission operations have been designed to minimize the potential of biologically contaminating any other solar bodies that might harbor life (JPL 1990). The probability that Saturn and Titan could harbor Earth-type life has been assessed as essentially nil.

4.2.4 Nonradiological Impacts of Shuttle Launch Accidents

The nonradiological impacts of Shuttle accidents have been addressed in previous NASA NEPA documents (Shuttle Program EIS [NASA 1978], Tier 1 Galileo and Ulysses Mission EIS [NASA 1988b], and Galileo and Ulysses Tier 2 EISs [NASA 1989b, NASA 1990]). The principal difference associated with the 1999 mission alternative is the use of two Shuttle launches.

4.2.5 Radiological Accident Assessment

4.2.5.1 Accident Scenarios and Environments

In view of the detailed analyses of the Shuttle launch vehicle (NASA 1988a, NASA 1988b, NASA 1989b, NASA 1990, DOE 1988b, DOE 1989a, DOE 1989b, DOE 1990a, DOE 1990b), several assumptions were made. Pre-launch and launch accidents were taken directly as described in the 1988 Shuttle Databook (NASA 1988a) used for the Ulysses FSAR, which has been updated with initiating accident probabilities (DOE 1990a).

This section briefly discusses the accident scenarios and their associated accident environments, as described in the *Preliminary Risk Estimates for the Cassini Mission STS Alternative Launch Option* (Halliburton NUS 1994b) and the *Accident Assessment for Shuttle Launch of Cassini* (Martin Marietta Astro Space 1994b). Since the launch accidents and environments are assumed to be the same as those defined for the Ulysses mission, the RTG responses were also taken to be the same (Martin Marietta Astro Space 1994b). There are, however, some differences. The primary differences are related to the three RTGs onboard the Cassini spacecraft versus the one RTG onboard Ulysses. Because the information was not available, other differences not taken into account included the placement and orientation of the Cassini spacecraft RTGs within the Shuttle Orbiter's cargo bay and the requirements for the on-orbit upper stage(s) and spacecraft assembly. In addition, differences in propulsion characteristics associated with the Cassini mission upper stage configuration compared to the Ulysses mission and their potential effect on reentry conditions for accidents in Phases 3 and 4 were not considered (Martin Marietta Astro Space 1994b, Halliburton NUS 1994b).

Shuttle Phase 0

During Phase 0, none of the accident scenarios or environments identified for pre-launch would cause the RTG to release fuel.

Shuttle Phase 1, First Stage

Phase 1 begins with liftoff and ends with SRB burnout and jettison at T + 128 seconds. Potential accidents during this phase include Solid Rocket Booster (SRB) failures, Range Safety Destruct, aft compartment explosion, launch vehicle breakup, and those leading to an Orbiter crash landing or ocean ditch (Martin Marietta Astro Space 1994b). During operation of an SRB, fragments will be produced upon rupture of the steel pressure-containment motor case either by random failure or range destruct action. These substantial fragments may damage an RTG or propel it into another structure (Martin Marietta Astro Space 1994b).

Shuttle Phase 2, Second Stage

Phase 2 begins with SRB separation at T + 128 seconds and continues through Shuttle main engine cutoff, external tank separation, and ends at T + 532 seconds when the Shuttle Orbital Maneuvering System (OMS) engines begin their first burn. Accidents during Phase 2 occur above 39 km (127,959 ft) and all the scenarios considered result in vehicle breakup. Following vehicle breakup, there is a conditional probability of 0.2 that RTGs would reenter intact because the reentry conditions would preclude RTG case melt. This could occur only in the early portion of Phase 2, so the RTGs would impact water. Otherwise, GPHS modules would reenter independently following RTG case melt with a conditional probability of 0.8 (Martin Marietta Astro Space 1994b).

Shuttle Phase 3, On Orbit

Phase 3 begins with the first burn of the OMS engines at T + 532 seconds and ends with deployment of the spacecraft/upper stage from the Orbiter. The orbital inclination would be 28 degrees. Accidents during this phase result in uncontrolled orbital decay reentry of the Orbiter, followed by Orbiter breakup and independent reentry of the GPHS modules. This could only occur if the failure was of such a nature that a mission abort from orbit to a safe landing was not possible (Martin Marietta Astro Space 1994b).

Shuttle Phase 4, Payload Deploy

Phase 4 begins with spacecraft/upper stage deployment from the Orbiter and ends with attainment of escape velocity after upper stage firing. Accidents during this phase resulting from upper stage malfunctions lead to spacecraft reentry, breakup, and independent reentry of GPHS modules (Martin Marietta Astro Space 1994b).

Inadvertent Reentry During Interplanetary Cruise

The accident scenarios and environments are determined by the interplanetary trajectory, (i.e., they are independent of the launch vehicle). It can be assumed, therefore, that both the accident scenarios (short-term or long-term inadvertent reentry) and accident environments would be identical for a similar trajectory for any launch vehicle. As such, the 1999 Shuttle mission alternative using a VEEGA trajectory would be assumed to have identical reentry conditions as the Titan IV (SRMU or SRM)/Centaur VEEGA trajectory.

The actual reentry conditions for an inadvertent reentry during the 1999 Shuttle mission interplanetary cruise would be identical to the those evaluated for the 1999 Titan IV backup launch opportunity. The interplanetary cruise portion of the two missions would be the same. For VEEGA trajectories with other launch dates, the reentry conditions could be different. It should be noted that for conservatism, the more severe VVEJGA reentry conditions were used when estimating the consequences of inadvertent reentry during the VEEGA trajectory. (See Appendix B for additional details of these analyses.)

4.2.5.2 Probabilities for Initiating Accidents

The *1988 Space Shuttle Databook* (NASA 1988a) contains initiating accident probabilities used for the Ulysses FSAR (DOE 1990a). The initiating probabilities for the Shuttle were developed by NASA (NASA 1990) and based on launch failure probabilities for the accidents identified for Phases 1 through 4. Table 4-22 summarizes the initiating, conditional, and total probabilities for the launch phase accidents for the Shuttle.

TABLE 4-22. SUMMARY OF LAUNCH PHASES 1 THROUGH 4 ACCIDENT SCENARIO SOURCE TERM PROBABILITIES FOR THE SHUTTLE LAUNCH[a]

Mission Phase	Time Period (s)	Accident Scenario Description	Initiating Probability	Conditional Probability[b]	Total Probability
1a	0-10	SRB Case Rupture	2.92×10^{-3}[c]	3.49×10^{-3}	1.02×10^{-5}
1b	11-20		—	8.56×10^{-4}	2.50×10^{-6}
1c	21-70		—	4.52×10^{-4}	1.32×10^{-6}
1d	71-104		—	4.59×10^{-4}	1.34×10^{-6}
1e	105-128		—	1.60×10^{-3}	4.68×10^{-6}
1a	0-10	Range Safety Destruct	1.70×10^{-6}[c]	1.18×10^{-4}	2.00×10^{-10}
1b	11-20		—	3.48×10^{-4}	5.91×10^{-10}
1c-d	21-104		—	3.30×10^{-3}	5.61×10^{-9}
1e	105-128		—	7.82×10^{-4}	1.33×10^{-9}
2	128-532	Vehicle Breakup	5.65×10^{-3}	1.03×10^{-2}	5.82×10^{-5}
3	532-24,000	Reentry	5.75×10^{-4}	2.18×10^{-1}	1.25×10^{-4}
4	24,000 to Earth Escape	Reentry	8.86×10^{-3}	2.18×10^{-1}	1.93×10^{-3}

Source: Halliburton NUS 1994b, Martin Marietta Astro Space 1994b, Owings 1994b

a. No source terms were identified in Phase 0.
b. Conditional probability of a fuel release (average source term) given the initiating accident.
c. The initiating accident probability for the scenario is constant throughout Phase 1.

Because the interplanetary cruise portion of the mission is determined by the type of trajectory, it can be assumed that the probability of an inadvertent reentry during an Earth swingby(s) would be the same for a similar trajectory. Therefore, the probabilities associated with a 1999 launched Titan IV (SRMU or SRM)/Centaur on a VEEGA trajectory would be assumed to be identical for the 1999 Shuttle mission alternative on a VEEGA trajectory.

4.2.5.3 Potential Accident Source Terms

This section describes the potential source terms for the accidents identified for the Shuttle. Table 4-23 summarizes the source terms based on expectation cases indicating the source release condition (i.e., involvement in the fireball, ground level impact, or altitude release).

Accidents in Phase 1 associated primarily with SRB Case Rupture and Range Safety Destruct could result in releases due to SRB fragment impacts and impacts of GPHS modules and fueled clads on concrete, steel, and sand in the launch area. During the time period T - 0 to T + 10 seconds, fragment-induced releases would occur within the fireball generated by the accident. Releases from GPHS modules and fueled clads impacting on concrete, steel, and sand would be entrained in the vertical plume associated with the fireball and afterfire. During the time period T + 21 to T + 70 seconds, fragment-induced releases would be at altitude with any surface impact releases associated with GPHS modules or fueled clads impacting sand. From T + 71 to T + 128 seconds, only fragment-induced releases at altitude could occur. The source terms would increase with altitude and mission elapsed time due to the increase in SRB internal pressure, which peaks just prior to burnout at T + 128 seconds (Martin Marietta Astro Space 1994b).

Accidents in Phase 2 could involve fuel releases if GPHS modules impact hard rock along the trajectory over Africa. This could occur only if the accident occurs during a 5.5-second interval near the end of Phase 2 when the instantaneous impact point (IIP) would be over Africa. Accidents prior to that time would result in GPHS modules impacting the ocean with no release (Martin Marietta Astro Space 1994b).

For accidents occurring during Phase 3 (i.e., spacecraft breakup during reentry), the reentry heating pulse would melt the RTGs converter housing by design and release individual GPHS modules. The GPHS modules are designed to remain intact under these reentry conditions. Individual reentering GPHS modules impacting rock could lead to fueled clad failures and fuel releases. No releases would be expected from soil or water impacts (Martin Marietta Astro Space 1994b).

During Phase 4 accidents, fuel release conditions, similar to Phase 3, would result from GPHS modules impacting rock (Martin Marietta Astro Space 1994b).

Short-Term Inadvertent Reentry During Earth Swingby

Since the trajectories for the Earth swingby portions of the 1999 Shuttle VEEGA primary launch opportunity and the 1999 Titan IV backup launch opportunity, also a VEEGA, would be identical, the source term for the inadvertent reentry during an Earth

TABLE 4-23. SUMMARY OF AVERAGE (EXPECTATION CASE) SOURCE TERMS FOR LAUNCH PHASES 1 THROUGH 4 FOR THE SHUTTLE LAUNCH

Mission Phase	Time Period (s)	Accident Scenario Description	Total Probability	Source Term, Bq (Curies)			Altitude, m (ft)[a]	Remarks
				Fireball	Ground-Level	At Altitude		
1a	0-10	SRB Case Rupture	1.02×10^{-5}	2.31×10^{12} (6.23×10^{1})	7.84×10^{10} (2.12×10^{0})	—	—	b
1b	11-20		2.50×10^{-6}	1.69×10^{10} (4.57×10^{-1})	1.69×10^{11} (4.56×10^{0})	2.68×10^{11} (7.24×10^{0})	576 (1,890)	c
1c	21-70		1.32×10^{-6}	—	2.19×10^{8} (5.92×10^{-3})	1.40×10^{11} (3.79×10^{0})	6,520 (21,400)	d
1d	71-104		1.34×10^{-6}	—	—	4.51×10^{11} (1.22×10^{1})	25,700 (84,300)	e
1e	105-128		4.68×10^{-6}	—	—	9.44×10^{12} (2.55×10^{2})	38,100 (125,000)	e
1a	0-10	Range Destruct	2.00×10^{-10}	4.66×10^{10} (1.26×10^{0})	4.40×10^{9} (1.19×10^{-1})	—	—	b
1b	11-20		5.91×10^{-10}	2.07×10^{10} (5.59×10^{-1})	1.31×10^{11} (3.54×10^{0})	9.18×19^{9} (2.48×10^{-3})	497 (1,630)	c
1c-d	21-104		5.61×10^{-9}	—	3.74×10^{9} (1.01×10^{-1})	4.29×10^{12} (1.16×10^{2})	21,900 (71,800)	d
1e	105-128		1.33×10^{-9}	—	—	2.46×10^{12} (6.65×10^{1})	37,800 (124,000)	e
2	128-532	Vehicle Breakup	5.82×10^{-5}	—	5.07×10^{10} (1.37×10^{0})	—	—	f
3	532-24,000	Reentry	1.25×10^{-4}	—	5.55×10^{10} (1.50×10^{0})	—	—	g
4	24,000 to Earth Escape	Reentry	1.93×10^{-3}	—	5.55×10^{10} (1.50×10^{0})	—	—	g

Sources: Martin Marietta Astro Space 1994b, Halliburton NUS 1994b, Owings 1994b

a. Altitude values refer to in air releases. A vertical plume configuration is associated with fireball releases. Ground-level releases are assumed to occur at a 2-m height. A further description of release configurations and assumptions can be found in the Ulysses FSAR (DOE 1990a).

b. Releases due to SRB fragments, modules impacts on steel, and fueled clad impacts on steel, concrete, and sand.

c. Releases due to SRB fragments and fueled clad impacts on concrete and sand.

d. Releases due to SRB fragments and fueled clad impacts on sand.

e. Releases due to SRB fragments at altitude.

f. Releases due to module impacts on rock with fueled clad failures along in Africa.

g. Releases due to module impacts on rock with fueled clad failures at worldwide locations determined by a 28-degree orbital inclination.

swingby would also be expected to be identical. The source terms for an inadvertent reentry during either of the two Earth swingbys are presented in Table 4-8 and the estimated footprint area is provided in Table 4-9.

Long-Term Inadvertent Reentry From Interplanetary Cruise

Since the trajectories for the interplanetary cruise portions of the 1999 Shuttle VEEGA launch opportunity and the 1999 Titan IV VEEGA backup launch opportunity would be identical, the response of the spacecraft to a long-term reentry and resulting source term would be expected to be similar.

4.2.6 Environmental Consequences and Impacts of Radiological Accidents

This section addresses the radiological consequences and impacts of accidents occurring with a release of the plutonium dioxide fuel from a Shuttle accident. The methodologies used to determine the consequences are the same as those used for the Proposed Action (Section 4.1.6.1). The potential for radiological impact to the affected area depends on the mission phase/scenario combination, the likelihood of the accident occurring with fuel release, the amount of fuel released and the radiological consequences from the release.

Mission Phases 0 through 4

The results of the radiological consequence analysis of accident scenarios in mission Phases 1 through 4, corresponding to the expectation cases and based on average source terms, are summarized in Table 4-24. Since the total probabilities associated with Range Safety Destruct are so low compared to SRB Case Rupture (i.e., less than a 10^{-7} probability cutoff), while releases are comparable, Range Safety Destruct does not contribute meaningfully to overall mission risk and is not considered further (Halliburton NUS 1994b).

In calculating radiological consequences in Phases 3 and 4, and for the EGA inadvertent reentries involving worldwide locations, average population densities were used based on a probability weighting over reentry conditions of the latitude-dependent population density distribution. In calculating maximum individual doses due to releases from intact components impacting Earth surfaces, the location of the maximally exposed individual relative to a given ground-level release was determined by considering the average area associated with an individual corresponding to the applicable population density. Due to uncertainties, there is actually some probability distribution over the dose to the maximally exposed individual, and the reported results represent expectation values of such distributions (Halliburton NUS 1994b).

For accident scenarios with a fuel release occurring near KSC, the collective dose and health effects would be small. For the Phases 1a, 1b, or 1c expectation source terms (Table 4-24), the highest collective dose would be about 1×10^{-1} person-Sv (1×10^{1} person-rem). For any of the representative accidents occurring near KSC, less than one health effect is estimated without de minimis and no health effects are projected with de minimis. An offsite individual (member of the general public) at least 16 km

TABLE 4-24. RADIOLOGICAL CONSEQUENCES FOR MISSION PHASES 1 THROUGH 4 (EXPECTATION CASE SOURCE TERM) FOR THE SHUTTLE LAUNCH[a,b]

Mission Phase	Time Period, s	Accident Scenario Description	Collective Dose, person-Sv (person-rem)[c]		Health Effects[d]		Maximum Individual Dose, Sv (rem)	Land Area, km^2 (mi^2), Above 0.2 μCi/m^2
			Without De Minimis	With De Minimis	Without De Minimis	With De Minimis		
1a	0-10	SRB Case Rupture	1.39×10^{-1} (1.39×10^{1})	—	4.86×10^{-3}	—	6.84×10^{-6} (6.84×10^{-4})	3.84×10^{0} (1.48×10^{0})
1b	11-20		3.83×10^{-2} (3.83×10^{0})	—	1.34×10^{-3}	—	5.07×10^{-6} (5.07×10^{-4})	4.58×10^{-1} (1.77×10^{-1})
1c	21-70		4.49×10^{-3} (4.49×10^{-1})	—	1.57×10^{-4}	—	4.02×10^{-7} (4.02×10^{-5})	6.74×10^{-1} (2.60×10^{-1})
1d	71-104		3.26×10^{-1} (3.26×10^{1})	—	1.14×10^{-2}	—	5.37×10^{-11} (5.37×10^{-9})	—
1e	105-128		3.96×10^{0} (3.96×10^{2})	—	1.39×10^{-1}	—	6.56×10^{-10} (6.56×10^{-8})	—
2	128-532	Vehicle Breakup	4.03×10^{-3} (4.03×10^{-1})	1.16×10^{-3} (1.16×10^{-1})	1.41×10^{-4}	4.06×10^{-5}	1.16×10^{-4} (1.16×10^{-2})	2.02×10^{-2} (7.80×10^{-3})
3	532-24,000	Reentry	1.97×10^{-2} (1.97×10^{0})	5.68×10^{-3} (5.68×10^{-1})	6.89×10^{-4}	1.99×10^{-4}	5.43×10^{-4} (5.43×10^{-2})	2.22×10^{-2} (8.57×10^{-3})
4	24,000 to Earth Escape	Reentry	1.97×10^{-2} (1.97×10^{0})	5.68×10^{-3} (5.68×10^{-1})	6.89×10^{-4}	1.99×10^{-4}	5.43×10^{-4} (5.43×10^{-2})	2.22×10^{-2} (8.57×10^{-3})

Source: Halliburton NUS 1994b

a. No source terms were identified for Phase 0.

b. The expectation source terms represent a probability weighted source term based on a range of release conditions for a given scenario.

c. The de minimis dose level for the purpose of this EIS is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year. The collective dose with de minimis is the total population dose to those people receiving individual doses greater than the de minimis dose level.

d. Excess latent cancer fatalities.

(10 mi) away could receive a maximum individual dose of up to about 7 x 10^{-6} Sv (7 x 10^{-4} rem) from expectation case source terms. Comparing these doses with individual doses received from natural background radiation (about 3 x 10^{-3} Sv/yr [3 x 10^{-1} rem/yr]) and from manmade sources (on the order of 6.4 x 10^{-4} Sv/yr [6.4 x 10^{-2} rem/yr]) (see Table 4-14) for a total 50-year effective dose commitment of about 1.82 x 10^{-1} Sv [1.82 x 10^{1} rem) (National Research Council 1990), these doses would be considered not detectable. Land area contamination for an accident occurring near KSC would potentially contaminate less than 4 km^2 (1.6 mi^2) above the U.S. EPA screening level.

For a fuel release occurring during a 5.5-second period of Phase 2, the GPHS modules could impact limited portions of the African continent under the vehicle flight path. The collective dose associated with the expectation source terms (Table 4-23) would be about 4.0 x 10^{-3} person-Sv (4.0 x 10^{-1} person-rem). Less than one health effect expressed over a 50-year collective dose was estimated for a Phase 2 accident. For the expectation case, the maximum individual dose would be about 1.2 x 10^{-4} Sv (1.2 x 10^{-2} rem). Again, the maximum individual dose would be well below that experienced from natural and manmade background radiation by the average U.S. citizen. Anticipated land contamination above the screening level would be less than 1 km^2 (0.39 mi^2) for the expectation source term case.

For Phase 3 and 4 accidents (as with a Phase 2 accident), the radiological consequences would be limited to the immediate vicinity of the individual GPHS impact sites. These accidents should be very similar in terms of consequences to the accidents identified for Phases 5 and 6 for the Titan IV launch described in Section 4.1.6.2. While 54 modules would be expected to independently reenter the Earth's atmosphere, only an average of 3 modules would be expected to impact on a hard surface and release plutonium fuel. For impacts onto a hard surface for a Phase 3 or 4 accident, the expectation release (source term) would be about 5.6 x 10^{10} Bq (1.5 Ci) and would result in a 50-year collective dose of about 1.97 x 10^{-2} person-Sv (1.97 x 10^{0} person-rem). Less than one health effect over the 50-year period would be anticipated, with or without de minimis. The maximum individual dose would be about 5.4 x 10^{-4} Sv (5.4 x 10^{-2} rem), substantially less than the 50-year effective dose commitment received as background by an average U.S. citizen (Table 4-14). Land area contamination would be less than 1 km^2 (0.4 mi^2) with the expectation case.

Potential Consequences for a Short-Term Inadvertent Reentry During Earth Swingby (VEEGA)

Since the trajectories would be identical, the potential consequences of an inadvertent reentry during either Earth swingby associated with the VEEGA trajectory would be expected to be identical to those evaluated for the VEEGA 1999 Titan IV backup launch opportunity. Those consequences are presented in Table 4-13 and discussed in Section 4.1.6.2. It should be noted that for conservatism, the more severe VVEJGA reentry conditions were used when estimating the consequences of the inadvertent reentry during the VEEGA trajectory.

Potential Consequences for a Long-Term Inadvertent Reentry from Interplanetary Cruise

As with the 1999 Titan IV backup launch opportunity, although highly improbable, there would also be the potential for a long-term Earth impact by the Cassini spacecraft given a failure prior to SOI. The results of that accident are assumed to be similar.

4.2.6.1 Impacts of the Radiological Consequences on the Environment

While unlikely, if an accident were to occur that resulted in a release of plutonium dioxide fuel, impacts could be confined to the CCAS/KSC region or could involve broader areas. For example, an early Phase 1 (Phase 1a, 1b, and 1c) accident with a release could "impact" the local CCAS/KSC area only, while a late Phase 1 (Phase 1d and 1e) accident when the Shuttle has gained altitude could result in an atmospheric release that would be dispersed over a wider area. Localized areas of the African continent under the flight path could be impacted with a Phase 2 accident that occurred while the Shuttle was in its 5.5-second transit of the continent. A Phase 3 or 4 accident could potentially impact indeterminate areas at various locations around the world. While the potential for an inadvertent reentry of the spacecraft during an Earth swingby maneuver is remote, a portion of the fuel released in such an event could impact the atmosphere on a global level.

In the unlikely event of a Phase 1 accident, especially in view of the extremely low level of health effects that would be expected and the composition of the population in the region (See Section 3.1.7), it is highly unlikely that any given racial, ethnic, or socioeconomic group of the population would bear a disproportionate share of the consequences. (It should be noted that impact of the African continent could occur only during a 5.5 second portion of the Shuttle launch timeline).

The impacts are assessed similarly to those for the Proposed Action (i.e., the potential areal extent of land contamination). Table 4-24 indicates that up to 3.84 km^2 (1.48 mi^2) of dry land could be contaminated above the screening level in an accident occurring during the first 10 seconds of the launch. Later in the launch phase, as the Shuttle gains altitude and distance from the launch pad, the expected amount of land contamination would be even less. Therefore, only small areas of cleanup would be necessary.

In the unlikely event of a Phase 2 accident, or an inadvertent reentry from Earth orbit during Phases 3 and 4, the amount of potential land contamination would be essentially the same as that reported in Section 4.1.6.3 for comparable accidents with the 1997 launch of the Titan IV vehicle. The short-term and long-term reentry accident scenarios would be identical to those identified for the VEEGA 1999 Titan IV backup launch opportunity.

4.2.7 Economic Impacts

The potential economic impacts would be similar to those described in Section 4.1.7.

4.2.8 Health Effects Risk Assessment

This section provides a preliminary risk assessment for the 1999 Shuttle mission alternative based on the *Preliminary Risk Estimates for the Cassini Mission STS Alternative Launch Option* (Halliburton NUS 1994b) and the *Accident Assessment for Shuttle Launch of Cassini* (Martin Marietta Astro Space 1994b) supplemented by supporting information from DOE (Owings 1994b). Tables 4-25 and 4-26 describe the health effects mission risk contribution and the average individual risk associated with the 1999 Shuttle mission alternative.

Mission Risk

Table 4-25 presents the preliminary estimates of the contribution to total mission risk for each representative accident scenario over the launch Phases 1 through 4 based upon the expectation case source terms. Table 4-25 also provides the total probability, consequences, and estimated contributions to the overall or total mission risk for the two Earth swingbys (E1 and E2) of the VEEGA trajectory. Total mission risk is the sum of the health effects mission risk contributions from each launch phase and from the VEEGA trajectory. However, it should be noted that when referring to total or overall mission risk, radiological consequences and/or contributions to risk from the (low probability) long-term inadvertent reentry scenario for the VEEGA trajectory cannot be estimated and are not included in the calculations.

Considering all launch phases, Phase 4 provides the largest contribution to overall or total mission risk of 1.3×10^{-6} number of health effects (without de minimis). This risk is closely followed by the total Phase 1 risk of 7.2×10^{-7} health effects. The population at risk from an early Phase 1 accident involving a release of plutonium dioxide would be the population in the vicinity of a CCAS/KSC region estimated to be on the order of 100,000 people (Halliburton NUS 1994b). When the concept of de minimis is applied, the health effects for Phase 1 would be considered negligible. In turn, the contribution to total mission risk from a Phase 1 accident would also be considered negligible.

For a Phase 2 accident with impact in Africa, the predicted health effects would be about 1.4×10^{-4} over an assumed reference population of about 1,000 people (Halliburton NUS 1994b). Since the total probability of an accident occurring in Phase 2 is 5.8×10^{-5} (1 in 17,000), the mission risk contribution or expected number of health effects would be 8.2×10^{-9}. Factoring in de minimis, the predicted health effects would be reduced by a factor of 3.5.

For a Phase 3 or 4 inadvertent reentry accident, assuming average world population densities in the latitude bands likely to be impacted by such an accident, the predicted number of health effects is 6.9×10^{-4} over a reference population assumed to be about 5,000 people (Halliburton NUS 1994b). With much less than 1 latent cancer fatality among 5,000 people, this effect is clearly indistinguishable from the normally observed cancer fatalities in that population. From a risk perspective, the mission risk contribution or expected number of health effects from Phase 3 and 4 accidents would be 1.4×10^{-6}. Accounting for de minimis, the number of predicted health effects and the contribution to total mission risk would be reduced by a factor of about three.

TABLE 4-25. PRELIMINARY HEALTH EFFECTS MISSION RISK ESTIMATES FOR THE 1999 MISSION ALTERNATIVE USING THE SHUTTLE

				Radiological Consequences, Health Effects[a,b]		Mission Risks, Health Effects[a,b,c,d]	
Mission Phase	Period, s	Accident Scenario Description	Total Probability	Without De Minimis	With De Minimis	Without De Minimis	With De Minimis
1a	0-10	SRB Case Rupture	1.02×10^{-5}	4.86×10^{-3}	–	5.0×10^{-8}	–
1b	11-20		2.50×10^{-6}	1.34×10^{-3}	–	3.4×10^{-9}	–
1c	21-70		1.32×10^{-6}	1.57×10^{-4}	–	2.1×10^{-10}	–
1d	71-104		1.34×10^{-6}	1.14×10^{-2}	–	1.5×10^{-8}	–
1e	105-128		4.68×10^{-6}	1.39×10^{-1}	–	6.5×10^{-7}	–
Subtotal						7.2×10^{-7}	–
2	128-532	Vehicle Breakup	5.82×10^{-5}	1.41×10^{-4}	4.06×10^{-5}	8.2×10^{-9}	2.4×10^{-9}
3	532-24,000	Reentry	1.25×10^{-4}	6.89×10^{-4}	1.99×10^{-4}	8.6×10^{-8}	2.5×10^{-8}
4	24,000 to Earth Escape	Reentry	1.93×10^{-3}	6.89×10^{-4}	1.99×10^{-4}	1.3×10^{-6}	3.8×10^{-7}
Total Mission Risk Contribution: Launch Phases						2.1×10^{-6}	4.1×10^{-7}
VEEGA	–	Inadvertent Reentry E1	1.9×10^{-7}	2.48×10^{3}	1.46×10^{1}	4.7×10^{-4}	2.8×10^{-6}
		Inadvertent Reentry E2	2.8×10^{-7}	4.56×10^{3}	1.47×10^{1}	1.3×10^{-3}	4.1×10^{-6}
Mission Risk Contribution: Primary and Backup VEEGA						1.8×10^{-3}	6.9×10^{-6}
Total Mission Risk Contribution: Primary and Backup VEEGA						1.8×10^{-3}	7.3×10^{-6}

Source: adapted from Halliburton NUS 1994b

a. Health effects are latent cancer fatalities.

b. Health effects, or excess latent cancer fatalities, for the short-term inadvertent reentry accident are evaluated based on collective exposure of approximately 5 billion persons worldwide. Most of the persons exposed would receive an individual radiation dose of less than 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year (the de minimis dose level). If only those individuals worldwide receiving higher than de minimis dose level were considered, the estimated health effects would be approximately 15 (excess latent cancer fatalities) with either the VEEGA E1 or E2.

c. Expectation of incremental latent cancer fatalities.

d. The mission risk contribution due to a given accident scenario (i) is: (Mission risk contribution)$_i$ = (Total Probability)$_i$ x (Consequences)$_i$

TABLE 4-26. PRELIMINARY AVERAGE INDIVIDUAL RISK ESTIMATES FOR THE 1999 MISSION ALTERNATIVE USING THE SHUTTLE

Mission Phase	Time Period, s	Accident Scenario Description	Mission Risks, Health Effects[a,b]		Exposed Population at Risk[c]	Average Individual Risk, Health Effects[a,b,c,d]	
			Without De Minimis	With De Minimis		Without De Minimis	With De Minimis
1a	0-10	SRB Case Rupture	5.0×10^{-8}	—	1×10^{5}	5.0×10^{-13}	—
1b	11-20		3.4×10^{-9}	—	1×10^{5}	3.4×10^{-14}	—
1c	21-70		2.1×10^{-10}	—	1×10^{5}	2.1×10^{-15}	—
1d	71-104		1.5×10^{-8}	—	5×10^{9}	3.0×10^{-18}	—
1e	105-128		6.5×10^{-7}	—	5×10^{9}	1.3×10^{-16}	—
2	128-532	Vehicle Breakup	8.2×10^{-9}	2.4×10^{-9}	1×10^{3}	8.2×10^{-12}	2.4×10^{-12}
3	532-24,000	Reentry	8.6×10^{-8}	2.5×10^{-8}	5×10^{3}	1.7×10^{-11}	5.0×10^{-12}
4	24,000 to Earth Escape	Reentry	1.3×10^{-6}	3.8×10^{-7}	5×10^{3}	2.6×10^{-10}	7.6×10^{-11}
VEEGA	—	Inadvertent Reentry E1	4.7×10^{-4}	2.8×10^{-6}	5×10^{9}	9.4×10^{-14}	5.6×10^{-16}
		Inadvertent Reentry E2	1.3×10^{-3}	4.1×10^{-6}	5×10^{9}	2.6×10^{-13}	8.2×10^{-16}
					Subtotal VEEGA	3.5×10^{-13}	1.4×10^{-15}

Source: adapted from Halliburton NUS 1994b

a. Expectation of incremental latent cancer fatalities.

b. The de minimis dose level for the purpose of this EIS is 1.0×10^{-3} Sv (1.0×10^{-3} rem) per year.

c. Population at risk is an order-of-magnitude estimate, representing the estimated number of persons that significantly accounted for most of the collective dose.

d. The average individual risk for a given accident scenario, i, is:

$$(\text{Average individual risk})_i = (\text{Mission risk contribution})_i / (\text{Exposed population at risk})_i$$

For an inadvertent reentry from a VEEGA Earth swingby, the potential health effects are identical to those identified earlier for the VEEGA 1999 Titan backup launch opportunity. Based on Table 4-25, the 2,480 or the 4,560 health effects for the VEEGA E1 or E2 inadvertent reentry, respectively, predicted over a 50-year period following an inadvertent reentry are likely to be indistinguishable from normally observed cancer fatalities among the world population. From a risk perspective, the mission risk contribution or expected number of health effects from a VEEGA inadvertent reentry during an Earth swingby accident would be 1.8×10^{-3}. The radiological consequences (health effects) and the contribution to total mission risk from the Earth-gravity-assist trajectories when accounting for de minimis is reduced two to three orders of magnitude.

The total or overall mission risk (i.e., the expected number of health effects due to the risk of radiological accidents associated with the overall mission) is dominated by an inadvertent reentry accident during Earth swingby(s). The overall mission risk (without de minimis) is 1.8×10^{-3}. As with the Proposed Action, these risks are clearly low when compared with the risks of many large projects and the risks faced by individuals daily. Applying the de minimis concept, the total mission risk for the 1999 primary launch opportunity would be reduced by two orders of magnitude.

Average Individual Risk

Table 4-26 presents the average individual risks estimated for launch Phases 1 through 4 and for the associated VEEGA trajectory (Halliburton NUS 1994b). The values provided in Table 4-26 were derived from the expectation case results presented in Tables 4-23, 4-24, and 4-25. The highest average individual risk would occur in Phase 4 of the launch, with the risk estimated at about 2.6×10^{-10}, or a chance of about 1 in 3.8 billion of the average exposed individual incurring a fatal cancer as a result of a Phase 4 accident with release of RTG fuel. Applying the de minimis concept, the average individual risk from such a Phase 4 accident would be reduced by a factor of about three to 7.6×10^{-11}, or a chance of about 1 in 13 billion of the average exposed individual contracting fatal cancer as a result of a Phase 4 RTG fuel release.

With respect to the Earth-gravity-assist trajectories and potential releases of plutonium fuel from an inadvertent reentry during an Earth swingby, the resulting exposed population would be essentially worldwide. On that basis, the average individual risk from an inadvertent reentry accounting for both Earth swingbys would be 3.5×10^{-13}, or a chance of about 1 in 3 trillion of the average exposed individual incurring a fatal cancer as a result of a fuel release.

Risk to the Maximum Exposed Individual

As with the Proposed Action, discussed in Section 4.1.8, another measure of the risk of implementation of this alternative is the latent cancer fatality risk of the maximally exposed individual in an accident, as distinguished from the average member of the exposed population. For Phase 1 launch accidents, the highest offsite doses (maximum individual doses) are predicted to be less than 10^{-5} Sv (10^{-3} rem) with total probabilities of 10^{-5} or less (see Tables 4-24 and 4-25). With the health effects conversion factor of

3.5×10^{-2} excess latent cancer fatalities per person-Sv (3.5×10^{-4} excess latent cancer fatalities per person-rem) of exposure, a person receiving the 10^{-5} Sv (10^{-3} rem) has a probability of about 3.5×10^{-7} (1 in 2.8 million) of being a cancer fatality as a result of that exposure. Since the probability of launch accidents that could result in offsite exposures of this magnitude are 10^{-5} or less, the highest offsite individual risk of latent cancer due to radiological accidents would be less than 3.5×10^{-12} (1 in 280 billion). Cancer fatality risks to most offsite people from launch accidents would be even lower, with the average CCAS/KSC area individual risk of a fatal cancer due to the Cassini launch estimated at approximately 5×10^{-13} (1 in 2 trillion) (see Table 4-26). These risks are more than a million times lower than that allowed for nuclear facilities with NRC safety objectives.

Both the accident probabilities and the estimated exposures to the maximally exposed individuals would be lower in Phase 1 for the exposed population within the general GPHS module impact areas than for Phases 2 through 4. For Phase 2, with an estimated probability of 5.8×10^{-5} and an estimated maximally exposed individual dose of 1.16×10^{-4} Sv (1.16×10^{-2} rem), the latent cancer fatality risk to the maximally exposed individual would be 2.4×10^{-10}. For Phases 3 and 4, the doses would increase to 5.43×10^{-4} Sv (5.43×10^{-2} rem) and the probabilities would increase to 1.2×10^{-4} and 1.9×10^{-3}, respectively. The corresponding latent cancer fatality risk to the maximally exposed individual within the general vicinity of the GPHS module impact areas would therefore be 2.3×10^{-9} (Phase 3) and 3.7×10^{-8} (Phase 4).

The risks to the maximally exposed individual in an inadvertent reentry during either of the Earth swingbys would be exactly the same as estimated for the VEEGA 1999 Titan IV backup launch opportunity (see Table 4-21). The estimated risk of a latent cancer fatality to the maximally exposed individual would be 3.2×10^{-9} and 3.5×10^{-9} for the E1 and E2 swingbys, respectively.

As with the risk estimates to the maximally exposed individual within the exposed population in a launch or reentry accident for the Proposed Action, the latent cancer fatality risk to the maximally exposed individual would be higher than the risk to the average person within the exposed population but still quite low. These risks would be quite small compared to everyday risks faced by the general population, as illustrated in Table 4-20.

4.2.9 Emergency Response Planning

Prior to the launch of the Cassini spacecraft with the RTGs and RHUs onboard, a comprehensive radiological contingency plan would be developed in accordance with the Federal Radiological Emergency Response Plan. This plan, similar to the one developed for the Galileo (NASA 1989b) and Ulysses (NASA 1990) missions, would ensure that any accident, whether it involves a radiological release or not, can be met with a well-developed and tested response. The plan would be developed through the combined efforts of NASA, DOE, DOD, EPA, the Federal Emergency Management Agency, State of Florida, and county organizations involved in emergency response. Portions of the plan would be exercised to ensure that the various organizations were prepared to support the launch. NASA would be the Cognizant Federal Agency coordinating the Federal response for accidents occurring within U.S. jurisdiction, and would coordinate with the Department of State and other cognizant agencies as appropriate, in the implementation of other responses.

4.3 ENVIRONMENTAL IMPACTS OF THE 2001 MISSION ALTERNATIVE

The environmental impacts for the 2001 mission alternative using a Titan IV (SRMU)/Centaur would be expected to be similar to those described for the Proposed Action, with one exception. Without a targeted Earth swingby as part of its VVVGA trajectory, the probability of an inadvertent reentry accident during an Earth swingby would be zero. Therefore, radiological consequences associated with the Earth swingby would be eliminated. However, if the spacecraft becomes uncommandable anytime after injection into its interplanetary trajectory and before the Saturn Orbit Insertion, the long-term probability of an Earth impact (i.e., reentry into the Earth's atmosphere) would exist. The mean probability of such an impact has been estimated to be on the order of 10^{-7} (JPL 1993f). The impacts of the long-term reentry would be similar to the impacts associated with the inadvertent VVEJGA or VEEGA Earth swingby accident scenarios described for the Proposed Action. The impacts and risks associated with the backup in 2002 using the Titan IV (SRMU) with a VEEGA trajectory would be assumed to be identical to those described for the VEEGA backup for the Proposed Action. As noted in Section 4.1.3, the Cassini mission operations will be conducted to minimize the potential of biologically contaminating Saturn and Titan (JPL 1990).

4.4 ENVIRONMENTAL IMPACTS OF THE NO-ACTION ALTERNATIVE

There would be no adverse environmental impacts associated with the No-Action alternative; however, there would be major programmatic and geopolitical impacts from such a cancellation. Cancellation of the mission would result in the loss of existing engineering and scientific services and expertise and the loss of the anticipated scientific gains identified in Section 1.2.

Currently, the Cassini spacecraft constitutes the world's only fully-funded science probe in development to explore the outer planets. The Cassini mission represents a rare opportunity to gain significant insight into the major scientific questions about the formation of the solar system and the conditions that led to life on Earth, in addition to a host of questions specific to the Saturn system. As the best-instrumented probe ever sent to another planet, Cassini would produce the most complete information about a planet system ever obtained. The mission is the next step in a highly productive, three-decade-old program of exploration of the solar system using robotic spacecraft. The scientific objectives for the mission were established by the appropriate scientific advisory committees, including the Committee on Planetary and Lunar Exploration of the National Research Council's Space Science Board (currently Space Studies Board) and NASA Advisory Council's Solar System Exploration Committee. Cancelling the mission would mean forgoing the near term opportunities of meeting the Cassini mission objectives and goals, and would represent a setback in our Nation's program to systematically explore the solar system.

If the mission did not proceed, the international scientific community would be deprived of near-term demonstrations of new instruments and innovative engineering techniques initially designed for Cassini. The Magnetospheric Imaging Instrument, for example, would obtain the first-ever images of a planetary magnetic field. Cancellation of the mission would leave unanswered major questions about the physical and dynamical properties of the Saturnian system. It would also mean forgoing an opportunity of gaining better insight into some of the dynamic mechanisms and processes on the Earth through comparative planetary study. Knowledge that could have been acquired from the Cassini mission to contribute to research in such fields as climatology, engineering and physics would not be available.

In addition, the U.S. Government and its European partners, the European Space Agency and its member states, and the Italian Space Agency would suffer adverse programmatic impacts if this alternative is adopted. There could also be significant impacts on the future ability of the United States to enter into international agreements for cooperative space activities.

4.5 ADVERSE ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED

During a normal launch of the Titan IV or Shuttle, the solid rocket motors would produce HCl and Al_2O_3 particles. The deposition of HCl during the movement of the exhaust cloud would probably produce short-term acidification of the marsh area and shallow surface waters near the launch pad, unless the winds at launch time were blowing in an offshore direction. The deposition of HCl from the solid rocket exhaust would probably damage vegetation near the launch pad and might kill fish in onsite ponds near the launch pad. The Banana River and nearshore areas of the Atlantic Ocean should not be adversely impacted due to the buffering capacity of these waters. The airborne concentrations of Al_2O_3 particulates within the exhaust cloud would exceed air quality standards (see Section 4.1.2.2) for a short period but should not adversely affect the overall ambient air quality of areas outside the exhaust cloud. The launch of the Cassini spacecraft would also introduce ozone-depleting chlorine into the stratosphere along its flight path. The depleted area would recover after a short period of time.

4.6 INCOMPLETE OR UNAVAILABLE INFORMATION

Because this EIS is being developed prior to the completion of preparations for the Cassini mission, some of the information used is still in the preliminary stage. This adds to the uncertainties of the impact analyses especially in comparison to the Galileo and Ulysses mission EISs, which were prepared considerably closer to the proposed launch dates. Still, sufficient information and analyses were available to reasonably evaluate the potentially significant impacts of the Proposed Action and the other alternatives.

The principal areas of either incomplete information or analyses include the following items:

1. In some cases, the amount of information on certain optional upper stages and for some of the launch vehicles under development is minimal. This is particularly true for the key parameters needed to understand their likely

availability for use with the Cassini mission and assessment of their safety and reliability.

2. While this EIS deals with a set of four credible launch phase accident scenarios that are deemed representative of those which could potentially result in a release of RTG fuel, NASA, the U.S. Air Force and DOE continue to conduct testing and to evaluate additional accident scenarios within the ongoing nuclear launch safety approval process. Ongoing evaluations include launch phase accident scenarios in which the RTGs might be threatened by explosions from SRMU propellant fragments. Should any of the ongoing investigations result in risk estimates greater than those presented in this EIS, NASA will evaluate the information, consider potential mitigation measures, and make a determination regarding preparation of additional NEPA documentation, including supplementing this EIS.

3. There is uncertainty in the estimated source terms resulting from an accident for both the Titan IV and Shuttle launches of the Cassini spacecraft. These uncertainties apply to not only the probability of impacts on the RTGs from fragments from the Titan IV SRMUs or SRMs, but also to the probability of impacts on the RTGs in the Shuttle cargo bay. Uncertainties will be addressed in the FSAR relative to the launch vehicle that will be used for the mission.

4. Although this EIS reports the results of preliminary analyses, there is uncertainty as to whether the GPHS modules or GISs would survive an inadvertent reentry during Earth swingby or release plutonium in the upper atmosphere. To estimate the potential environmental impacts of a short-term inadvertent reentry accident, a range of reentry conditions was explored and the consequences reported. The specific behavior of the modules and GISs under the range of VEEGA reentry conditions was not explicitly evaluated but bounded by the more severe VVEJGA reentry conditions.

5. With respect to the long-term inadvertent reentry accident, the performance and behavior of the materials used in the RTGs after many years (a decade to millennia) in a space environment are highly uncertain. Therefore, the response of the GPHS modules and GISs in the long-term inadvertent reentry is also highly uncertain. The radiological consequences of a long-term inadvertent reentry were therefore assumed to be similar to (same order of magnitude) those estimated for the short-term VVEJGA inadvertent reentry.

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

4.7.1 Short-Term Uses

The affected environment, for the short term, includes the CCAS/KSC and surrounding areas. The short-term uses of the areas include NASA and Air Force operations, urban communities, a fish and wildlife refuge, citrus groves, residential communities, and recreational areas. Both the Proposed Action and the mission alternatives would be conducted in accordance with past and ongoing Air Force and NASA procedures for operations at the CCAS/KSC launch sites. Should an accident occur causing a radiological release, short-term uses of contaminated land areas could be curtailed, pending mitigation.

4.7.2 Long-Term Productivity

The CCAS/KSC region has and probably will continue to support citrus groves and wildlife habitat, as well as human activities. Neither the Proposed Action nor the mission alternatives should have long-term effects on these uses. Should an accident occur causing a radiological release, the long-term productivity of contaminated land areas could be impacted.

The successful completion of the Cassini mission, however, could beneficially affect the future of the U.S. space program, which is important to the economic stability of the surrounding areas. In addition to the localized economic benefits, implementation of the Cassini mission has a number of broader socioeconomic benefits. They include technology spinoffs to industry and other space missions, maintaining the unique capability of the U.S. to conduct complex outer planetary missions by a large number of scientists and engineers, and supporting the continued scientific development of graduate students in a number of universities and colleges. In addition, the Cassini mission's international cooperative efforts will further peaceful and scientific international joint space exploration ventures.

A potentially large benefit to be gained from the successful completion of this mission is a better understanding of the Earth and its origins through the exploration and study of the planet Saturn, its atmosphere, moons, rings, and magnetosphere. The Cassini mission may also increase the current understanding of how the solar system evolved and how life began on the Earth.

4.8 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

Irreversible and irretrievable commitment of resources relate to the use of non-renewable resources and the effects of their usage on future generations. An irreversible resource commitment results from the use of a resource that cannot be replaced within a reasonable timeframe. The use of a resource that cannot be replaced is termed an irretrievable resource commitment.

For each launch alternative, quantities of various resources including energy and fuels, iridium metal, plutonium and other material, would be irreversibly and irretrievably committed. The use of these resources would be associated with the fabrication, launch and operation of the Cassini spacecraft.

4.8.1 Energy and Fuels

The fabrication processes for the Cassini spacecraft would use electrical and fossil-fuel energy. This usage constitutes an irretrievable commitment of resources that would not impose any significant energy impacts. The launch and operation of the Cassini spacecraft would consume solid and liquid propellants and related fluids. The solid propellant ingredients would be ammonium perchlorate, aluminum powder, and PBAN or

HTPB binder. The fluid substances would include liquid oxygen and liquid hydrogen, helium gas, nitrogen tetroxide, monomethylhydrazine, unsymmetrical dimethylhydrazine and hydrazine. The quantities of these resources that would be used for the Cassini mission have been discussed in Sections 2.2.5, 2.2.6, and 2.3.6.

4.8.2 Iridium

Approximately 329 troy ounces of iridium will be contained in the Cassini RTGs. This amount represents less than 0.0002 percent of the discovered reserves in the world (DOI 1993). The United States maintains a strategic stockpile of iridium. However, the present inventory is currently unpublished (DOI 1994).

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. Based on the world reserves, the amount of iridium lost in the successful implementation of the mission could easily be replaced from the world supply through current sources.

4.8.3 Plutonium

The RTGs and RHUs would contain approximately 28.1 kg (61.8 lb) of a mixture of several plutonium isotopes. Therefore, successful implementation of the Cassini mission would result in a commitment of this amount of plutonium.

Plutonium (mainly Pu-238) is produced in nuclear reactors. Although the launching of the RTGs and RHUs represents a commitment of Pu-238 resources that would never be recovered, additional plutonium could be manufactured in the U.S. or purchased from an appropriate international source.

4.8.4 Other Materials

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

5. CONTRIBUTORS TO THE EIS

This Final Environmental Impact Statement (FEIS) was prepared by the Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration (NASA). The U.S. Department of Energy has contributed expertise in the preparation of this EIS. The organizations and individuals listed below contributed to the overall effort used by NASA in the preparation of this document.

LIST OF CONTRIBUTORS

National Aeronautics and Space Administration

Peter Ulrich, Ph.D.	Chief, Flight Programs Branch
Kenneth Kumor	NASA NEPA Coordinator
Michael Carney	Aerospace Engineer

Science Applications International Corporation

Dennis Ford, Ph.D.	EIS Project Manager
Suzanne Crede	Environmental Analyst
Reginald Gotchy, Ph.D., CHP	Senior Scientist
Isaac Kwarteng, Ph.D.	Environmental Engineer
Douglas Outlaw, Ph.D.	Senior Environmental Scientist
Daniel Spadoni	Senior Engineer
Robert Wayland, Ph.D.	Senior Scientist

Jet Propulsion Laboratory

Reed Wilcox	Manager, Launch Approval Engineering, Cassini Project
Sandra Dawson	Cassini Launch Approval Planning Engineer
Roger Diehl, Ph.D.	Cassini Mission Design Manager
Charles Kohlhase	Manager, Science and Project Engineering, Cassini Project
Paul VanDamme	Member of Technical Staff

U.S. Department of Energy

Robert Lange	Director, Radioisotope Power Systems Division
Beverly Cook	Operations Manager, Radioisotope Power Systems Division
Donald Owings	Physical Scientist

Martin Marietta (Astro Space Division)

Richard Hemler	Manager of RTG Programs

Independent Consultant to Martin Marietta (Astro Space Division)

Thomas Bradshaw	Nuclear Engineer

Halliburton NUS

Henry Firstenberg	Project Manager
Bart Bartram	Consultant

TABLE 5-1. CONTRIBUTORS TO THE EIS

Responsible Person	Executive Summary	Section								Appendix				
		1	2	3	4	5	6	7	8	A	B	C	D	E
NASA														
PETER ULRICH Ph.D., Physics	X				X		X						X	
KENNETH KUMOR J.D.							X						X	
MICHAEL CARNEY M.S., Mechanical Engineering			X		X									
SAIC														
DENNIS FORD Ph.D., Zoology	X	X	X	X	X		X				X		X	X
SUZANNE CREDE B.S., Chemistry Education		X	X	X			X	X	X		X	X	X	X
REGINALD GOTCHY, CHP Ph.D., Radiation Biology					X							X	X	
ISAAC KWARTENG Ph.D., Chemical Engineering		X	X	X	X	X		X		X			X	X
DOUGLAS OUTLAW Ph.D., Nuclear Physics	X	X	X		X						X		X	X
DANIEL SPADONI M.B.A.	X	X	X		X		X						X	
ROBERT WAYLAND Ph.D., Atmospheric Science				X	X									X
JET PROPULSION LABORATORY														
REED WILCOX M.S., City and Regional Planning	X	X	X		X						X			
SANDRA DAWSON M.I.S., International Studies	X	X	X		X						X		X	X
ROGER DIEHL Ph.D., Aerospace Engineering			X		X						X			
CHARLES KOHLHASE M.S., Engineering	X		X								X			
PAUL VANDAMME M.S., Public Policy	X	X	X		X						X		X	X

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

		Section								Appendix				
Responsible Person	Executive Summary	1	2	3	4	5	6	7	8	A	B	C	D	E
U.S. DEPARTMENT OF ENERGY														
ROBERT LANGE M.S., Mechanical Engineering			X		X									
BEVERLY COOK B.S., Metallurgical Engineering	X		X		X								X	X
DONALD OWINGS M.S., Physics	X		X		X						X		X	X
MARTIN MARIETTA (ASTRO SPACE DIVISION)														
RICHARD HEMLER M.S., Nuclear Engineering					X									
INDEPENDENT CONSULTANT TO MARTIN MARIETTA (ASTRO SPACE DIVISION)														
THOMAS BRADSHAW B.N.E., Nuclear Engineering					X						X			
HALLIBURTON NUS														
HENRY FIRSTENBERG M. Eng. Sci.					X						X		X	
BART BARTRAM M.S., Mechanical Engineering M.S., Physics	X		X		X						X	X	X	X

6. AGENCIES AND INDIVIDUALS CONSULTED

This Final Environmental Impact Statement (FEIS) was preceded by a Draft EIS (DEIS) which was made available for review and comment by Federal, state, and local agencies and the public on October 21, 1994. The public review and comment period closed on December 20, 1994. Timely comments were considered during the preparation of the FEIS. Where no extension of the comment period was requested or otherwise authorized by NASA, comments received before March 3, 1995 were also considered.

In preparing this EIS, NASA has actively solicited input from a broad range of interested parties. In addition to the publication in the Federal Register of a Notice of Intent (NOI) (56 FR 8219), an Information Update (57 FR 46198), and a Notice of Availability (59 FR 53164) for the DEIS, NASA mailed copies of the DEIS directly to agencies, organizations, and individuals who may have interest in environmental impacts and alternatives associated with the Cassini mission.

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

Federal Agencies:

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

State Agencies:

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

Local Agencies:

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

Organizations:

American Institute of Aeronautics and Astronautics (AIAA)
American Society of Mechanical Engineers (ASME)
Brazos Valley Peace and Justice Coalition
Citizens for Peace in Space
Citizens for Nuclear Responsibility
Citizens to Stop Plutonium in Space
Committee for Risk Analysis and Regulation
Christic Institute
Energy Research Foundation
Environmental Defense Fund
Federation of American Scientists
Florida Coalition for Peace and Justice
Foundation on Economic Trends
Friends of the Earth
GE Stockholders Alliance
Indian River Citizens for a Safe Environment
Institute for Space and Security Studies
Lee County Coalition for Peace
Lehigh-Pocono Committee of Concern
National Audobon Society
National Space Society
National Wildlife Federation
Natural Resources Defense Council
Physicians for Social Responsibility
Pikes Peak Justice and Peace Commission
Religious Education for the Catholic Deaf and Blind
Sierra Club
Sierra Club, Florida Chapter
South Dakota Peace and Justice Center
Southern California Federation of Scientists
Southern Rainbow Education Project (SREP)
The American Association for the Advancement of Science
The Committee to Bridge the Gap
The Planetary Society
The Union of Concerned Scientists

Women's International League for Peace and Freedom
World Family

Individuals:

Geraldine Jenara Amato
Harvey and Lois Baker
Ron Balogh
Linda Bermann
John Chaplick
Ken Chase
Robert Chirpin (responded to NOI; no address provided)
Mrs. Fran Collier
John Cullewasit
Edward Dierauf
Arthur Draving
Chris and Eva Dunlop (responded to NOI; no address provided)
Bob Ellenberg
John P. Ferrell
V. Fuqua
Rose Gaines
Sonya Guidry
Louis Haik (responded to NOI; no address provided)
Richard H. Hiers, Ph.D., J.D.
Merilyn Hiller
Barbara and John Hirron (responded to NOI; no address provided)
Robert R. Holt, Ph.D.
Carole and Frank Hyneman
Kathleen Kelly
Mr. & Mrs. Harry Kernes
James Koob (responded to NOI; no address provided)
Dr. Mary Ann Lawrence
Martina and John Linnehan
Sidney and Olive Manuel
Patricia Marida
Karen McFadyen
Margery D. McIntire
Margaret Morris
Georgia Van Orman
Debbie Pappler
Anna B. Pilson
H. Platt
Dr. Horst Poehler
Mr. and Mrs. Paul Puchstein
Ruth Putz
Beth Raps
Ronald P. Reed
Ingeborg F. Roberts

Paul Schultz
Edwina Scinta (responded to NOI; no address provided)
Phil Seligman
Dorothy Scott Smith
Kevin Smith
Ruth E. and Jack Snyder
Nancy Strong
Kei Utsumi
Rea D. Ward
Harvey Wasserman
Arnie Welber
William Westall, III
Warren and Olive Wilson

Other Organizations or Individuals Who Requested Copies of the Cassini DEIS:

Organizations:

Cancer Prevention Coalition
Center for Defense Information
Colorado State University Libraries
Dynamac Corporation
World Spaceflight News

Individuals:

Steve Berry
Blaine Browning
Harry A. Bryson
Bob Carroll
Bob Cutler
Harry Garcia, Jr.
Gerry Greer
Brian Hoppy
John Huff
A. Marshall
Dr. Hans-Arthur Marsiske
Gary Pluck
Lisa Pugh
William Smirnow
Dr. Brian Wade

7. INDEX

8. REFERENCES

Aarkrog, A. 1977. Environmental Behavior of Plutonium Accidentally Released at Thule, Greenland. Health Physics Society Journal, Volume 32, pp. 271-284. April 1977.

American Cancer Society. 1994. Cancer Facts and Figures—1994. Atlanta, GA. 1994.

American Industrial Hygiene Association (AIHA). 1989. Emergency Response Planning Guideline for Hydrogen Chloride. March 30, 1989.

American Institute of Aeronautics and Astronautics (AIAA). 1991. Atmospheric Effects of Chemical Rocket Propulsion. Report of an AIAA Workshop, Sacramento, California. 52p. June 28-29, 1991.

Anspaugh, L., J. Shinn, P. Phelps, and N. Kennedy. 1975. Resuspension and Redistribution of Plutonium in Soils. Health Physics Society Journal, Volume 29, pp. 571-582. October 1975.

Baes, C., R. Sharp, A. Sjoreen, and R. Shor. 1984. A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides Through Agriculture. Oak Ridge National Laboratory, ORNL-5786. September 1984.

Bair, Frank. 1992. The Weather Almanac, 6th Edition. Gale Research Inc., Detroit. 1992.

Bionetics Corporation. 1990. Climate of the Kennedy Space Center and Vicinity. Prepared for National Aeronautics and Space Administration, Kennedy Space Center, FL. NASA Technical Memorandum 103498. June 1990.

Bionetics Corporation. 1991. Ambient Water Quality Conditions at the John F. Kennedy Space Center (KSC). Contract Report # 009. Prepared for the NASA Biomedical Operations and Research Office at KSC, Florida. 1991.

Bream, B.L. 1994. Personal Communication from B. Bream, NASA Lewis Research Center to W. Piotrowski, National Aeronautics and Space Administration, Headquarters, Washington, DC. Regarding sufficiently high orbit. January 18, 1994.

Brevard County. 1988. Brevard County Comprehensive Plan. Prepared by the Brevard County Research and Cartography Division, Research Section, Brevard County, Florida. September 1988.

Busacca, M., C. Hall, and B. Summerfield. 1991. Personal communication from M. Busacca, C. Hall, and B. Summerfield, National Aeronautics and Space Administration, to B. Nichols, Science Applications International Corporation. August 27, 1991.

Cassini Swingby Independent Review Panel. 1995. Cassini Swingby Independent Review Final Report. April 1995.

Denison, M.R., J.J. Lamb, W.D. Bjorndahl, E.Y. Wong and P.D. Lohn. 1994. Solid Rocket Exhaust in the Stratosphere: Plume Diffusion and Chemical Reactions. *Journal of Spacecraft and Rockets*, **31**(3), pp. 435-442, May-June 1994.

East Central Florida Regional Planning Council (ECFRPC). Undated-a. Perspective on Regional Growth 1987-1991. Winter Park, Florida. Undated.

East Central Florida Regional Planning Council (ECFRPC). Undated-b. 1990 Census of Population and Housing, Summary Tape File 3A. Undated.

East Central Florida Regional Planning Council (ECFRPC). 1988. GBS Database for Land Cover, Endangered Species, and Indian River Lagoon Fishes. Winter Park, Florida. October 15, 1988.

East Central Florida Regional Planning Council (ECFRPC). 1991a. The Council Quarterly, Fourth Quarter 1990. Winter Park, Florida. 1991.

East Central Florida Regional Planning Council (ECFRPC). 1991b. Database for Endangered Species. Winter Park, Florida. 1991.

East Central Florida Regional Planning Council (ECFRPC). 1992a. East Central Florida Comprehensive Regional Policy Plan. Winter Park, Florida. February 1992.

East Central Florida Regional Planning Council (ECFRPC). 1992b. 1990 Census Data Report, Volume 1. Prepared by Laurie Reyburn and Mark Sievers. April 1992.

Fairchild Space (Currently Orbital Sciences Corporation). 1993. Personal Communication from R. Carpenter, Fairchild Space to D. Owings, U.S. Department of Energy, Washington, DC. Regarding the radioisotopic composition of the RTGs. April 28, 1993.

Federal Register (51 FR 28044) "Policy Statement on Safety Goals for the Operation of Nuclear Power Plants," August 4, 1986.

Federal Register (56 FR 8219) Notice of Intent to Prepare an Environmental Impact Statement for the Outer Solar System Exploration, Including the CRAF and Cassini Mission. February 27, 1991.

Federal Register (57 FR 46198) Information Update to Notice of Intent to Prepare and EIS for the Outer Solar System Exploration Program. October 7, 1992.

Florida State University. 1984. Water Resources Atlas of Florida. (E. A. Fernald and D. J. Patton, Editors). Published by Institute of Science and Public Affairs. Tallahassee, Florida. 1984.

Foils Engineering. 1993. Final Report on Earth Swingby Reentry. Prepared by M. Eck. Prepared for Jet Propulsion Laboratory. November 22, 1993.

Halliburton NUS Corporation. 1992. World Demographic Update through 1990 for Space Nuclear System Safety Analyses. Prepared for U.S. Department of Energy, Office of Special Applications, Washington, DC. June 12, 1992.

Halliburton NUS Corporation. 1994a. Preliminary Risk Analysis of the Cassini Mission. Prepared for U.S. Department of Energy, Radioisotope Power Systems Division, Washington, DC. Document Number EPC-94-R03C. February 4, 1994, as updated August 29, 1994.

Halliburton NUS Corporation. 1994b. Preliminary Risk Estimates for the Cassini Mission STS Alternative Launch Option. Prepared for U.S. Department of Energy, Radioisotope Power Systems Division, Washington, DC. Document Number EPC-94-R03D. May 23, 1994, as updated August 29, 1994.

Harwood, R.S., C.H. Jackman, I.L. Karol, and L.X. Qiu. 1991. Predicted Rocket and Shuttle Effects on Stratospheric Ozone in: Scientific Assessment of Ozone Depletion 1991, World Meteorological Organization, Global Ozone Research and Monitoring Project Report, No. 25., 13 pp. 1991.

Hinkle, C. and W. Knott, III. 1985. A Summary of Environmental Effects of Space Shuttle Launches at John F. Kennedy Space Center, Florida After the First 24 Launches. 152nd Annual Meeting, American Association for the Advancement of Science. Philadelphia, PA. May 25-30, 1985.

Interagency Nuclear Safety Review Panel (INSRP). 1989a. Safety Evaluation Report for the Galileo Mission, Volumes 1 and 2. INSRP 89-01. May 1989.

Interagency Nuclear Safety Review Panel (INSRP). 1989b. Reentry Subpanel Report for Galileo. INSRP 89-03. May 1989.

Interagency Nuclear Safety Review Panel (INSRP). 1989c. Biomedical and Environmental Effects Subpanel Report for Galileo. INSRP Report 89-06. October 1989.

Interagency Nuclear Safety Review Panel (INSRP). 1990. Safety Evaluation Report for Ulysses Mission, Volumes 1 and 2. INSRP 90-01. September 1990.

International Atomic Energy Agency (IAEA). 1975. Interaction of $^{238}PuO_2$ Heat Sources with Terrestrial and Aquatic Environments. IAEA Report SM-199/100. Vienna, Austria. 1975.

International Atomic Energy Agency (IAEA). 1976. Transuranium Nuclides in the Environment. IAEA Report STI/PUB/410. Vienna, Austria. 1976.

International Commission on Radiological Protection (ICRP). 1977. Recommendations of the International Commission on Radiological Protection. ICRP Publication 26. 1977.

International Commission on Radiological Protection (ICRP). 1979. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30, Part I, pp. 105-107. 1979.

International Commission on Radiological Protection (ICRP). 1986. The Metabolism of Plutonium and Related Elements. ICRP Publication 48. 1986.

International Commission on Radiological Protection (ICRP). 1990. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. 1990.

Jackman, C.H. 1994. Personal Communication from C. Jackman, National Aeronautics and Space Administration, to R. Wayland, Science Applications International Corporation. Regarding current information on ozone depletion from launch emissions. January 3, 1994.

Jackman, C.H. 1995. Personal Communication from C. Jackman, National Aeronautics and Space Administration, to R. Wayland, Science Applications International Corporation. Regarding current information on ozone depletion from launch emissions. January 19, 1995.

Jet Propulsion Laboratory (JPL). 1989. Jupiter Solar Mission Alternative Feasibility Study, JPL Publication No. D-6679. August 15, 1989.

Jet Propulsion Laboratory (JPL). 1990. CRAF/Cassini Planetary Protection Plan. JPL Publication No. Number D-7869. September 1990.

Jet Propulsion Laboratory (JPL). 1993a. Cassini Program Environmental Impact Statement Supporting Study, Volume 1: Program Description. JPL Publication No. D-10178-1. Pasadena, CA. June 4, 1993.

Jet Propulsion Laboratory (JPL). 1993b. Letter sent from R. Spehalski, Jet Propulsion Laboratory to H. Wright, National Aeronautics and Space Administration, Headquarters, Washington, DC. Regarding the 2001 mission alternative. July 23, 1993.

Jet Propulsion Laboratory (JPL). 1993c. Cassini Project Mission Plan. JPL Publication No. D-5564, Rev. C. Pasadena, CA. August 16, 1993.

Jet Propulsion Laboratory (JPL). 1993d. Cassini Project Policies and Requirements Document, PD 699-004. Pasadena, CA. September 1993.

Jet Propulsion Laboratory (JPL). 1993e. Personal communication from R. Spehalski, Jet Propulsion Laboratory to D. Ford, Science Applications International Corporation. Regarding 2001 mission trajectory. November 10, 1993.

Jet Propulsion Laboratory (JPL). 1993f. Cassini Program Environmental Impact Statement Supporting Study, Volume 3: Cassini Earth Swingby Plan. JPL Publication No. D-10178-3. Pasadena, CA. November 18, 1993, with addendum dated August 24, 1994.

Jet Propulsion Laboratory (JPL). 1993g. Cassini Program Environmental Impact Statement Supporting Study, Executive Summary. JPL Publication No. D-10178-4. Pasadena, CA. November 18, 1993.

Jet Propulsion Laboratory (JPL). 1994a. Cassini Program Environmental Impact Statement Supporting Study, Volume 2: Alternative Mission and Power Study. JPL Publication No. D-11777. Pasadena, CA. July 1994.

Karol, I., Y. Ozolin and E. Rozanov. 1992. Effect of Space Rocket Launches on Ozone. Ann. Geophisicae, 10. pp. 810-814. October 1992.

Kaye, J. 1994. Personal Communication from J. Kaye, National Aeronautics and Space Administration to R. Wayland, Science Applications International Corporation. Regarding current information on ozone depletion from launch emissions. January 3, 1994.

Ko, M. 1994. Personal Communication from Dr. M. Ko, Atmospheric and Environmental Research, Inc. to R. Wayland, Science Applications International Corporation. Regarding current information on ozone depletion from launch emissions. January 3, 1994.

Krüger, B.C., M.M. Hirschberg, and P. Fabian. 1992. Effects of Solid-Fueled Rocket Exhausts on the Stratospheric Ozone Layer. Ber. Bunsenges. Phys. Chem., 96, pp. 268-272. 1992.

Lamb Associates, 1993. Personal communication between E. Johnson, Lamb Associates and D. Owings, U.S. Department of Energy, Washington, DC. Regarding the LWRHU response to Cassini accident environments. June 2, 1993.

Lamb, J.J. 1995. Personal Communication from J. Lamb, TRW, to R. Wayland, Science Applications International Corporation. Regarding current information on ozone depletion from launch emissions. January 23, 1995.

Leu, M. 1988. Heterogeneous Reactions of N_2O_5 with H_2O and Cl on Ice Surfaces: Implications for Antarctic Ozone Depletion. Journal of Geophysical Research, p. 851-854. 1988.

Martin Marietta (Currently Lockheed Martin). 1989. Titan IV Radioisotope Thermoelectric Generator Safety Databook, MCR-88-2559. Martin Marietta Space Launch Systems, Denver, CO. March 1989.

Martin Marietta (Currently Lockheed Martin). 1992. Titan IV CRAF/Cassini EIS Databook, MCR-91-2580, Rev: Basic, Martin Marietta Space Launch Systems, Denver, CO. December 1991. Chapter 10 was published in September 1992.

Martin Marietta Astro Space. 1993. RTG Safety Assessment for the Cassini RTG Program. Prepared for U.S. Department of Energy, San Francisco Field Office, Oakland, CA. May 7, 1993.

Martin Marietta Astro Space. 1994a. Attachment B to the Cassini Safety Meeting Minutes, GPHS EGA Reentry Response Event Tree—Cassini. January 4, 1994.

Martin Marietta Astro Space. 1994b. Accident Assessment for Shuttle Launch of Cassini, Martin Marietta Corporation, Astro-Space Division. April 1994.

Martin Marietta Astro Space. 1994c. Personal Communication from R. Hemler, Martin Marietta Astro Space to B. Cook, U.S. Department of Energy, Washington, DC. Regarding the SRM versus SRMUs for the Cassini mission. June 29, 1994.

McRonald, A. 1988. "Surface Footprint of GIS on Inadvertent Reentry on VEEGA Flyby of GLL Spacecraft," Jet Propulsion Laboratory, Memorandum 312/86.3-4371 December 29, 1988.

McRonald, A. 1992a. Personal Communication from A. McRonald to L. Reinhart, "RTG Module Release Conditions for Inadvertent Earth Reentry of the Cassini Spacecraft During the VVEJGA Earth Flyby on 8-17-99," Jet Propulsion Laboratory, Memorandum 312/92.3-5037. November 10, 1992.

McRonald, A. 1992b. Personal Communication from A. McRonald to L. Reinhart, "RTG Module Release Conditions for Inadvertent Earth Reentry of the Galileo Spacecraft During the VEEGA-2 Earth Flyby on 12-8-92," Jet Propulsion Laboratory, Memorandum 312/92.3-5041. November 12, 1992.

National Aeronautics and Space Administration (NASA). 1978. Final Environmental Impact Statement, Space Shuttle Program. Washington, DC. April 1978.

National Aeronautics and Space Administration (NASA). 1979. Environmental Impact Statement for the Kennedy Space Center, Final. Washington, DC. October 1979.

National Aeronautics and Space Administration (NASA). 1986. Environmental Resources Document, Kennedy Space Center. KSC-DF-3080. Prepared for NASA by Edward E. Clark Engineers-Scientists, Inc. November 1986.

National Aeronautics and Space Administration (NASA). 1988a. Space Shuttle Data for Planetary Mission Radioisotope Thermoelectric Generator (RTG) Safety Analysis. NSTS 08116, Revision B. September 1988.

National Aeronautics and Space Administration (NASA). 1988b. Final (Tier 1) Environmental Impact Statement for the Galileo and Ulysses Missions. Washington, DC. November 1988.

National Aeronautics and Space Administration (NASA). 1989a. Final Environmental Impact Statement Space Shuttle Advanced Solid Rocket Motor Program, John C. Stennis Space Center, George C. Marshall Flight Center. March 1989.

National Aeronautics and Space Administration (NASA). 1989b. Final Environmental Impact Statement for the Galileo Mission (Tier 2). May 1989.

National Aeronautics and Space Administration (NASA). 1990. Final Environmental Impact Statement for the Ulysses Mission (Tier 2). June 1990.

National Aeronautics and Space Administration (NASA). 1994. Environmental Resources Document, Kennedy Space Center. KSC-DF-3080, Rev. B., Prepared for the NASA J. F. Kennedy Space Center by EG&G Florida. October 1994.

National Council on Radiation Protection and Measurements (NCRP). 1987. "Ionizing Radiation Exposure of the Population of the United States." NCRP Report 93. September 1, 1987.

National Oceanic and Atmospheric Administration (NOAA). 1980. Delta Atlas - Eastern United States Coastal and Ocean Zones. Washington, DC. August 1980.

National Research Council. 1988. Health Risks of Radon and Other Internally Deposited Alpha Emitters. Report from the Committee on the Biological Effects of Ionizing Radiation (BEIR IV), National Academy Press, Washington, DC. 1988.

National Research Council. 1990. Health Effects of Exposure to Low Levels of Ionizing Radiation. Report from the Committee on the Biological Effects of Ionizing Radiation (BEIR V), Board on Radiation Effects Research, Commission on Life Sciences. National Academy Press. Washington, DC. 1990.

National Safety Council. 1992. Accident Facts, 1992 edition. Published in Itasca, IL. 1992.

NUS Corporation. 1982. Overall Safety Manual, Map of the Climates of the Earth. Prepared by the Environmental Systems Group for the U.S. Atomic Energy Commission. 1982.

Owings, W.D. 1994a. Personal Communication from D. Owings, U.S. Department of Energy, Washington, DC to H. Firstenberg, Halliburton NUS Corporation. Regarding supplemental information for the preliminary risk analysis of the Cassini mission. February 1994.

Owings, W.D. 1994b. Personal Communication from D. Owings, U.S. Department of Energy, Washington, DC to H. Firstenberg, Halliburton NUS Corporation. Regarding supplemental information for the Cassini mission STS launch option. March 10, 1994.

Patrick Air Force Base (PAFB). 1990. Economic Resource Impact Statement for the Patrick Air Force Base, Florida. Cost Analysis Division. Comptroller. September 30, 1990.

Pinder, J., and A. Doswell. 1985. Retention of ^{238}Pu-Bearing Particles by Corn Plants. Health Physics Society Journal, Volume 49, pp. 771-776. 1985.

Pinder, J., D. Adriano, T. Ciravolo, A. Doswell, and D. Yehling. 1987. The interception and Retention of ^{238}Pu Deposition by Orange Trees. Health Physics Society Journal, Volume 52, pp. 707-715. May 8, 1987.

Poole, L.R., R.J. Jones, M.J. Kurylo and A. Wahner. 1991. Heterogeneous Processes: Laboratory, Field and Modeling Studies, in: Scientific Assessment of Ozone Depletion: 1991. World Meteorological Organization, Global Ozone Research and Monitoring Project, Report No. 25. 1991.

Prather, M., M. Garcia, A. Douglass, C. Jackman, M. Ko, and N. Sze. 1990. The Space Shuttle's Impact on the Stratosphere. Journal of Geophysical Research, 95. D-11, pp. 18,583-18,590. 1990.

Presidential Directive/National Security Council-25 (PD/NSC-25). 1977. Scientific or Technological Experiments with Possible Large-Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space. December 14, 1977.

Reagan, M. 1993. Personal Communication from M. Reagan, Johnson Controls to S. Crede, Science Applications International Corporation. Regarding groundwater parameter report for Launch Complex 40, CCAS, FL. September 30, 1993.

Reagan, M. 1995. Personal Communication from M. Reagan, Johnson Controls to K. Toney, Science Applications International Corporation. Regarding groundwater parameter report Launch Complexes 40 and 41, January 26, 1995.

Rockey, D.E., R. Ramford, M.G. Hollars, R.W. Klemetson, T.W. Koerner, E.L. Marsh, H. Price, and C. Uphoff. 1981. Proceedings of the 16th Intersociety Energy Conversion Engineering Conference, Atlanta, Georgia. pp. 440-445. August 9-14, 1981.

Rupp, E. 1980. Age Dependent Values of Dietary Intake for Assessing Human Exposures to Environmental Pollutants. Health Physics Society Journal. Volume 39, pp. 151-163. August 1980.

State of Florida. 1990. Southeast Fisheries Center, 1990 Annual Landing Summary. Miami, Florida. July 22, 1991.

State of Florida. 1991a. Florida Air Pollution Rules, 1991 Part IV, Area Designation and Attainment Dates, Section 17-2.460, Designation of Air Quality Maintenance Areas.

State of Florida. 1991b. Florida Water Quality Standards, 1991. Part IV, Water Quality Criteria - Ground Water, Section 17-3.403 Classification of Ground Water, Usage, Reclassification.

State of Florida. 1991c. Surface Water Quality Standards, 1991. Section 17-302, Department of Environmental Protection, Bureau of Surface Water Management, Tallahassee, Florida.

State of Florida. 1991d. Listing of Outstanding Florida Waters by County. 1991. Department of Environmental Protection, Standards and Monitoring Section, Tallahassee, Florida. March 1991.

Stella, P. and G. Crotty. 1987. Solar Cell Design for Avoiding LILT Degradation. Record of the 19th Institute of Electrical and Electronics Engineers Photovoltaic Specialist Conference. 1987.

Stolarski, R.S., P. Bloomfield, and R.D. McPeters. 1991. Total Ozone Trends Deduced from Nimbus 7 TOMS Data. Geophysical Research Letters 18. pp. 1015-1018. 1991.

Turco, R.P., O.B. Toon, R.C. Whitten, and R.J. Cicerone. 1982. Space Shuttle Ice Nuclei. Nature, 298. pp. 830-832. 1982.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1988. Sources, Effects, and Risks of Ionizing Radiation. UN Report E.88.IX.7. 1988.

U.S. Air Force (USAF). 1986. Environmental Assessment for the Complementary Expendable Launch Vehicle (CELV) at Cape Canaveral Air Station, Florida. Department of the Air Force, Headquarters Space Division. (The Complementary Expendable Launch Vehicle, i.e., 34D7, has been renamed the Titan IV.) June 1986.

U.S. Air Force (USAF). 1988a. Final Environmental Assessment Titan IV Space Launch Vehicle Modifications and Launch Operations Program. Vandenberg Air Force Base, CA. February 1988.

U.S. Air Force (USAF). 1988b. A Supplement to the Environmental Assessment for the U.S. Air Force, Space Division Titan IV Program at Cape Canaveral Air Force Station, Florida. Department of the Air Force, Headquarters Space Systems Division, Los Angeles Air Force Station, CA. May 1988.

U.S. Air Force (USAF). 1990. Environmental Assessment Titan IV/Solid Rocket Motor Upgrade Program, Cape Canaveral Air Force Station Florida, and Vandenberg Air Force Base, CA. Department of the Air Force, Headquarters Space Systems Division, Los Angeles Air Force Station, CA. February 1990.

U.S. Atomic Energy Commission (AEC). 1974. Plutonium and Other Transuranium Elements, Sources, Environmental Distribution and Biomedical Effects. USAEC WASH 1359, available from NTIS. December 1984.

U.S. Bureau of Census. 1992. Statistical Abstract of the United States: 1992 (112th edition). Washington DC. 1992.

U.S. Department of Energy (DOE). 1980. Transuranic Elements in the Environment. Wayne C. Hanson, Editor. DOE Document No. DOE/TIC-22800. Government Printing Office. Washington, DC. April 1980.

U.S. Department of Energy (DOE). 1987a. Atomic Power in Space. A History. March 1987.

U.S. Department of Energy (DOE). 1987b. Environmental Research on Actinide Elements, DOE 86008713. Washington, DC. August 1987.

U.S. Department of Energy (DOE). 1988a. Light-Weight Radioisotope Heater Unit Final Safety Analysis Report (LWRHU-FSAR) Volume 1, Reference Design Document (RDD). Prepared by Mound Applied Technologies. Document No. MLM-3540. October 1988.

U.S. Department of Energy (DOE). 1988b. Final Safety Analysis Report for the Galileo Mission, Volume II (Book 2), Accident Model. Prepared by GE Astro-Space Division. Document No. 87SDS4213. December 1988.

U.S. Department of Energy (DOE). 1989a. Final Safety Analysis Report for the Galileo Mission, Volume III, (Book 2) Nuclear Risk Analysis Document Appendices. Prepared by NUS Corporation Document No. NUS-5126, Revision 1. January 1989.

U.S. Department of Energy (DOE). 1989b. Supplement to the Final Safety Analysis Report for the Galileo Mission. Document No. 89SDS4221. August 1989.

U.S. Department of Energy (DOE). 1990a. Final Safety Analysis Report for the Ulysses Mission, Volume II, Books 1 and 2, Accident Model Document. ULS-FSAR-003 and 004. March 1990.

U.S. Department of Energy (DOE). 1990b. Final Safety Analysis Report for the Ulysses Mission, Volume III, (Book 2), Nuclear Risk Analysis Document - Appendices. Prepared by NUS Corporation. March 1990.

U.S. Department of Energy (DOE). 1991. Environmental Assessment for Radioisotope Heat Source Fuel Processing and Fabrication. Prepared by the U.S. Department of Energy, Radioisotope Power Systems Division. July 1991.

U.S. Department of Energy (DOE) and National Aeronautics and Space Administration (NASA). 1991. Memorandum of Understanding between the Department of Energy and the National Aeronautics and Space Administration concerning radioisotope power systems for space missions. July 1991.

U.S. Department of Energy (DOE). 1995. Updated Space Vehicle Intact Impact Assessment (Letter from B. Cook, U.S. Department of Energy to R. Wilcox, Jet Propulsion Laboratory) March 23, 1995.

U.S. Department of the Interior (DOI). 1991. National Register of Historic Places, Florida Index. National Park Service, Washington, DC. July 25, 1991.

U.S. Department of the Interior (DOI). 1993. Bureau of Mines Mineral Industry Surveys. Platinum Quarterly. January 1993.

U.S. Department of the Interior (DOI). 1994. Mineral Commodity Summaries 1994, Bureau of Mines. 1994.

U.S. Environmental Protection Agency (EPA). 1977. Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment. U.S. EPA 520/4-77-016; NTIS PB 290314. September 1977.

U.S. Environmental Protection Agency (EPA). 1990. Transuranium Elements, Volume 2, Technical Basis for Remedial Actions. Prepared by the U.S. Office of Radiation Programs, Washington, DC. Report No. EPA/520-1-90-016. June 1990.

U.S. Nuclear Regulatory Commission (NRC). 1975. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants. WASH-1400. Washington, DC. 1975.

U.S. Nuclear Regulatory Commission (NRC). 1987. Report on the Accident at the Chernobyl Nuclear Power Station. Prepared as NUREG-1250. January 1987.

Wayne, R.P. 1991. Chemistry of Atmospheres. Second Edition, Oxford Science Publications, Oxford University Press Incorporated, New York, New York, 447p. 1991.

The White House. 1990. Office of the Press Secretary, Fact Sheet, Commercial Space Launch Policy. September 5, 1990.

Willard, M. 1994. Personal Communication from M. Willard, Martin Marietta to D. Scott, Science Applications International Corporation. Regarding air permitting requirements on CCAS. March 14, 1994.

APPENDIX A

GLOSSARY OF TERMS

APPENDIX A

GLOSSARY OF TERMS

absorbed dose—Energy from ionizing radiation absorbed per unit mass of tissue. For this report, the energy is assumed to be averaged over the organs or tissues being irradiated.

accident environment—Resulting conditions from an accident scenario, such as blast overpressures, fragments, and fire.

accident scenario—Launch vehicle and/or spacecraft condition resulting from failure model(s) at the component and/or subsystem level(s). Different failure modes can result in the same accident scenario.

air quality—A measure of the levels of constituents in the air.

air quality standards—The legally prescribed level of constituents in the outside air that cannot be exceeded during a specified time in a specified area. The National Ambient Air Quality Standards (NAAQS) establish minimum concentration levels set on a scientific basis for specific pollutants or group of pollutants, such as particulates.

alpha particle—Ionizing radiation produced from the spontaneous decay of certain radioactive materials, including Pu-238. An alpha particle consists of the nucleus of a helium atom. Alpha particles are easily stopped by tissue or other material; therefore, damage occurs only to tissues close to the radiation source.

ambient air—The surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures. (It is not the air in the immediate proximity of the emission source.)

aquifer—A water-bearing subsurface formation capable of producing significant quantities of water under ordinary hydraulic gradients; the water can be pumped to the surface through a well or emerge naturally as a spring.

archaeological sites—Sites where material remains (e.g., fossils, relics, artifacts, and monuments) of past human life and activities and cultural remains exist.

astronomical unit (AU)—The distance from the Earth to the Sun. It is equal to 149,599,000 km (92,960,818 mi).

background radiation—Ionizing radiation present in the environment from cosmic rays and natural sources in the Earth; background radiation varies considerable with location.

Becquerel (Bq)—Unit of activity equal to 1 disintegration per second.

Biological Opinion—A formal opinion from the Fish and Wildlife Service regarding impact or potential consequences to endangered or threatened species from a proposed action.

biological resources—A group of plants, animals, and other living organisms located in a specific region.

cancer—A group of diseases characterized by uncontrolled cellular growth.

carbon dioxide (CO_2)—A heavy colorless, odorless, nonpoisonous gas that is a normal component of the ambient air; it does not support combustion; it dissolves in water to form carbonic acid; it can be formed by the combustion or decomposition of organic substances and can be absorbed from the air by plants during photosynthesis.

carbon monoxide (CO)—A colorless, odorless gas that is toxic if breathed in high concentrations over a certain period of time; it is a normal component of most automotive exhaust systems and is a product of incomplete fossil-fuel combustion.

clad—Thin-walled metal enclosure that forms the outer shell of nuclear fuel and prevents the release of plutonium dioxide and alpha particles into the environment.

committed effective dose equivalent—The sum of the committed dose equivalents to various tissues of the body, expressed in Sieverts (rem).

complementary cumulative distribution function (CCDF)—The consequence-probability distribution curves used to represent the conditional probabilities for the various health effects due to accidents.

conditional probability—The probability that a release of radioactive material could occur given an initiating accident (i.e., the accident has occurred).

cumulative density function—Alternate form by which to describe the probability distribution of an accident.

cumulative impacts—Additive environmental, health, safety, and significant socioeconomic impacts that result from a number of similar activities in an area.

Curie (Ci)—A measure of the radioactivity level of a substance (i.e., the number of unstable nuclei that are undergoing transformation in the process of radioactivity decay); one curie equals the disintegration of 3.7×10^{10} (37 billion) nuclei per second and is equal to the radioactivity of one gram of radium-226.

decay heat—The heat produced by the energy of decay of radionuclides.

decay, radioactive—The decrease in the amount of any radioactive material with the passage of time due to the transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The decay process results in the emission of nuclear radiation (alpha, beta, or gamma radiation) and heat.

decontamination (radioactive)—The reduction or removal of radioactive contaminants from surfaces of equipment by cleaning or washing with chemicals, by wet abrasive blasting, or by chemical processing.

de minimis—This is a concept to indicate a collective dose level at which the risks to human health are considered negligible.

deposition—In atmospheric transport terms, the settling out on ground and building surfaces of atmospheric aerosols and particles (dry deposition) or their removal from the air to the ground by precipitation (wet deposition or rainout).

dose—The amount of energy deposited in the body by ionizing radiation per unit body mass.

dose commitment—The dose that an organ or tissue would receive during a specified period of time (e.g., usually 50 years) as a result of intake (as by ingestion or inhalation), frequently over 1 year, of one or more radionuclides from a defined release.

dose equivalent—The product of the absorbed dose from ionizing radiation and such factors that account for the difference in biological effectiveness due to the type of radiation and its distribution in the body (measured in Sieverts [rem]). The weighting factor for beta and gamma radiation is 1 and for alpha radiation it is approximately 20; thus, 1 Gy (100 rad) gamma radiation is equivalent to 1 Sv (100 rem), and 1 Gy (100 rad) alpha radiation is equivalent to 1 Sv (2,000 rem).

effective dose equivalent—The dose to the whole body that would have the same biological effect as a given dose equivalent to a particular organ or tissue.

endangered species —Plant and animal species that are threatened with either extinction or serious depletion in an area and are formally listed by the U.S. Fish and Wildlife Service.

Environmental Impact Statement—The document prepared pursuant to Section 102(2)(C) of the National Environmental Policy Act (NEPA) of 1969 for a major Federal action that could potentially significantly affect the environment.

exposure to radiation—The incidence of radiation from either external or internal sources on living or inanimate material by accident or intent:

- Background—exposure to natural background ionizing radiation
- Occupational—exposure to ionizing radiation that takes place during a person's working hours
- Population (or collective)—sum of the exposures to a number of persons who inhabit an area.

Failure Mode Effects and Analysis—A technique to identify all the events that might lead to a system breakdown or failure.

Gaussian plume—The distribution of material (a plume) in the atmosphere resulting from the release of pollutants from a stack or other source exhibiting the characteristic bell-shaped (Gaussian) curve. The distribution of concentrations about the centerline of the plume, which is assumed to decrease as a function of its distance from the source and centerline, depends on the mean wind speed and atmospheric stability.

general public—Individuals who are normally at and beyond the affected boundary. For this EIS, the general public includes individuals on CCAS open-access ways (roads, rivers, creeks, railways).

global environment—The environment that includes worldwide factors, such as population distribution and density, general climatological condition characteristics, surface type (i.e., oceans, rock, soil), and global atmospheric inventory of plutonium.

gravity-assist—Using the planetary gravitational field to increase the velocity or decrease the injection energy of a spacecraft.

groundwater—Water within a subsurface formation that can supply springs and wells.

habitat—The place or type of site where a plant or animal naturally or normally lives and grows.

half-life (radiological)—The period required for the disintegration of half the atoms in a given amount of a specific radioactive substance. The half-life varies for specific radioisotopes from millionths of a second to billions of years.

health effect (for this EIS)—The impact to human health due to radiation doses. The number of excess latent cancer fatalities over and above the normal occurrence rate that could occur in the exposed population as a result of radiation from a launch accident or swingby accident.

historical resources—The sites, districts, structures, and objects considered limited and nonrenewable because of their association with historic events, persons, or social or historical movements.

hydrology—The science dealing with the properties, distribution, and circulation of natural water systems in and upon the Earth, including groundwater, surface water, and rainfall.

initiating event (failure)—An event that can begin an accident sequence if followed by systems failures or operator errors.

initiating probability—The probability that an identified accident scenario and associated adverse conditions (accident environment) will occur.

ionizing radiation—Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions.

isotope—One of perhaps several different species of a given chemical element with the same number of protons, which are distinguishable by variations in the number of neutrons in the atomic nucleus but indistinguishable by chemical means.

maximally exposed individual—A hypothetical person located to receive the maximum possible dose.

maximum individual dose—The maximum individual dose commitment that an individual could receive over a 50-year commitment period.

micron (μm)—Unit of measure expressed as 10^{-6} meters or a micrometer.

NO_X—Refers to the oxides of nitrogen, primarily NO and NO_2. Gases, formed primarily by fuel combustion, that contribute to air pollution problems, such as the formation of acid rain and smog.

offsite—The area outside the property boundary of the CCAS site.

onsite—The area within the property boundary of the CCAS site.

onsite population—NASA, DOD, and contractor personnel who are on duty at CCAS or KSC and badged onsite visitors.

Orbiter—For purposes of this EIS, a spacecraft, such as Cassini, designed to orbit a planet (i.e., a celestial body) without landing on its surface.

ozone (O_3)—A triatomic form of oxygen that is a bluish irritating gas of pungent odor. Ozone is formed naturally in the upper atmosphere by a photochemical reaction with ultraviolet radiation.

particulates—Microscopic pieces of solids (usually air pollutants) that emanate from a range of sources. In this case, the particulates released from combustion are mainly composed of aluminum oxide (Al_2O_3). Under the NAAQS, particulates are measured in the ambient air as PM_{10} (i.e., particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers).

Pascal—A metric unit of pressure; 101,000 Pascals is equal to 14.7 pounds per square inch (psi).

person-Sievert (person-rem)—The unit of collective radiation dose commitment to a given population or the sum of the individual doses received by a population segment.

pH—A measure of the hydrogen ion concentration in an aqueous solution, specifically the negative logarithm of the hydrogen ion concentration. Acidic solutions have a pH from 0 to 7; basic solutions have a pH greater than 7.

plume—The elongated pattern of contaminated air or water originating from a point-source emission, such as a smokestack, or from a waste source, such as a hazardous waste disposal site.

plutonium—A heavy artificially produced radioactive metal (atomic number 94) with 15 isotopes. The Pu-238 isotope forms the basis for the fuel in the RTG. With a decay half-life of 87.7 years, Pu-238 is produced from the neutron bombardment of neptunium-237.

probability density function—A representative of the probability distribution of a continuous random variable.

proposed action—Significant activity(ies) evaluated by an EIS for which alternatives are proposed. For this EIS, the proposed action consists of completing the preparation for and launch of the Cassini spacecraft for its 4-year science tour of Saturn.

radiation—The emitted particles (alpha, beta, neutrons) or photons (gamma) from the nuclei of unstable (radioactive) atoms as a result of radioactive decay. Some elements are naturally radioactive; others are induced to become radioactive by bombardment in a nuclear reactor or other particle accelerator. The characteristics of naturally occurring radiation are indistinguishable from those of induced radiation.

radioactivity—The spontaneous decay or disintegration of unstable atomic nuclei, usually accompanied by the emission of ionizing radiation.

radioisotope heater unit (RHU)—An RHU is a radioisotope-fueled system consisting of a 1-watt pellet of plutonium-238 dioxide, a platinum-30 rhodium (Pt-30Rh) clad, an insulation system of pyrolitic graphite (PG), and an aeroshell/impact body of fine-weave pierced fabric (FWPF). RHUs help to regulate temperatures onboard the spacecraft and the Huygens Probe.

radioisotope thermoelectric generator (RTG)—An RTG is a power system consisting of a radioisotopic heat source and a thermoelectric converter that transforms thermal energy into electricity from the radioactive decay of plutonium-238.

radioisotopes—Unstable isotopes of an element that decay or disintegrate and spontaneously emit particles or electromagnetic radiation.

receiving waters—Rivers, lakes, oceans, or other water bodies that receive treated or untreated wastewaters.

reference population—A representative group of people in a specified area that would be exposed to radiation.

rem—The unit dose representing the amount of ionizing radiation needed to produce the same biological effects as one roentgen of high-penetration X-rays (about 200 kv).

risk—The accident frequency coupled with the expected consequences. For severe accidents with high consequences, the risk is balanced by the low accident frequency. Risk is defined quantitatively as the product of the frequency and the consequence. In the case of the Cassini mission, the risk is the probability (per unit dose) of producing, in an individual or a population, a radiation-induced detrimental health effect, such as cancer.

risk assessment—A process comprising the identification of the hazards, such as patterns and level of exposure, and the evaluation of the risk (i.e., accident frequency and consequences) to affected individuals or population from a known event.

Sievert (Sv)—The SI unit of dose equivalent. One Sv is equivalent to 100 rem.

socioeconomics—Relating to or involving a combination of social and economic factors.

solar energy—Energy from the Sun or heat from the Sun converted into an energy source.

solid rocket motor (SRM)—A chemical rocket propulsion system employed for launch vehicles that uses solid propellants.

source term—The quantities of materials released during an accident to air or water pathways and the characteristics of the releases (e.g., particle size distribution, release height and duration); used for determining accident consequences.

stratosphere—An upper portion of the atmosphere above the troposphere reaching a maximum height of 50 km (164.050 ft)above the Earth's surface. The temperature is relatively constant in the lower stratosphere and gradually increases with altitude. The stratosphere is Earth's main ozone producing region.

surface water—All water on the Earth's surface, as distinguished from groundwater.

swingby—Part of the trajectory when, during an interplanetary mission, a space vehicle passes by a planet to use the planetary gravitation to change course and to obtain additional velocity/momentum.

torus—The doughnut-shape region of space swept out by the Earth as it orbits the Sun.

trajectory—The flight path that a spacecraft will take during a mission.

troposphere—The portion of the atmosphere next to the Earth's surface in which the temperature rapidly decreases with altitude, clouds form, and convection is active. The troposphere begins at ground level and extends to an altitude of 10 to 12 km (32,808 to 39,370 ft) above the Earth's surface.

upper stage—The portion of the launch system that injects the spacecraft (payload) from a parking orbit into the desired orbit or interplanetary trajectory.

water quality standards—The levels of constituents or characteristics that affect the suitability of water for a given use or classification (e.g., drinking water, recreation use, propagation of fish and aquatic life, and agricultural and industrial use). Standards are legally enforceable.

wetlands—Land or areas exhibiting the following characteristics: hydric soil conditions; saturated or inundated soil during some portion of the year and plant species tolerant of such conditions; also, areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, under normal circumstances, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

wind rose—A diagram showing the relative frequency and strength of winds from different directions for a given place.

APPENDIX B

PROBABILITIES AND SOURCE TERM METHODOLOGY FOR INADVERTENT REENTRY DURING AN EARTH SWINGBY AND INTERPLANETARY CRUISE FOR THE VVEJGA AND VEEGA TRAJECTORIES

APPENDIX B

PROBABILITIES AND SOURCE TERM METHODOLOGY FOR INADVERTENT REENTRY DURING AN EARTH SWINGBY AND INTERPLANETARY CRUISE FOR THE VVEJGA AND VEEGA TRAJECTORIES

B.1 EARTH GRAVITY-ASSIST CONSIDERATIONS IN DETERMINING PROBABILITIES

The Proposed Action, the 1999 mission alternative, and the 2001 mission alternative would utilize planetary gravity-assist trajectories to gain enough energy to reach Saturn. A planetary gravity-assist uses the planet's gravity for the extra energy needed by the spacecraft to maintain or increase its velocity so that it can reach its mission destination (in this case, Saturn). The Proposed Action's primary launch opportunity would use a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to reach Saturn. The spacecraft on this trajectory would make four planetary gravity-assist swingbys—the first two around Venus, the third around the Earth, and the fourth around Jupiter before reaching Saturn. The 1997 secondary and 1999 backup contingency launch opportunities under the Proposed Action as well as the 1999 dual Shuttle alternative would each use a Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory to reach Saturn. The primary launch opportunity for the 2001 mission alternative would use a non-Earth-gravity-assist trajectory, a 10.3-year Venus-Venus-Venus-Gravity-Assist (VVVGA).

If a failure occurs during a planetary gravity-assist swingby, the spacecraft could be placed in a planet-impacting trajectory. For these launch opportunities, multiple opportunities would exist for planetary impacts to occur during swingby activities: four for the primary launch VVEJGA opportunity (Venus, Venus, Earth, Jupiter swingbys), and three each for the VEEGA (Venus, Earth, Earth swingbys) and VVVGA (Venus, Venus, Venus swingbys) opportunities. The Earth swingby(s) would be the primary concern.

If an accident or failure occurs during the swingby process resulting in loss of control of the spacecraft and the spacecraft is placed on an Earth-impacting trajectory, the three radioisotope thermoelectric generators (RTGs) and 117 radioisotope heater units (RHUs) onboard the Orbiter and 40 RHUs on the Huygens Probe could impact the Earth. (Earth impact is defined as the inadvertent reentry of the spacecraft into the Earth's atmosphere.) The RTGs could reenter the Earth's atmosphere leading to a range of fuel-end states that include intact modules (damaged and undamaged), intact GISs, particulate, and vaporized fuel. Of the 157 RHUs, the 117 in the Orbiter would be predicted to vaporize but the 40 RHUs in the Probe would be expected to survive reentry.

The potential would also exist for a failure to occur that could result in a loss of spacecraft control during the non-swingby or interplanetary cruise portion of the gravity-assist trajectories. If such an event occurred and the spacecraft drifted in its orbit around the Sun, an Earth impact could occur a decade to centuries later, after many revolutions around the Sun. Once the spacecraft has successfully completed its planetary gravity-assist trajectory and the Saturn Orbit Insertion (SOI) has occurred, the spacecraft would come under the gravitational influence of Saturn and would no longer pose a threat of

Earth impact. Even if SOI is not achieved or a spacecraft failure occurs after the gravity-assists, the resulting trajectories would probably not cross the Earth's torus and would likely eject the spacecraft from the solar system.

Precautions are taken in the mission design to ensure that an inadvertent reentry into Earth's atmosphere resulting in an impact with the Earth's surface does not occur during the Earth-gravity-assist swingbys. This ongoing design is also intended to assure spacecraft control during interplanetary cruise to preclude a potential Earth impact years later.

To this end, a formal design requirement was imposed to ensure the expected probability of Earth impact would not exceed 10^{-6} (i.e., 1 in a million) (Jet Propulsion Laboratory [JPL] 1993f).

> *Following injection, the probability of Earth impact by the spacecraft shall not exceed 10^{-6} taking into account potential failures.*

To verify that this requirement can be satisfied during this mission, JPL assessed the probability of Earth impact (JPL 1993f). This requirement was interpreted to mean that the expected value of the Earth impact probability, from injection of the spacecraft into its planetary gravity-assist trajectory to Saturn (i.e., from the end of launch Phase 6) to 100 years beyond the nominal Saturn encounter date, should not exceed 10^{-6}.

The JPL study was performed to determine the necessary actions in the design of the spacecraft, ground system, and navigation planning to ensure that the probability of Earth impact satisfied the design requirement (JPL 1993f). The study incorporated a quantitative assessment of the probability of Earth impact, including an evaluation of the uncertainties in the assessment process. Additionally, an independent review panel found the approach taken by JPL to assess the probability of an inadvertent reentry to be sound and reported that JPL's results are reasonable (Cassini Swingby Independent Review Panel 1995).

The following sections present the methodology used for determining the Earth impact probability and the failure mode analysis that leads directly to short-term, long-term, and total probability of an Earth impact from an inadvertent reentry. Two trajectories were evaluated: the VVEJGA trajectory of the primary launch opportunity and the VEEGA trajectories associated with both the 1997 secondary and 1999 backup launch opportunities and the 1999 dual Shuttle launch alternative. Because the VEEGA trajectories for the secondary and backup launch opportunities have essentially the same characteristics, and because the VEEGA trajectories are identical for the 1999 backup launch opportunity and the dual Shuttle launch alternative, only the 1999 launch opportunity is referenced throughout the discussion. The probabilities associated with the secondary launch opportunity are expected to be similar to or less than those for the 1999 launch opportunity.

B.1.1 Methodology

The Earth impact probability developed by JPL consists of short- and long-term components. The short-term component is the contribution resulting from the navigation of the Earth swingby(s) for a given trajectory (VVEJGA or VEEGA). The long-term component is the contribution from a failure during the interplanetary cruise that leads to a disabled spacecraft drifting in an orbit around the Sun, so that the spacecraft could reencounter the Earth sometime beyond the nominal Saturn encounter date. For this analysis, the probability of impact during the first 100 years beyond SOI was considered.

For either component, the Earth impact probability (P_I) can be expressed as:

$$P_I = \sum_i P_F(i)\, P_{I/F}(i)\, P_{NR}(i) \qquad \text{(C-1)}$$

where:

P_I = Probability of Earth impact

$P_F(i)$ = Probability of failure of i-th failure mode

$P_{I/F}(i)$ = Probability of a resultant Earth impact trajectory given an occurrence of the i-th failure mode

$P_{NR}(i)$ = Probability of no recovery given the failure mode and the time to impact; this probability is conditional on the occurrence of the failure and on the spacecraft being on an impact trajectory because of the failure.

This relationship represents several important concepts. A number of failure modes contribute to impact probability. One objective of the JPL study was to identify these failure modes. It is important to note that not all failures would place the spacecraft on an impacting trajectory and that all failures would not adversely affect the capability of mission controllers to achieve successful Earth swingby(s), illustrated by the $P_{I/F}$ and P_{NR} terms. For example, the Galileo high-gain antenna anomaly resulted in only a partial deployment of the antenna, which did not prevent the precise delivery of the Galileo spacecraft at the second Earth swingby.

To keep the short-term impact probability low, a trajectory-biasing strategy is used in the trajectory design and implementation plan to reduce the probability of an Earth impacting trajectory if a failure were to occur (i.e., to reduce $P_{I/F}$). During most of Cassini's inner solar system journey, the spacecraft would be on a trajectory that, without further maneuvers, would miss the Earth by tens of thousands of kilometers. As part of the Earth impact avoidance strategy, the spacecraft would either be placed on a trajectory passing through the required Earth swingby point just 10 days prior to the Earth swingby for the VVEJGA, or 7 days prior to each of the two Earth swingbys for the VEEGA.

The JPL study determined that, although a trajectory-biasing strategy to control the potential for Earth impact during a planned swingby would affect the probability over the long term, such a strategy could not be relied upon exclusively to control the long-term probability. Failures on legs targeted toward Earth or Venus would tend to result in spacecraft trajectories that remain in the vicinity of Earth's orbit. Failures during legs targeted toward Jupiter or Saturn tend to result in trajectories that would never return to the vicinity of Earth's orbit. Gravity-assists by the massive outer planets, for example, would virtually ensure that failures during the last 73 percent of the primary and the last 44 percent of the backup interplanetary cruise do not result in an Earth impact. Over a long-time period, the Earth impact probability is dominated by third-body perturbations to the spacecraft trajectory and by accidental planetary gravity-assist swingbys while the errant spacecraft is drifting in a Sun orbit. Therefore, the long-term Earth impact probability would have to be controlled by designing the spacecraft and mission operations so that the failure probabilities would be low.

Not all failures would place the spacecraft on an Earth-impacting trajectory. The P_{NR} term includes the ability to recover control of the spacecraft and successfully apply a corrective maneuver after a failure. If the spacecraft was not completely incapacitated by the failure, then the normal course of action would be to accurately determine the spacecraft trajectory and, if required, command a recovery sequence to modify the trajectory and avoid Earth impact.

B.1.2 Failure Mode Analysis

Two general categories of uncertainty can lead to an Earth-impacting trajectory. First, Earth-impacting trajectories could result from uncertainties in the normal operation of the spacecraft and its navigation system (navigation uncertainties). During a maneuver (i.e., a normal trajectory correction), for example, the actual change in position and/or change in velocity of the spacecraft may differ slightly from the desired change or that estimated by the navigation system. Changes in actual position and/or velocity, if large enough and uncorrected, could lead to Earth impact. Such uncertainties are not considered failures; they are expected variations in the operation of the systems. The second general category would be failures. In general, failures can be classified into three categories: environmentally-induced failures, internal spacecraft failures, and ground-induced failures. These types of failures can result in an anomalous spacecraft velocity change that could place the spacecraft on an Earth-impacting trajectory. A subset of these failures could prevent the spacecraft from being recovered after being placed on an Earth-impacting trajectory.

Of all the environmentally-induced failure modes identified by the JPL study, only micrometeoroid-induced tank rupture was a significant contributor to the short-term Earth impact probability (JPL 1993f). The Cassini spacecraft design would include components to provide protection from micrometeoroids; however, some particles in space have sufficiently high energies to penetrate or overcome those protective measures and damage the spacecraft. Current analyses indicate that the spacecraft on the VEEGA trajectory would require the equivalent of three times the particle shielding protection as used on the VVEJGA trajectory. A rupture of a propellant or a pressurant tank could cause an anomalous spacecraft velocity change and loss of spacecraft control or commandability.

The contribution to Earth impact probability from all other failure modes (environmentally-induced, internal spacecraft failures, and ground-induced) was more than an order of magnitude less than that from micrometeoroid-induced failures. Thus, micrometeroid-induced failures are the primary factor in evaluation of the probability of an Earth impact during a planned swingby. Other failure modes evaluated included stuck-open thruster valves, main engine valve failures, accelerometer failures, main engine gimbal actuator failures, and anomalous Sun searches due to stellar reference unit or inertial reference unit failures. Coding errors in the Attitude and Articulation Control Subsystem (AACS) and Command and Data Subsystem (CDS) flight software were determined to be the spacecraft software contributors to Earth impact probability (JPL 1993f).

The dominant failure mode for the long-term Earth impact probability was determined to be loss of control due to internal spacecraft system failures. Internal failures include design and implementation errors, common-mode failures, electronic parts failures, hardware failures, and software errors. Ground-induced errors made by spacecraft controllers are sent to the spacecraft and executed. Two categories of ground-induced errors are erroneous ground commands and navigation design errors. These potential ground-induced errors were determined to be insignificant contributors to Earth impact probability.

In addition to these potential failures that could place the spacecraft on an Earth-impacting trajectory, failures that could prevent the spacecraft from being recovered once it is on an Earth-impacting trajectory were also considered. In some cases, the same failure that would place the spacecraft on an impacting trajectory would also prevent recovery.

For the failures that would put the spacecraft on an Earth-impacting trajectory but do not preclude the execution of recovery maneuvers, the key factor in determining whether or not recovery could actually be accomplished and Earth impact avoided is the amount of time remaining before the Earth swingby, not the cause of the initial failure. (Until the spacecraft is close to the Earth swingby, only new failures that would completely disable the spacecraft need to be considered. Other failures can be diagnosed and corrected with sufficient time to make another recovery attempt.) The spacecraft primary disabling failures were determined to be micrometeoroid hits and spacecraft system internal failures. For initial failures that occur very close to swingby (i.e., within 2 days of Earth encounters), it was assumed that there would not be enough time to detect the failure and take corrective action. For failures occurring 39 or more days before Earth encounter, sufficient time would exist for problem diagnosis, development of a recovery plan, and execution of at least one and probably more recovery attempt(s). If a failure occurred between 39 and 2 days before the Earth encounter, there would be time to make only one recovery attempt; any subsequent failure was conservatively assumed to abort recovery attempts. JPL's evaluations indicated that the major contributors during this period would be ground failures preventing successful execution of a recovery maneuver and a spacecraft failure requiring ground intervention (JPL 1993f).

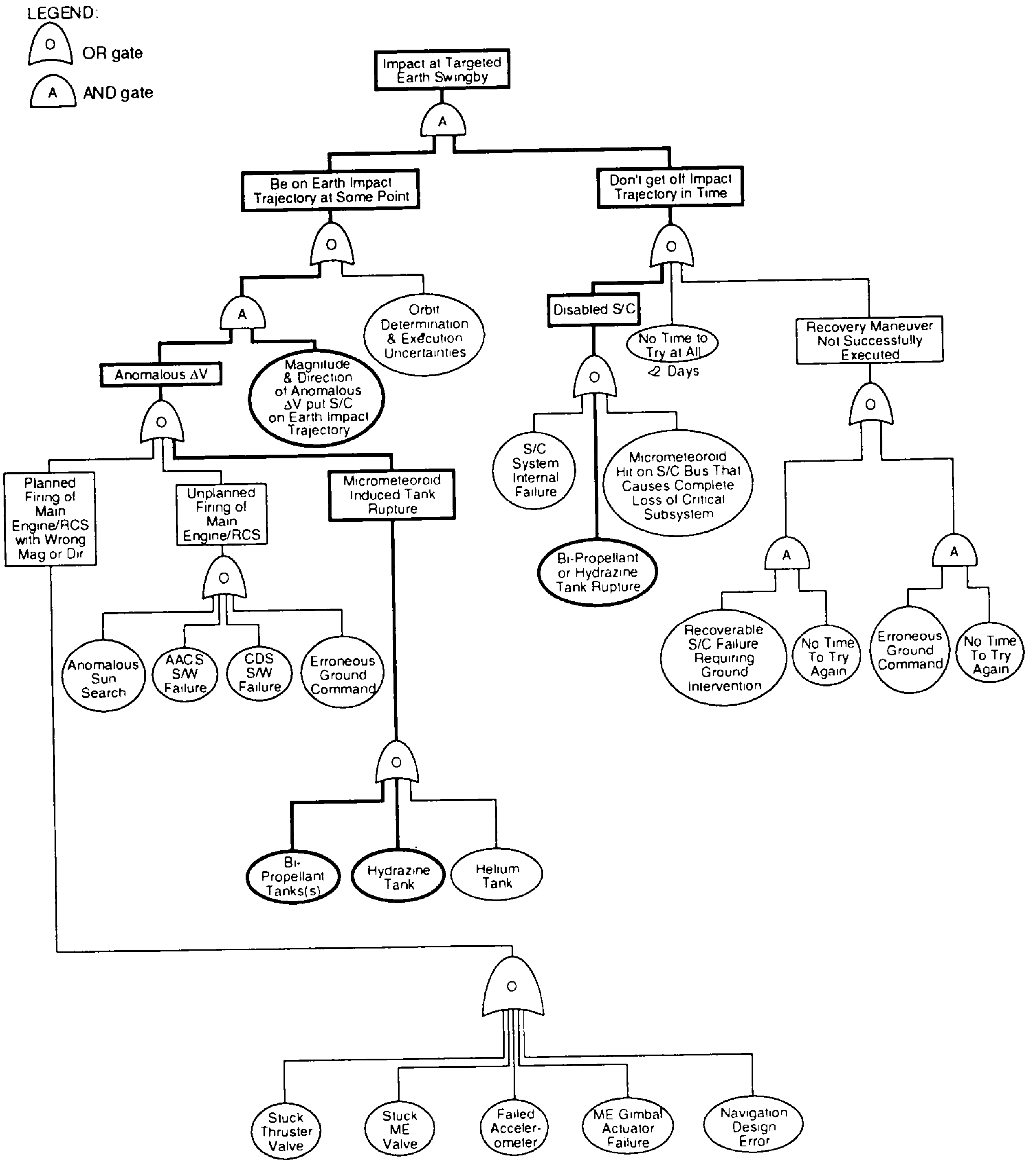
B.1.3 Short-Term Impact Probability

The objective of the trajectory-biasing navigation strategy from the point of Earth escape to the Earth swingby(s) is to satisfy the Earth impact probability while delivering the spacecraft to the necessary Earth swingby aimpoint. The navigation strategy is driven by the requirement to control the trajectory so that the spacecraft can satisfy the mission objectives and maintain a low probability of inadvertent reentry. The navigation strategy discussed here is not concerned with the overall trajectory design, which is controlled by the launch vehicle capabilities and mission objectives, but with the small variations in this trajectory. The trajectory-biasing navigation strategy that would be used for the Cassini mission would break the overall trajectory leading to Earth swingby into segments or steps, where the overall Earth impact probability of each segment would be controlled by biasing the aimpoint to avoid Earth impact. Prior to launch, an analysis would be performed to determine the duration and swingby conditions for each segment of the trajectory. Two rules would guide the analysis: 1) at no point during the mission, from injection into the planetary gravity-assist trajectory to Saturn to the final Earth swingby, would the expected probability of being on an Earth impact trajectory, following completion of a maneuver, be greater than 10^{-6}, and 2) if a maneuver terminated early, the probability of an Earth-impacting trajectory would be no greater than that for a completed maneuver. After launch, the Cassini spacecraft would be controlled to these conditions.

Calculation of the short-term probability of Earth impact requires evaluation of three factors: the failure probabilities and associated anomalous velocity changes, the uncertainties in the navigation process, and the characteristics of the spacecraft trajectory. For the purpose of defining an Earth swingby navigation strategy, steps would be taken to minimize the effect of both failures and navigation uncertainties. The navigation strategy would focus on specifying and controlling the spacecraft trajectory conditions given the failure probabilities and navigation uncertainties.

In general, the Earth impact probability decreases as the swingby altitude increases; therefore, impact avoidance requirements could be satisfied by simply raising the swingby altitude. However, specific swingby conditions would be needed to shape the trajectory, and the spacecraft cannot carry sufficient propellant to replace this effect (except possibly for a very small bias). There would, however, be enough propellant to bring the trajectory in toward the Earth in several steps before the swingby.

The probability of Earth impact is presented as a probability density function (PDF) over the model uncertainties. To calculate a PDF for the short-term Earth impact probability, it was necessary to perform a Monte Carlo simulation for both the primary and backup mission trajectories. (It is reasonable to assume that the Earth impact probability for the 1997 secondary launch opportunity's VEEGA trajectory would be similar to or less than that estimated for the 1999 launch opportunity.) A best estimate of the short-term Earth impact probability was estimated by calculating the probability of impact for each significant failure mode. To provide an understanding of the contributing failure modes to the short-term Earth impact probability, a logic diagram (see Figure B-1) was generated. In the figure, the significant contributors are in bold (JPL 1993f).



Source: JPL 1993f

FIGURE B-1. SHORT-TERM EARTH IMPACT PROBABILITY LOGIC DIAGRAM

Using values of navigation uncertainty at three confidence levels (i.e., 10 percent, 50 percent or best estimate, and 90 percent) and three values of the anomalous spacecraft velocity change associated with a given failure, the probability of Earth impact was computed along the trajectory at maneuvers or at discrete time steps, depending on the failure mode being considered. The Monte Carlo simulation was performed with random selections of failure mode confidence levels, effects of the failure mode on imparting an Earth-impacting trajectory change, and the probability of recovering spacecraft control given the failure and time of occurrence in the simulated mission. A total of 1,000 Monte Carlo runs or simulated missions were performed for each launch opportunity (primary and backup), with each run breaking the mission trajectory into a number of time steps. All failure modes were sampled. By sampling the failure probability and the probability to recover at the 10, 50 (best estimate), and 90 percent confidence levels and the probability of an impact trajectory resulting from the failure at a random time step, a distribution of the overall Earth impact probabilities was developed. The factors, after each had been sampled, were multiplied together to determine the probability of Earth impact at a given time step. The individual probabilities were then summed over the time step and across all failure modes to obtain the overall probability of Earth impact for the given trajectory (Table B-1). Micrometeoroid-induced failures, as noted previously, dominate the failure modes. The analyses performed for the Perseids meteor shower (an event that occurs in August every year) predicted that the Cassini spacecraft while on the VVEJGA trajectory would pass through both enhanced and storm environments but only the enhanced environment would apply while on the VEEGA (backup) trajectory. Calculated (i.e., best estimates) flux levels (of micrometeoroids) in the enhanced environment are about 3 times greater than background, and about 30 times greater than background in the storm environment. The mean values for the short-term probability of Earth impact occurring under the Proposed Action were estimated at 7.6×10^{-7} for the VVEJGA trajectory of the primary launch opportunity and at 4.7×10^{-7} for the backup opportunity's VEEGA trajectory (JPL 1993f).

As additional analyses for the short-term Earth impact case, JPL calculated the distribution of spacecraft reentry angles into Earth's atmosphere. These calculated distributions are representative of the reentry angle estimated for an Earth swingby accident. The Department of Energy used part of the JPL analysis to evaluate the potential consequences to the RTGs and RHUs of an Earth swingby accident. JPL's analysis indicated that reentry angles less than 7 degrees would probably cause the spacecraft (plus RTGs and RHUs) to skip back out of the atmosphere and not impact the Earth. The frequency distributions of reentry angles for the primary launch opportunity's VVEJGA trajectory and for the second Earth swingby in the 1999 launch opportunity's VEEGA trajectory tended to be greatest in the lower entry angles (about 7 to 30 degrees), indicating that this reentry would be more likely to occur in the lower entry angles. Specifically, the reentry would be relatively "shallow." The first Earth swingby of the VEEGA had a nearly uniform distribution of reentry angles between 10 and 80 degrees ranging from shallow to steep. With a shallow reentry, the spacecraft would spend more time passing through Earth's atmosphere before impacting than during a steep reentry. Figures B-2, B-3, and B-4 illustrate the conditional probabilities for various entry angles for the primary and backup launches (JPL 1993f).

TABLE B-1. SHORT-TERM MEAN EARTH IMPACT PROBABILITIES

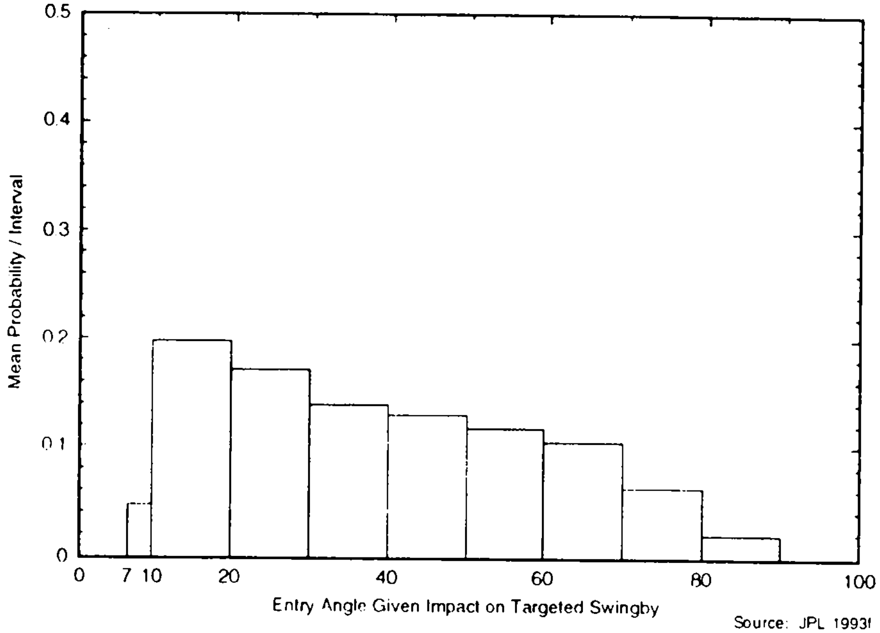
Failure Mode	Primary (VVEJGA)	1999 (VEEGA)	
		Earth 1	Earth 2
I Environmental Failures			
1) Micrometeoroid (the only significant environment failure mode)			
A) Bipropellant Tank	6.11×10^{-7}	1.52×10^{-7}	2.33×10^{-7}
B) Hydrazine Tank	1.13×10^{-7}	2.91×10^{-8}	3.06×10^{-8}
C) Helium Tank	3.02×10^{-8}	7.04×10^{-9}	6.36×10^{-9}
D) Engineering Bus	2.21×10^{-10}	Nil	1.03×10^{-12}
II Major Spacecraft Failures			
1) Stuck-Open Thruster Valve			
A) Z Thruster			
1) Mechanical Failure	1.37×10^{-12}	Nil	Nil
2) Electrical Failure	3.23×10^{-12}	Nil	Nil
B) X Thruster			
1) Mechanical Failure	2.33×10^{-10}	Nil	Nil
2) Electrical Failure	4.86×10^{-11}	Nil	Nil
2) Stuck-Open Main Engine Valve			
A) Mechanical Failure			
1) Oxidizer Valve	Nil	Nil	Nil
2) Fuel Valve	Nil	Nil	Nil
B) Electrical Failure	Nil	Nil	Nil
3) Accelerometer Failure	2.45×10^{-10}	Nil	7.17×10^{-9}
4) Main Engine Gimbal Actuator Failure	2.07×10^{-12}	Nil	2.66×10^{-12}
5) AACS Flight Software Error	3.00×10^{-12}	Nil	Nil
6) CDS Flight Software Error	Nil	Nil	1.60×10^{-9}
7) Anomalous Sun Search	1.35×10^{-11}	Nil	Nil
8) Spacecraft System Internal Failure	1.93×10^{-9}	Nil	2.90×10^{-11}
III Ground-Induced Errors			
1) Erroneous Ground[a] Command	1.76×10^{-10}	1.92×10^{-10}	3.04×10^{-10}
2) Navigation Design[b] Error	6.94×10^{-10}	4.11×10^{-10}	2.40×10^{-10}
TOTAL	7.6×10^{-7}	1.9×10^{-7}	2.8×10^{-7}

Source: JPL 1993f

[a] Computed as a bound by setting $P_{I/F} = 1.0$.

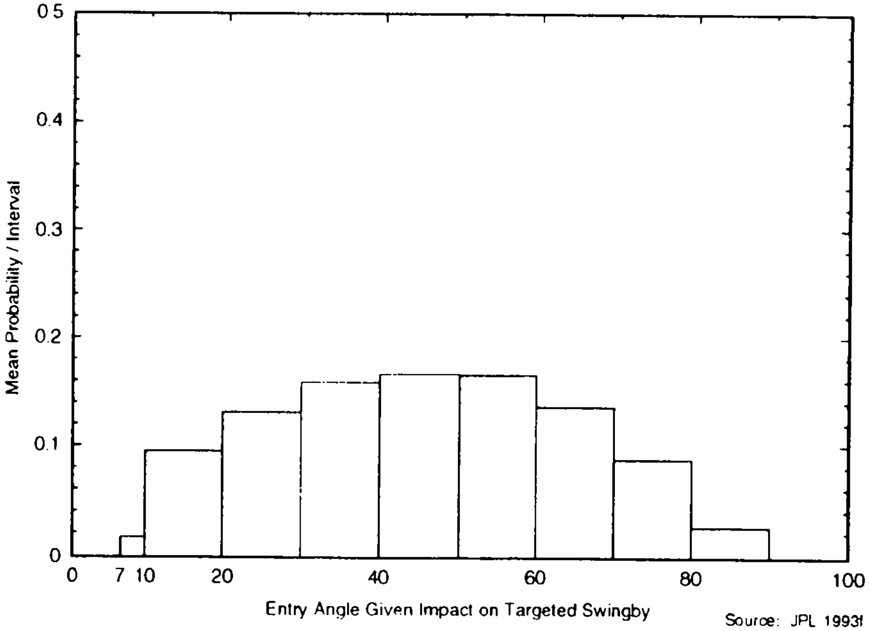
[b] Computed as a bound by setting ΔV toward the Earth.

Note: Nil indicates that the mean fractional Earth impact probability is less than 10^{-12}; three-digit precision is retained to facilitate addition.



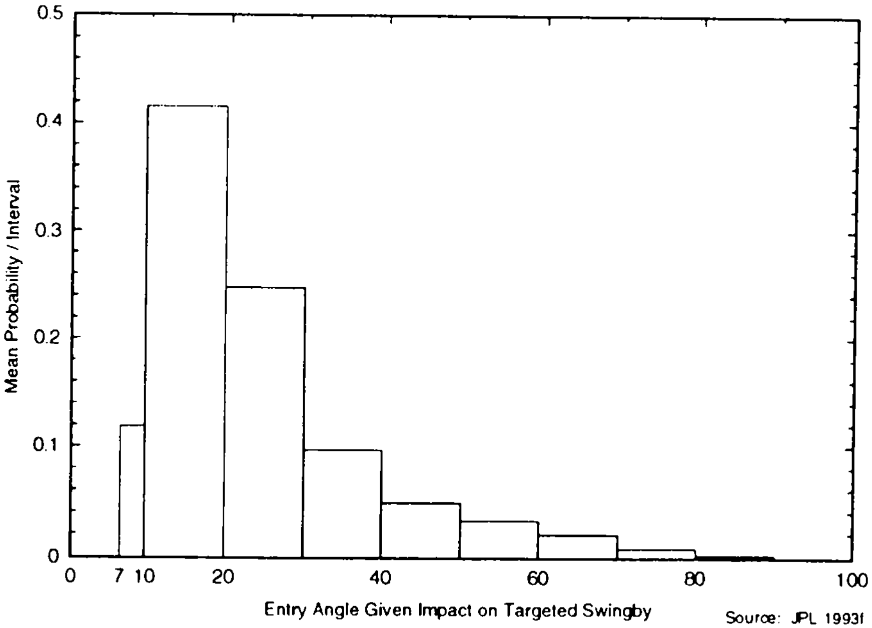
Source: JPL 1993f

FIGURE B-2. PRIMARY: CONDITIONAL PROBABILITY VERSUS ENTRY ANGLE



Source: JPL 1993f

FIGURE B-3. BACKUP - E1: CONDITIONAL PROBABILITY VERSUS ENTRY ANGLE



Source: JPL 1993f

FIGURE B-4. BACKUP - E2: CONDITIONAL PROBABILITY VERSUS ENTRY ANGLE

In addition, JPL calculated the latitudes at which Earth impact would probably occur. The VVEJGA trajectory would most likely result in reentry between the equator and about 30 degrees south latitude (see Figure B-5); the first Earth swingby (see Figure B-6) of the VEEGA trajectory would probably have the greatest spread in reentry/altitude with most reentries ranging from 36 degrees north latitude to about 17 degrees south latitude. The second Earth swingby of the VEEGA would probably reenter between roughly 23 degrees north latitude and 5 degrees south latitude (see Figure B-7).

B.1.4 Long-Term Impact Probability

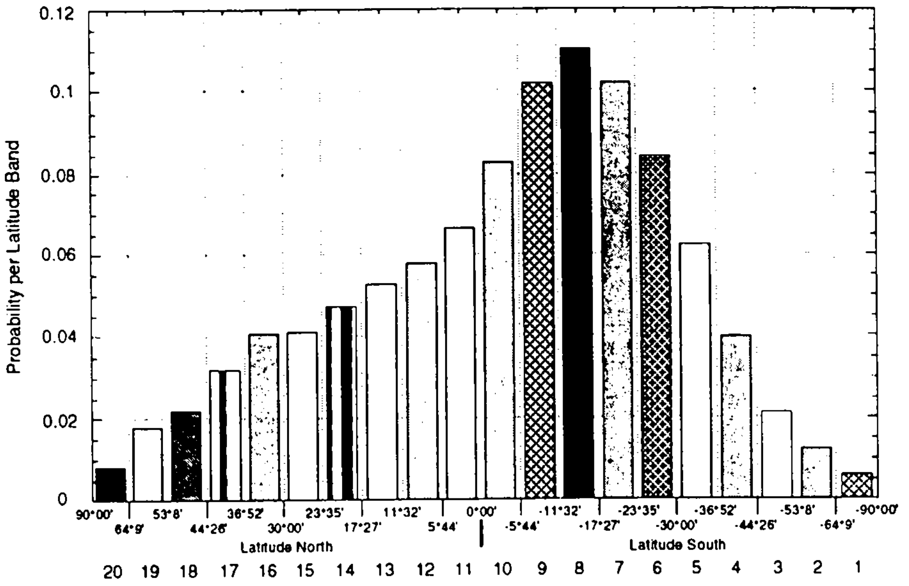
The short-term impact analysis indicates that the probability of Earth impact during a targeted Earth swingby is extremely small. However, if control of the spacecraft is lost before SOI and the spacecraft does not impact the Earth during a targeted swingby, there would still be a remote possibility that long-term perturbations to the orbit could cause the spacecraft to eventually reencounter the Earth. JPL's long-term analysis computed the probability of Earth impact through a non-targeted (i.e., unplanned) Earth swingby from the time of spacecraft failure to 100 years beyond the planned SOI date.

To compute the long-term probability of Earth impact, a knowledge of the spacecraft failure probabilities and associated anomalous spacecraft velocity changes, the uncertainties in the navigation process, and the long-term motion of the spacecraft is required. The long-term analysis only evaluated failures causing a loss of spacecraft control with no chance of recovery. Figure B-8 illustrates the logic diagram for this analysis with the dominant scenarios contributing to the long-term Earth impact are in bold.

Because a large number of spacecraft trajectories could result given a failure during interplanetary cruise, a Monte Carlo analysis was performed using thousands of trajectories and a wide range of failure times and associated anomalous velocity changes. Each case included an initial spacecraft orbital state that was then perturbed by navigation uncertainty and any associated velocity changes. Each state was then propagated for 100 years for use in the analysis.

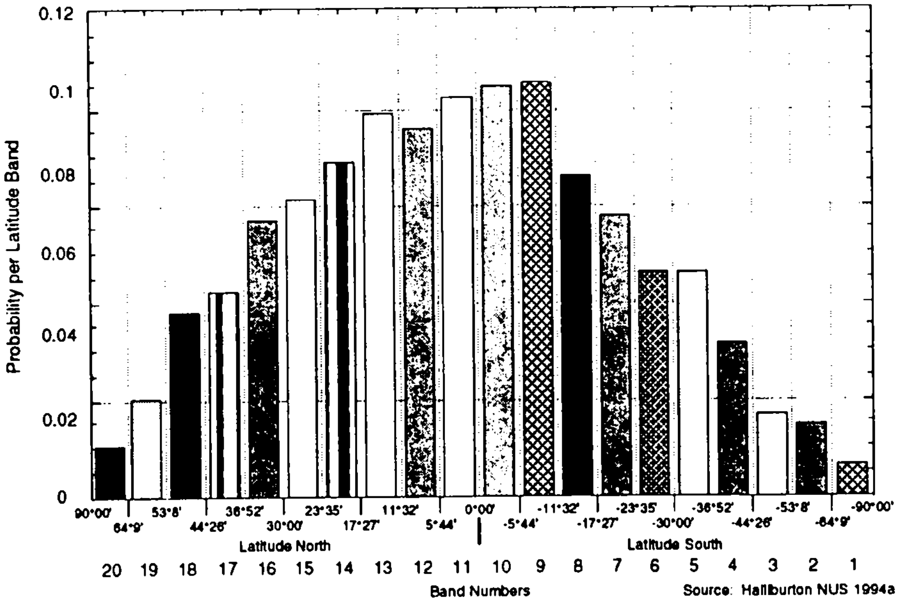
To determine the probability of Earth impact given a failure, a large body of work refined over the past 40 years was used to estimate the probability of impact by Earth-crossing asteroids. Existing theory applicable to lifetime analysis of asteroids and comets was modified to apply to this spacecraft impact analysis. In this method, the number of passages of the spacecraft through the Earth torus (the region of space swept out by the Earth as it orbits the Sun) are used to compute the probability of Earth impact. For an impact to occur, the spacecraft would have to cross through the Earth torus and, at the time of the crossing, the Earth would have to be at a position within the torus to cause impact (JPL 1993f).

The number of torus crossings for all Monte Carlo cases were computed by propagating the initial conditions for each case using a high-precision numerical integration program and then counting each passage through the Earth torus. For a given torus crossing, the Earth-crossing asteroid theory was used to analytically compute the



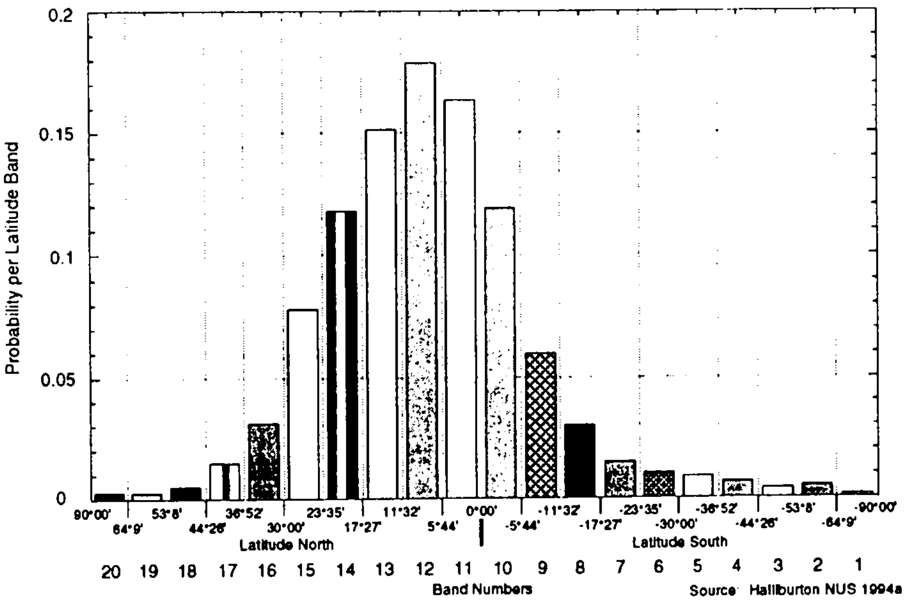
Source: Halliburton NUS 1994a

FIGURE B-5. PRIMARY: ENTRY LATITUDE CONDITIONAL PROBABILITY DISTRIBUTION



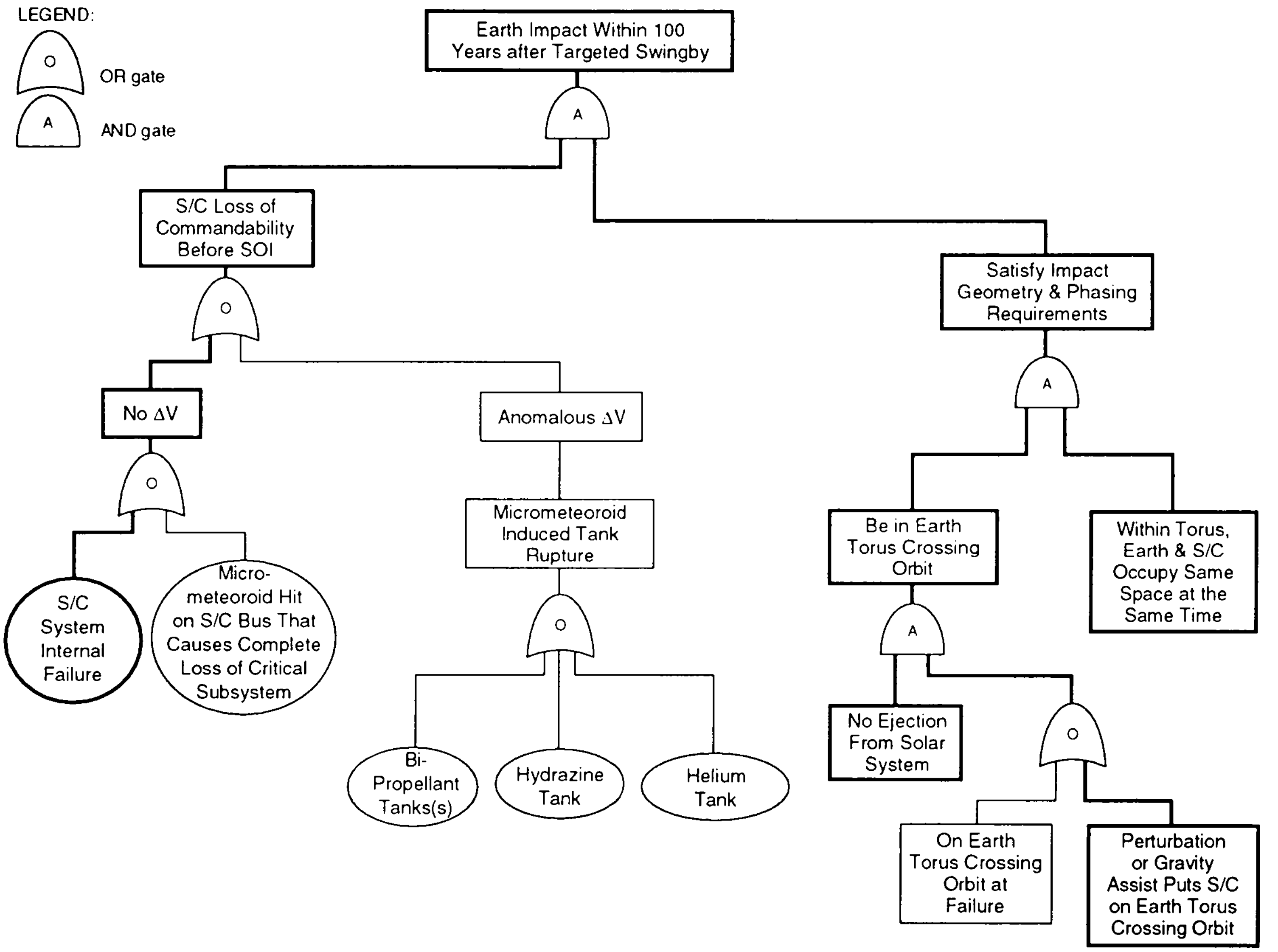
Source: Halliburton NUS 1994a

FIGURE B-6. BACKUP - E1: ENTRY LATITUDE CONDITIONAL PROBABILITY DISTRIBUTION



Source: Halliburton NUS 1994a

FIGURE B-7. BACKUP - E2: ENTRY LATITUDE CONDITIONAL PROBABILITY DISTRIBUTION



Source: JPL 1993f

FIGURE B-8. LONG-TERM EARTH IMPACT PROBABILITY LOGIC DIAGRAM probability of the Earth being in the position required for Earth impact. An uncertainty analysis was performed to yield probability distributions for both the number of torus crossings per case and the probability of Earth impact given a torus crossing. These distributions were combined with the spacecraft failure distribution to yield a PDF for the long-term Earth impact probability.

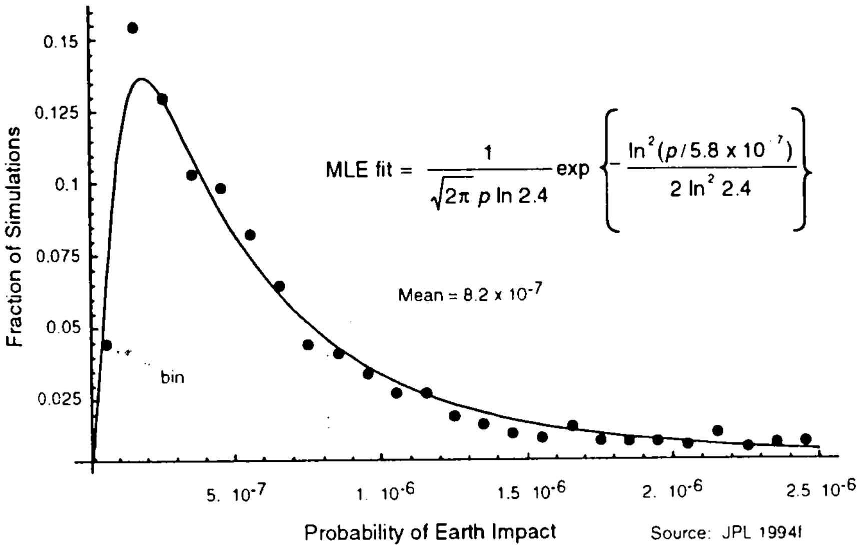
The mean long-term Earth impact probability for 100 years was estimated at 6.0×10^{-8} for the primary launch opportunity and 4.0×10^{-7} for the backup launch opportunity. The impact probability is larger for the backup opportunity because of the longer cruise duration and the different interplanetary trajectory characteristics. It is reasonable to assume that the probability associated with the secondary launch opportunity would be similar to or less than that for the backup opportunity. An important result of the analysis is that for failures occurring during the latter half of the interplanetary cruise for all launch opportunities, in nearly all cases, the spacecraft would be quickly ejected from the solar system by a strong Saturn gravity assist, thereby precluding any possibility of Earth impact.

As a point of interest, a subset (approximately 20 percent) of all the Monte Carlo cases was also propagated for 1,000 years to study the very long-term probability of Earth impact. The same methodology used for the 100-year case was used for these 1,000-year cases. The mean probability of Earth impact over 1,000 years was about 2.5 times higher for the primary opportunity and about 1.5 times higher for the backup opportunity than that for a 100-year period (JPL 1993f).

B.1.5 Total Impact Probability

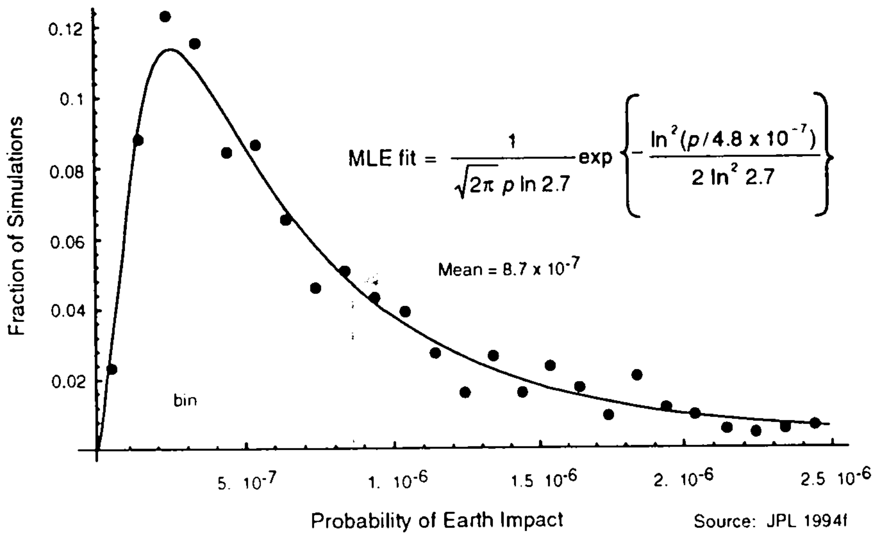
As mentioned previously, the expected probability of Earth impact for the Cassini mission must be less than or equal to one in a million (10^{-6}). A number of parameters can be used to describe the characteristics and interpretation of a PDF (or of a complementary cumulative probability curve). The expected value of a random variable is expressed by the mean of the probability distribution. Thus, this Project requirement is fulfilled when the mean of the assessed probability distribution is less than or equal to 10^{-6}.

The total Earth impact probability distribution is the probabilistic sum of the short- and long-term Earth impact probability distributions. A 1,000-trial Monte Carlo simulation was used to perform this probabilistic summation. Figure B-9 presents the PDF and complementary cumulative probabilities for the primary and backup trajectories. The mean values of these distributions are 8.2×10^{-7} for the primary trajectory and 8.7×10^{-7} for the backup trajectory. It is reasonable to assume that the value for the secondary launch opportunity would be similar to or less than that for the backup opportunity. Because the mean of both distributions is less than 10^{-6}, the Project Earth swingby requirement is satisfied for all launch opportunities. (Figure B-9 also indicates values below which 90 percent of the possible Earth impact probabilities lie.) During the ongoing process of monitoring the inputs and assumptions used in estimating the probability of accidental Earth impact, small variations are anticipated in the exact PDF parameters. However, the Cassini project would always take those actions necessary to ensure that the expected impact probability mean is held below the 1.0×10^{-6} overriding constraint.



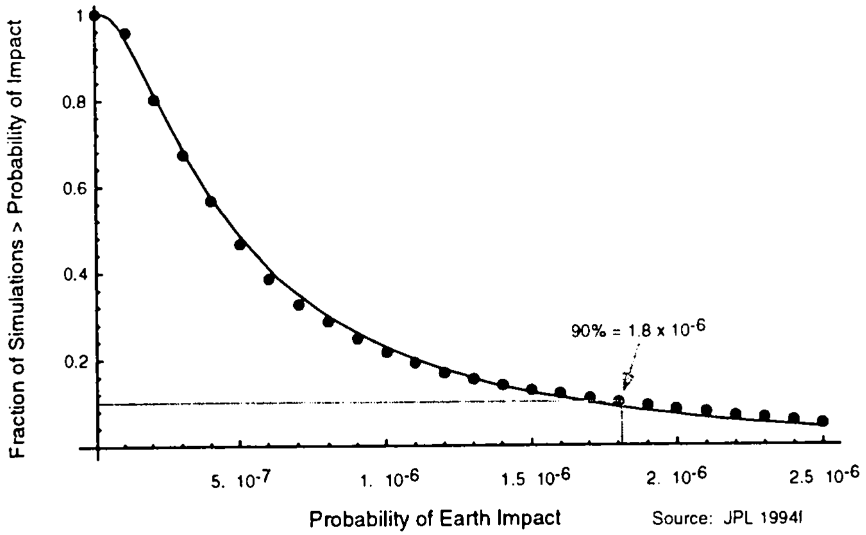
Source: JPL 1994f

Probability Density Function for the Primary Launch Opportunity



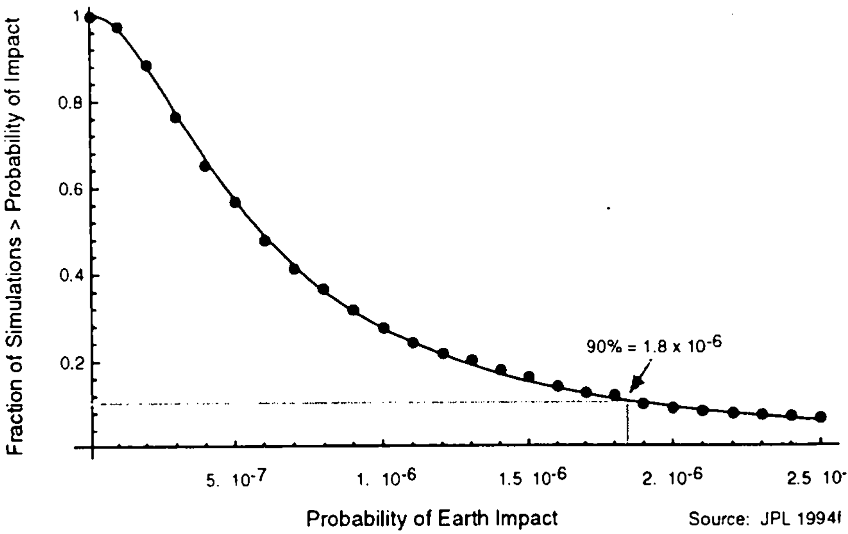
Source: JPL 1994f

Probability Density Function for the Backup Launch Opportunity



Source: JPL 1994f

Complementary Cumulative Probability for the Primary Launch Opportunity



Source: JPL 1994f

Complementary Cumulative Probability for the Backup Launch Opportunity

FIGURE B-9. TOTAL EARTH IMPACT PROABILITY

B.2 EARTH GRAVITY-ASSIST CONSIDERATIONS IN DETERMINING SOURCE TERMS

This section of the appendix presents the methodology used in estimating the source terms for a conditional short-term inadvertent reentry during the VVEJGA and VEEGA trajectories prior to an Earth swingby(s).

For VEEGA short-term inadvertent reentries, reentry velocities would be approximately 16.5 km/s (54,000 ft/s) for the E1 and 17.3 km/s (56,800 ft/s) for the E2 compared to the VVEJGA reentry velocity of 19.1 km/s (62,700 ft/s). For purposes of this EIS, the module reentry response for the VEEGA inadvertent reentries has been conservatively assumed to be the same as for the more severe VVEJGA inadvertent reentry. Source terms for the VEEGA inadvertent reentries have been developed using the same approach or methodology use for the VVEJGA source terms (Halliburton NUS 1994a).

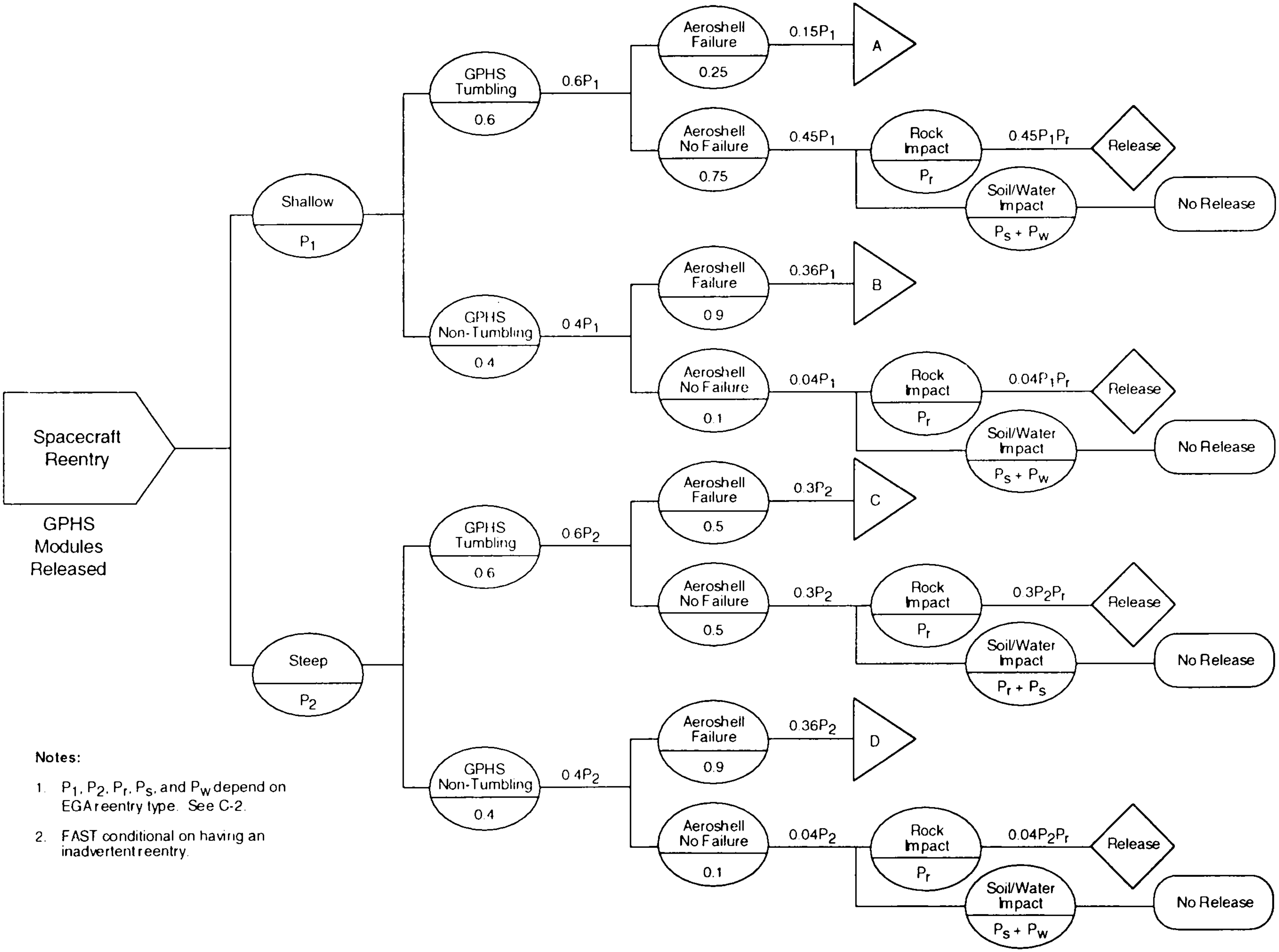
Radiological consequences (i.e., source term) for the long-term inadvertent reentry cannot be estimated because of several uncertainties. These uncertainties involve the timing of the reentry which affects the inventory of radioactive materials onboard, the reentry-angle, -velocity, and -latitude, and the world population/density at the time of reentry. In addition, there is uncertainty as to the RTG response to reentry conditions and therefore the resulting fuel end states. Therefore, in the following discussions, an inadvertent reentry applies only to the short-term reentry possibility.

Section B.2.1 presents the methodology for determining the General Purpose Heat Source (GPHS) module reentry response. Section B.2.2 summarizes the source term calculation methods, while Section B.2.3 provides the results of the radiological consequences based on the fuel end states.

B.2.1 Methodology for GPHS Module Reentry Response

As presented in Section 4.1.5.4, a range of fuel end states were postulated to occur as a result of the reentry of the GPHS modules: intact undamaged modules, intact GPHS modules with damaged but intact graphite impact shells (GISs), intact GISs, and particulate and vaporized fuel. U.S. Department of Energy (DOE) staff and contractors with expertise in RTG-reentry and -safety developed probability estimates of the range of these potential fuel end states using Failure Abort Sequence Trees (FASTs) based on available analyses (Martin Marietta Astro Space 1994a). The resulting FASTs are presented in Figure B-10, and are conditional upon having an inadvertent reentry for the VVEJGA or VEEGA. For sequences resulting in a release of plutonium dioxide fuel (i.e., a source term), the final event of release is shown in the form of a diamond. Conditional probabilities for each oval are noted. Important features of the FASTs and their technical bases are as follows:

- Tumbling (as opposed to non-tumbling) of the GPHS module involves full rotation or large oscillations about an axis. Non-tumbling involves the flight orientation in which a side or face of the GPHS module remains more constant even though there may be a slight wobble or flat spin. The branching probabilities for tumbling (0.6) and non-tumbling (0.4) GPHS module are based

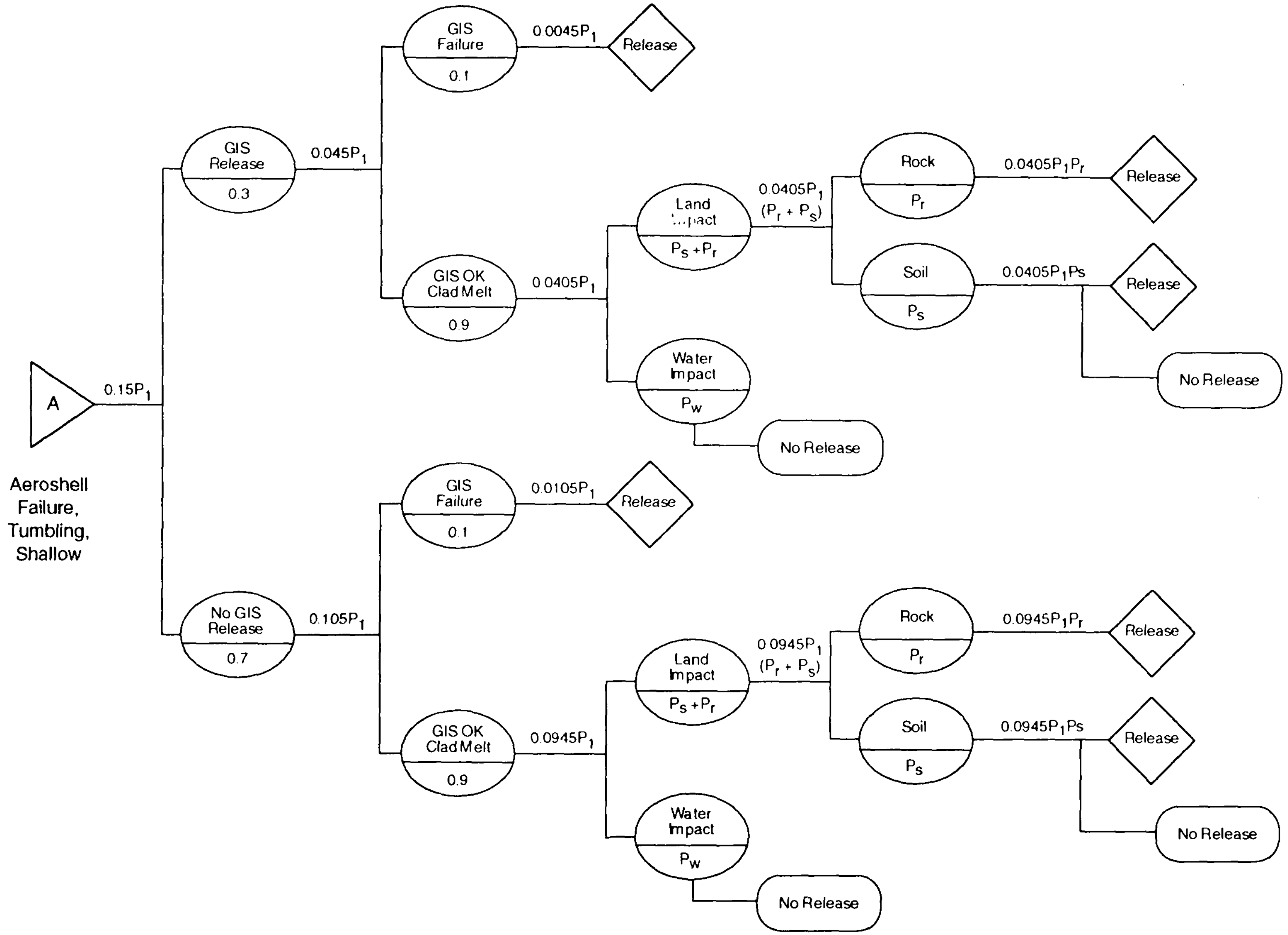


Notes:

1. P_1, P_2, P_r, P_s, and P_w depend on EGA reentry type. See C-2.
2. FAST conditional on having an inadvertent reentry.

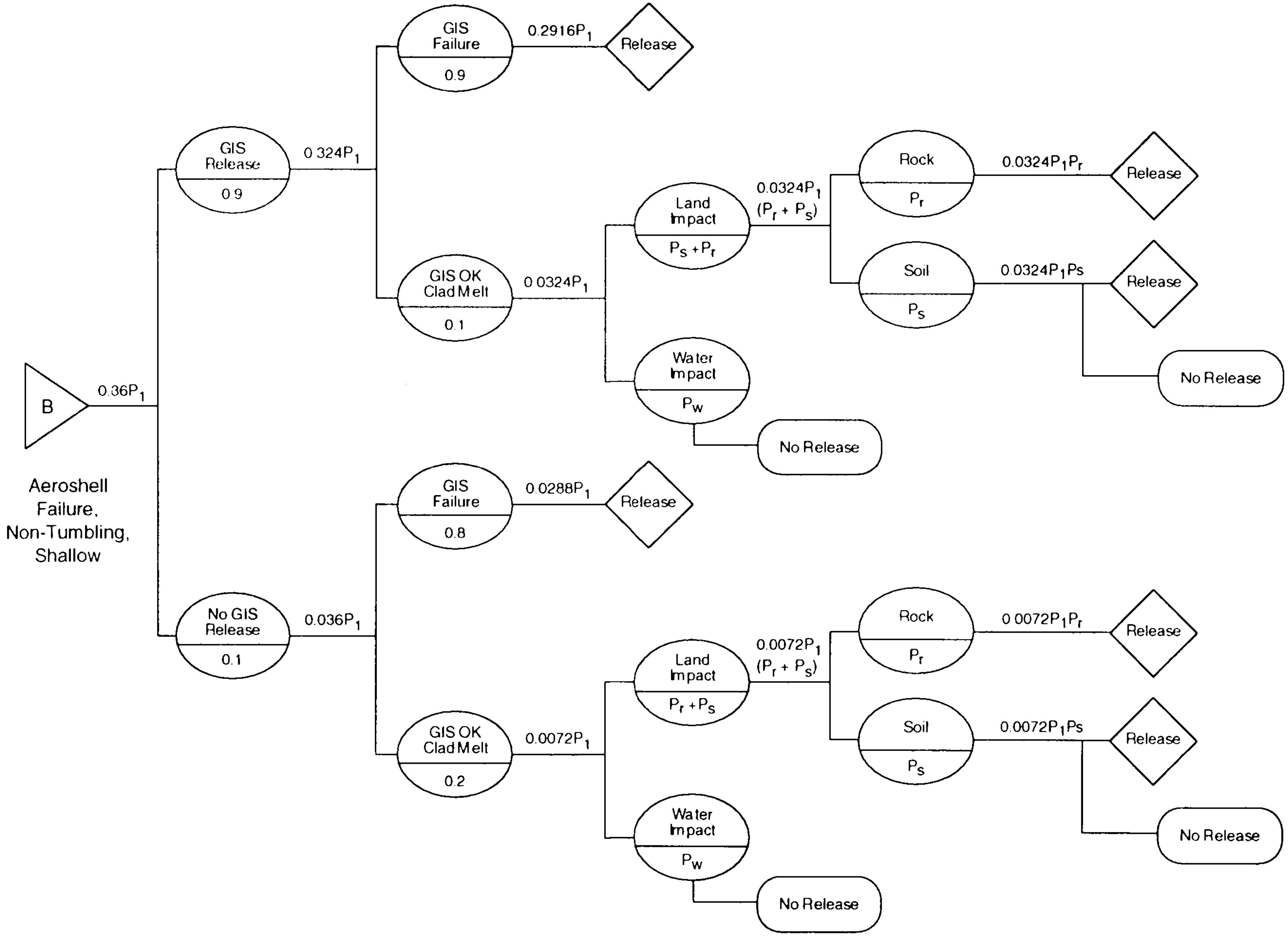
Source: Martin Marietta Astro Space 1994a

FIGURE B-10. FAILURE/ABORT SEQUENCE TREES FOR VVEJGA INADVERTENT REENTRY (Page 1 of 5)



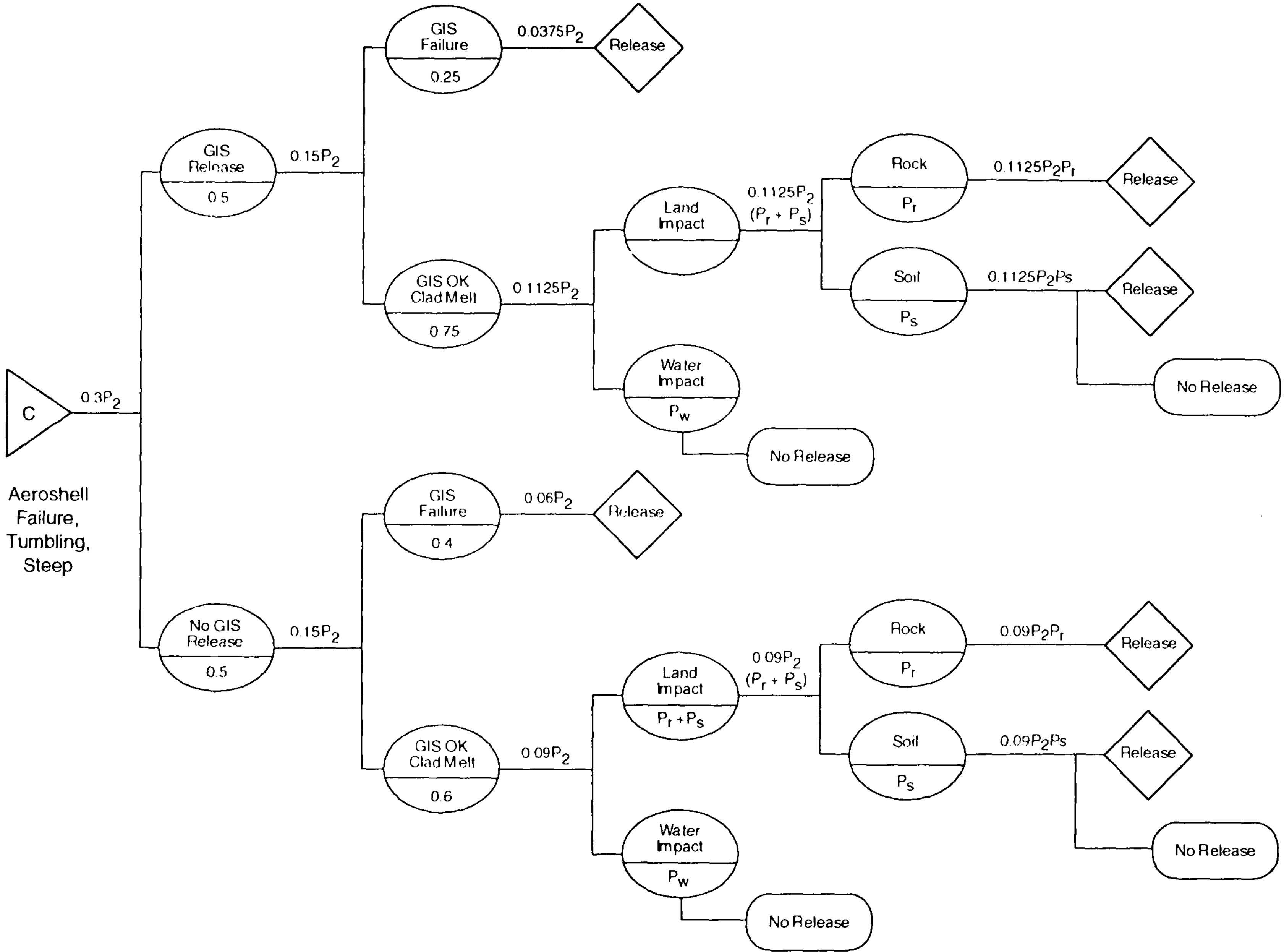
Source: Martin Marietta Astro Space 1994a

FIGURE B-10. FAILURE/ABORT SEQUENCE TREES FOR VVEJGA INADVERTENT REENTRY (Page 2 of 5)



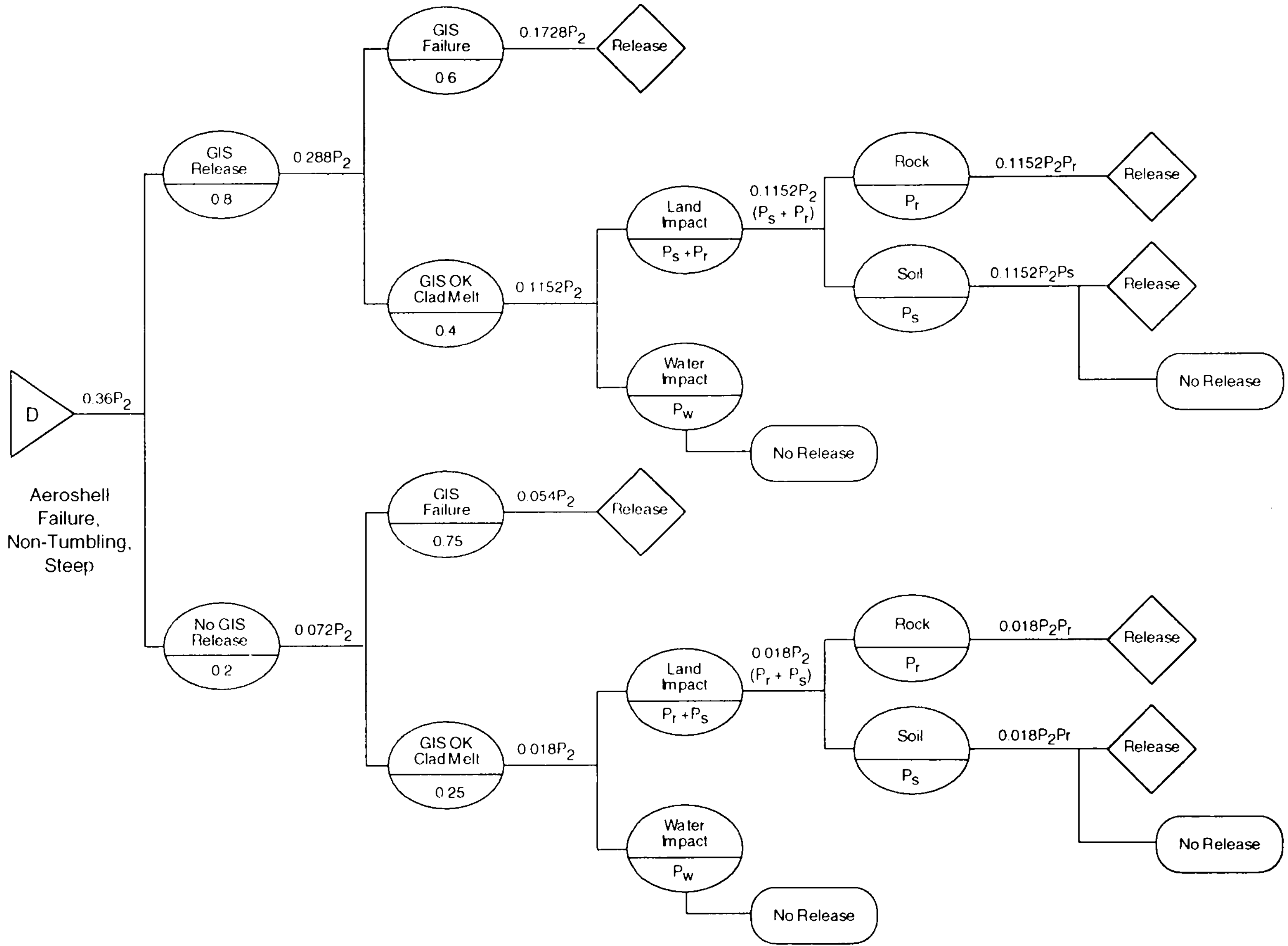
Source: Martin Marietta Astro Space 1994a

FIGURE B-10. FAILURE/ABORT SEQUENCE TREES FOR VVEJGA INADVERTENT REENTRY (Page 3 of 5)



Source: Martin Marietta Astro Space 1994a

FIGURE B-10. FAILURE/ABORT SEQUENCE TREES FOR VVEJGA INADVERTENT REENTRY (Page 4 of 5)



Source: Martin Marietta Astro Space 1994a

FIGURE B-10. FAILURE/ABORT SEQUENCE TREES FOR VVEJGA INADVERTENT REENTRY (Page 5 of 5)

on 6 degree-of-freedom (6 DOF) motion studies done for the Galileo VEEGA inadvertent reentry conditions (Halliburton NUS 1994a). A preliminary 6 DOF analyses for the VVEJGA reentry has confirmed the validity of the Galileo results. For the reentry response, the non-tumbling cases have been analyzed as module broadface stable motion. This is considered a conservative approach in that any motion other than the broadface stable would result in lower reentry heating fluxes.

- The potential for ablation of the graphitic components (modules and GISs) due to the reentry heating environment has been the focus of the VVEJGA inadvertent reentry analyses performed to date. The response of intact GISs to VVEJGA reentry conditions has been evaluated in a JPL-sponsored study undertaken by NASA-Ames Research Center and Foils Engineering (Foils Engineering 1993). The results indicated that for ablation due to reentry heating only, GIS burn-through is predicted at reentry angles less than 15 degrees for stable (non-tumbling and non-spinning) GIS configuration. No burn-through was predicted for the spinning GIS configuration, considered in the JPL-sponsored study to have a much higher probability than the stable GIS configuration. However, the probabilities assigned to branching fractions associated with module and GIS failure are higher than that predicted due to reentry heating only, in order to account for structural failures induced by thermal and mechanical stresses under the severe force- and thermal-gradients that would be experienced during the deceleration process to terminal velocity. These types of failures would tend to be more probable under steep-reentry angle conditions. The associated probability trends have been reflected in the FASTs. Based on the best available information (i.e., ablation due to reentry heating only), the increased probability associated with structural failure can be considered to be conservative with respect to consideration of thermal heating only. Structural analyses will be performed as part of the Final Safety Analysis Report (FSAR)-related work.

- The conditional probabilities for a VVEJGA shallow-angle reentry (P_1), and steep-angle reentry (P_2), depend on the Earth-Gravity-Assist entry-angle probability distribution given in Table B-2.

- The conditional probabilities of impacting rock (P_r), soil (P_s), and water (P_w) also presented in Table B-2 depend on the reentry latitude probability distribution show in Figure B-4.

Table B-3 summarizes the inadvertent reentry fuel end state conditional probabilities. The four fuel end states are correlated to the appropriate branching FAST in Figure B-10.

B.2.2 Source Term Calculation

The source term calculations treat the modules independently except with respect to steep and shallow reentry (i.e., all reenter at steep angles or all reenter at shallow

TABLE B-2. SURFACE IMPACT PROBABILITIES FOR SHORT-TERM INADVERTENT REENTRIES

Mission	Reentry Type	Conditional Probabilities					Population Density,[b] persons/km^2 (persons/mi^2)
		Reentry	Water (P_w)	Land	Rock (P_r)	Soil (P_s)	
Primary[a]	Shallow, P_1	0.25	0.749	0.251	0.040	0.211	36.5 (95)
	Steep, P_2	0.75	0.749	0.251	0.040	0.211	36.5 (95)
Backup E1[c]	Shallow, P_1	0.11	0.727	0.273	0.0476	0.225	44.7 (115.8)
	Steep, P_2	0.89	0.727	0.273	0.0476	0.225	44.7 (115.8)
Backup E2[d]	Shallow, P_1	0.54	0.735	0.265	0.0244	0.241	55.6 (144.0)
	Steep, P_2	0.46	0.735	0.265	0.0244	0.241	55.6 (144.0)

Source: Halliburton NUS 1994a

a. Conditional VVEJGA short-term inadvertent reentry probability: 7.6×10^{-7}.
b. Population density given land impact based on 1990 population data (Halliburton NUS 1992).
c. Backup E1 conditional short-term inadvertent reentry probability: 1.9×10^{-7}.
d. Backup E2 conditional short-term inadvertent reentry probability: 2.8×10^{-7}.

TABLE B-3. SUMMARY OF EGA INADVERTENT REENTRY FUEL END STATE CONDITIONAL PROBABILITIES

Fuel End State	FAST Branches Contributing	Shallow		Steep	
		FAST	Probability	FAST	Probability
Intact Modules (Undamaged)	GPHS Tumbling/No Aeroshell Failure	S/C Reentry	0.45	S/C Reentry	0.30
	Non-Tumbling/No Aeroshell Failure	S/C Reentry	0.04	S/C Reentry	0.04
		Subtotal	0.49	Subtotal	0.34
Intact Modules (Damaged/GISs Intact)	GPHS Tumbling/Aeroshell Failure	A			
	No GIS Release/GIS OK, Clad Melt		0.0945	C	0.090
	GPHS Non-Tumbling/Aeroshell Failure	B			
	No GIS Release/GIS OK, Clad Melt		0.0072	D	0.018
		Subtotal	0.1017	Subtotal	0.108
Intact GISs	GPHS Tumbling/Aeroshell Failure	A		C	0.1125
	GIS Release/GIS OK, Clad Melt		0.0405		
	GPHS Non-Tumbling/Aeroshell Failure	B		D	0.1125
	GIS Release/GIS OK, Clad Melt		0.0324		
		Subtotal	0.0729	Subtotal	0.2277
Bare Fuel	GPHS Tumbling/Aeroshell Failure	A			
	GIS Release/GIS Failure	A	0.0045	C	0.0375
	No GIS Release/GIS Failure		0.0105	C	0.0600
	GPHS Non-Tumbling/Aeroshell Failure	B			
	GIS Release/GIS Failure	B	0.2916	D	0.1728
	No GIS Release/GIS Failure		0.0288	D	0.0540
		Subtotal	0.3354	Subtotal	0.3243
		Total	1.0000	Total	1.0000

Source: Halliburton NUS 1994a

a. Shallow angle reentry conditional probability: P_1.
b. Steep angle reentry conditional probability: P_2.

angles). The expectation source term for each fuel end state is then determined as a probability-weighted average over all 54 modules.

Table B-4 presents an outline for source term calculation based on four fuel end states and the Earth surface impact conditional probabilities for both VVEJGA and VEEGA inadvertent reentries.

B.2.3. Results of the Radiological Consequences Based on the Fuel End States

Given the inadvertent reentry type (i.e., shallow or steep), the reentry latitude, and surface impact probabilities, radiological consequences were estimated for the fuel end states. Tables B-5, B-6, and B-7 summarize the results of the specific source term contributor (i.e., fuel end state) and the resulting radiological consequences for the VVEJGA and VEEGA inadvertent reentries.

TABLE B-4. EGA INADVERTENT REENTRY SOURCE TERM CALCULATION OUTLINE

Fuel-End State	Shallow		Steep	
	Number of Components	Source Term, Ci[a]	Number of Components	Source Term, Ci[a]
Intact Module	$N_m = (0.49)(54) = 26.5$		$N_m = (0.34)(54) = 18.4$	
Rock Impact	N_mP_r	$0.25Q_mN_mP_r$	N_mP_r	$0.25Q_mN_mP_r$
Soil Impact	N_mP_s	—	N_mP_s	—
Water Impact	N_mP_w	—	N_mP_w	—
Intact Module (Damaged/ GIS Intact)	$N_{dm} = (0.1017)(54) = 5.5$		$N_{dm} = (0.108)(54) = 5.8$	
Rock Impact	$N_{dm}P_r$	$Q_mN_{dm}P_r$	$N_{dm}P_r$	$Q_mN_{dm}P_r$
Soil Impact	$N_{dm}P_s$	$0.25Q_mN_{dm}P_s$	$N_{dm}P_s$	$0.25Q_mN_{dm}P_s$
Water Impact	$N_{dm}P_w$	—	N_mP_w	—
Intact GISs	$N_g = (0.0729)(108) = 7.9$		$N_g = (0.2277)(108) = 24.6$	
Rock Impact	N_gP_r	$Q_gN_gP_r$	N_gP_r	$Q_gN_gP_r$
Soil Impact	N_gP_s	$0.25Q_gN_gP_s$	N_gP_s	$0.25Q_gN_gP_s$
Water Impact	N_gP_w	—	N_gP_w	—
Fuel[b]	$F_f = 0.335$	Q_fF_f	$F_f = 0.324$	Q_fF_f

Source: Halliburton NUS 1994a

a. Q_m = (132,920 Ci/RTG)/(18 modules/RTG) = 7,384 Ci/module.
Q_g = (132,920 Ci/RTG)/(36 GISs/RTG) = 3,692 Ci/GIS.
b. F_f = Fraction of total fuel inventory.

TABLE B-5. RADIOLOGICAL CONSEQUENCES FOR VVEJGA INADVERTENT REENTRY (Shallow and Steep Case)

Reentry Type	Source Term Contributor	Collective Dose, person-Sv (person-rem)[a]		Health Effects[b]		Maximum Individual Dose, Sv (rem)	Land Area, km^2 (mi^2) Above 7.4×10^3 Bq/m^2 (0.2 $\mu Ci/m^2$)
		w/o De Minimis	w De Minimis	w/o De Minimis	w De Minimis		
Shallow Reentry	Intact Components[c]	1.17×10^1 (1.17×10^3)	6.74×10^0 (6.74×10^2)	4.10×10^{-1}	2.36×10^{-1}	2.14×10^{-1} (2.14×10^1)	1.02×10^1 (3.94×10^0)
	Mostly Vapor[d]	9.89×10^4 (9.89×10^6)	– –	3.46×10^3	–	3.51×10^{-5} (3.51×10^{-3})	– –
	Mostly Particulate[e]	3.49×10^2 (3.49×10^4)	2.01×10^2 (2.01×10^4)	1.22×10^1	7.04×10^0	2.78×10^{-3} (2.78×10^{-1})	5.33×10^3 (2.06×10^3)
	Total	9.93×10^4 (9.93×10^6)	2.08×10^2 (2.08×10^4)	3.48×10^3	7.28×10^0	2.14×10^{-1} (2.14×10^1)	5.34×10^3 (2.06×10^3)
Steep Reentry	Intact Components	1.87×10^1 (1.87×10^3)	1.08×10^1 (1.08×10^3)	6.54×10^{-1}	3.78×10^{-1}	3.37×10^{-1} (3.37×10^1)	1.63×10^1 (6.29×10^0)
	Mostly Vapor	5.41×10^4 (5.41×10^6)	– –	1.89×10^3	–	1.92×10^{-5} (1.92×10^{-3})	–
	Mostly Particulate	5.09×10^2 (5.09×10^4)	2.93×10^2 (2.93×10^4)	1.78×10^1	1.03×10^1	2.31×10^{-3} (2.31×10^{-1})	1.58×10^3 (6.10×10^2)
	Total	5.46×10^4 (5.46×10^6)	3.04×10^2 (3.04×10^4)	1.91×10^3	1.06×10^1	3.37×10^{-1} (3.37×10^1)	1.60×10^3 (6.18×10^2)

Source: Halliburton NUS 1994a

a. The de minimis dose level for the purpose of this report is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year.
b. Excess latent cancer fatalities.
c. Includes intact modules (damaged and undamaged) and GISs impacting rock and soil.
d. Fuel released at high altitude in particle sizes less than or equal to 10 microns in physical diameter.
e. Fuel released at high altitude in particle sizes greater than 10 microns in physical diameter.

TABLE B-6. RADIOLOGICAL CONSEQUENCES FOR BACKUP E1 INADVERTENT REENTRY
(Shallow and Steep Case)

Reentry Type	Source Term Contributor	Collective Dose, person-SV (person-rem)[a]		Health Effects[b]		Maximum Individual Dose, Sv (rem)	Land Area, km^2 (mi^2) Above 7.4×10^3 Bq/m^2 ($0.2\ \mu Ci/m^2$)
		w/o De Minimis	w De Minimis	w/o De Minimis	w De Minimis		
Shallow Reentry	Intact Components[c]	1.70×10^1 (1.70×10^3)	9.79×10^0 (9.79×10^2)	5.95×10^{-1}	3.43×10^{-1}	2.61×10^{-1} (2.61×10^1)	1.16×10^1 (4.48×10^0)
	Mostly Vapor[d]	1.24×10^5 (1.24×10^7)	– –	4.34×10^3	–	3.41×10^{-5} (3.41×10^{-3})	– –
	Mostly Particulate[e]	4.90×10^2 (4.90×10^4)	2.82×10^2 (2.82×10^4)	1.72×10^1	9.87×10^0	3.01×10^{-3} (3.01×10^{-1})	5.70×10^3 (2.20×10^3)
	Total	1.25×10^5 (1.25×10^7)	2.92×10^2 (2.92×10^4)	4.38×10^3	1.02×10^1	2.61×10^{-1} (2.61×10^1)	5.71×10^3 (2.20×10^3)
Steep Reentry	Intact Components	2.71×10^1 (2.71×10^3)	1.56×10^1 (1.56×10^3)	9.49×10^{-1}	5.46×10^{-1}	5.03×10^{-1} (5.03×10^1)	1.85×10^1 (7.14×10^0)
	Mostly Vapor	6.32×10^4 (6.32×10^6)	– –	2.21×10^3	–	1.74×10^{-5} (1.74×10^{-3})	– –
	Mostly Particulate	7.27×10^2 (7.27×10^4)	4.18×10^2 (4.18×10^4)	2.54×10^1	1.46×10^1	2.89×10^{-3} (2.89×10^{-1})	1.52×10^3 (5.87×10^2)
	Total	6.40×10^4 (6.40×10^6)	4.34×10^2 (4.34×10^4)	2.24×10^3	1.52×10^1	5.03×10^{-1} (5.03×10^1)	1.54×10^3 (5.95×10^2)

Source: Halliburton NUS 1994a

a. The de minimis dose level for the purpose of this report is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year.
b. Incremental latent cancer fatalities.
c. Includes intact modules (damaged and undamaged) and GISs impacting rock and soil.
d. Fuel released at high altitude in particle sizes less than or equal to 10 microns in physical diameter.
e. Fuel released at high altitude in particle sizes greater than 10 microns in physical diameter.

TABLE B-7. RADIOLOGICAL CONSEQUENCES FOR BACKUP E2 INADVERTENT REENTRY
(Shallow and Steep Case)

Reentry Type	Source Term Contributor	Collective Dose, person-SV (person-rem)[a]		Health Effects[b]		Maximum Individual Dose, Sv (rem)	Land Area, km^2 (mi^2) Above 7.4×10^3 Bq/m^2 ($0.2\ \mu Ci/m^2$)
		w/o De Minimis	w De Minimis	w/o De Minimis	w De Minimis		
Shallow Reentry	Intact Components[c]	1.61×10^{1} (1.61×10^{3})	9.27×10^{0} (9.27×10^{2})	5.64×10^{-1}	3.24×10^{-1}	3.25×10^{-1} (3.25×10^{1})	8.34×10^{0} (3.22×10^{0})
	Mostly Vapor[d]	1.52×10^{5} (1.52×10^{7})	– –	5.32×10^{3}	–	4.16×10^{-5} (4.16×10^{-3})	– –
	Mostly Particulate[e]	6.16×10^{2} (6.16×10^{4})	3.55×10^{2} (3.55×10^{4})	2.16×10^{1}	1.24×10^{1}	2.97×10^{-3} (2.97×10^{-1})	5.72×10^{3} (2.20×10^{3})
	Total	1.53×10^{5} (1.53×10^{7})	3.64×10^{2} (3.64×10^{4})	5.36×10^{3}	1.27×10^{1}	3.25×10^{-1} (3.25×10^{1})	5.73×10^{3} (2.21×10^{3})
Steep Reentry	Intact Components	2.78×10^{1} (2.78×10^{3})	1.60×10^{1} (1.60×10^{3})	9.73×10^{-1}	5.60×10^{-1}	3.90×10^{-1} (3.90×10^{1})	1.44×10^{1} (5.56×10^{0})
	Mostly Vapor	1.02×10^{5} (1.02×10^{7})	– –	3.57×10^{3}	–	2.81×10^{-5} (2.81×10^{-3})	– –
	Mostly Particulate	8.11×10^{2} (8.11×10^{4})	4.67×10^{2} (4.67×10^{4})	2.84×10^{1}	1.63×10^{1}	1.52×10^{-2} (1.52×10^{0})	2.25×10^{3} (8.69×10^{2})
	Total	1.03×10^{5} (1.03×10^{7})	4.83×10^{2} (4.83×10^{4})	3.60×10^{3}	1.69×10^{1}	3.90×10^{-1} (3.90×10^{1})	2.26×10^{3} (8.73×10^{2})

Source: Halliburton NUS 1994a

a. The de minimis dose level for the purpose of this report is 1.0×10^{-5} Sv (1.0×10^{-3} rem) per year.
b. Incremental latent cancer fatalities.
c. Includes intact modules (damaged and undamaged) and GISs impacting rock and soil.
d. Fuel released at high altitude in particle sizes less than or equal to 10 microns in physical diameter.
e. Fuel released at high altitude in particle sizes greater than 10 microns in physical diameter.

APPENDIX C

ENVIRONMENTAL EFFECTS OF PLUTONIUM DIOXIDE

APPENDIX C

ENVIRONMENTAL EFFECTS OF PLUTONIUM DIOXIDE

This appendix addresses the potential impacts from plutonium dioxide (PuO_2) released to the environment, which could occur in any of the representative, low-probability accident scenarios described in Section 4. The health and environmental risks associated with plutonium (mainly Pu-238) dioxide were previously addressed in the Galileo and Ulysses EISs (NASA 1989b, NASA 1990). This appendix briefly describes the general physical and chemical characteristics, transport, and biological effects of plutonium dioxide.

C.1 PHYSICAL AND CHEMICAL CHARACTERISTICS OF PLUTONIUM DIOXIDE

Plutonium is one of the most widely studied elements in terms of chemistry and environmental behavior. Although its chemistry and oxidation states are quite diverse, the element's environmental mobility is very limited (INSRP 1989a).

The extent and magnitude of potential environmental impacts caused by PuO_2 releases depend on the mobility and availability of PuO_2 in the environment. The mobility and availability of PuO_2, in turn, are directly controlled by a number of physical and chemical parameters, including particle size, potential for suspension, deposition and resuspension, solubility, and oxidation state of any dissolved plutonium. These factors, in conjunction with the three potential exposure pathways (i.e., direct external exposure from ground-deposited material, ingestion, and inhalation), determine the potential impacts. Of the three pathways, only the potential for direct exposure from ground-deposited material or surface contact is not significant, because alpha radiation cannot pass through more than a few inches of air.

The size of plutonium dioxide particles can affect the rate of dissolution in water and the initial deposition and subsequent resuspension of particles in both air and water. The dissolution and the suspension and 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 the particle size decreases, particles are more easily kept in suspension or resuspension.

A number of factors can affect the solubility of PuO_2 in water. Physiochemical parameters most important to the solubility of PuO_2 are the reactive surface area and oxidation state of plutonium and the water chemistry, including pH, reduction/oxidation potential, and temperature. The mass to surface area ratios of particles affect reactivity and solubility, with solubility being inversely related to particle size. The dissolution rate of the plutonium dioxide fuel is very small, ranging from 1.2 to 90 $\mu Ci/m^2/s$ (0.1 to 7.3 $\mu g/m^2/s$) in seawater and freshwater, respectively, based upon the dissolution rate per unit surface area of the fuel (NASA 1990, INSRP 1990). In general, PuO_2 is insoluble.

Chemically, PuO_2 is extremely resistant to dissolution, including dissolution in the environment as well as in lung or digestive fluids of the human body. PuO_2 is slowly removed from environmental pathways by sedimentation processes, percolation into soil, and other physical means.

Clays, organics, and other anionic constituents tend to bind most of the PuO_2 particles in the soil column. The binding of PuO_2 would occur in the first few centimeters of sediment, greatly reducing the concentration of this constituent with depth. This natural filtering of PuO_2 would probably reduce the concentrations in drinking water to levels below the Primary Drinking Water Standard of 4 mrem/year (NASA 1990).

It is also possible that surface water runoff containing PuO_2 could directly contaminate drinking water supplies from surface water bodies, because this type of contamination is greatest due to suspended PuO_2 particles and not from dissolved PuO_2. Filtering the surface water before chemical treatment would reduce the concentration of total plutonium to very low levels (NASA 1990).

C.2 MODELS USED TO STUDY TRANSPORT AND EFFECTS OF PLUTONIUM DIOXIDE

PuO_2, including its transport in the environment, its uptake in the human body by ingestion or inhalation, and its fate following uptake, has been studied in great detail over the last 50 years. Models have been developed to determine the radiation dose from plutonium transport and uptake (e.g., NUS 1982, ICRP 1977, ICRP 1979, ICRP 1990). When developing these pathway, dosimetry, and risk models, the following factors are usually considered:

1. PuO_2 enters the environment and a fraction of it is transported via air, groundwater, surface water, or foodstuffs to humans. Because Pu-238 has a relatively long radioactive half-life (an initial quantity of Pu-238 will decay to 50 percent in 87.75 years), only a small fraction of it will be removed from the environment by radioactive decay.

2. A quantity of the PuO_2 is inhaled or ingested and a fraction of it is transferred to the bloodstream and then to organs within the human body, retained in the lungs, or excreted. It is assumed for this analysis that other entry mechanisms in the body, such as injection, are not significant.

3. The plutonium that resides in certain organs, principally the lungs, liver, and bone surfaces, is retained for a long period of time with a slow rate of excretion.

4. Alpha radiation, characteristic of Pu-238, irradiates nearby cells and cell components, such as chromosomes, and a fraction of the cells are killed or damaged. Most non-lethal damage is completely repairable by the cell.

5. A very small fraction of the damaged cells survive, undergo defective repair, mutate, and, may after many years delay, produce significant detrimental effects in humans, including cancer and genetic abnormalities. This fraction is the basis for the associated health risks discussed in the following sections.

Due to the extremely small amount of plutonium transported to and accumulated in the human body from exposure to a release from a postulated Cassini accident and the stochastic (random) nature of the detrimental effects produced in irradiated cells, it is not possible to accurately predict the long-term effects to any one individual exposed during the postulated accident. However, it is possible to use the risk estimates experienced in a large exposed population to provide an estimate of the average risk to an individual (National Research Council 1988, National Research Council 1990). Detrimental effects, such as an increased rate of cancer, may possibly be predicted for a very large population, on the order of several millions of exposed individuals. From such estimates the average risk to a member of that population may also be calculated.

Dose equivalents to critical organs and tissues for all members of the general public exposed to the worst case postulated accident during the Cassini mission would be many orders of magnitude below those that produce acute effects, such as "radiation sickness," and even subtle acute effects, such as changes in blood chemistry, should not be detectable.

C.3 TRANSPORT OF PLUTONIUM DIOXIDE IN THE ENVIRONMENT

The transport mechanisms and pathways of any accidental releases of PuO_2 in the environment will depend on the mission phase and the subsequent environment in which the release occurs. For example, if the accident occurs near the launch pad, the concentrated release would primarily result in the formation of larger, more environmentally inert particles that would be deposited in a relatively small area within a short period of time. Conversely, should the release occur during the short-term reentry scenario, a widely dispersed cloud of smaller particles would gradually fall to Earth over a much larger area in much lower concentrations.

Because PuO_2 is so insoluble, the movement through the environment depends on physical processes. PuO_2 may be carried into the soil by a number of routes, including percolation of rainfall and subsequent leaching of particles into the soil, animal burrowing activity, and plowing or other disturbance of the soil by humans. Migration of the PuO_2 particles into the soil column is of concern, primarily because of the potential for PuO_2 to reach groundwater aquifers used as drinking water supplies. Once deposited on soil, however, PuO_2 appears to be extremely stable. Soil profile studies have shown that generally more than 95 percent of the PuO_2 from nuclear weapons fallout remained in the top 5 cm (2 in.) of surface soil (in undisturbed areas) for 10 to 20 years following deposition (DOE 1987b).

In the unlikely event of an accident, PuO_2 would be taken up in the human body primarily via inhalation with ingestion of contaminated water and foodstuffs as a secondary means. These pathways and the generalized behavior of Pu-238 in the environment are described in the literature (e.g., Aarkrog 1977, Anspaugh et al. 1975, Pinder and Doswell 1985, Pinder et al. 1987, Yang and Nelson 1984).

In general, PuO_2 is insoluble and is poorly transported in aquatic, marine, and terrestrial environments. Most forms of plutonium, including PuO_2, are removed from biological pathways by processes such as sedimentation and fixation in soil. Only small amounts of material are concentrated by biological accumulation into most seafood, grazing animals, and other food products.

In marine and aquatic systems, larger particles will quickly settle to the bottom sediments; 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), forming a thin layer on the water surface and subsequently transported to the shoreline by wind and wave action. Resuspension of smaller particles from the bottom can occur due to physical disturbance of the sediments by wave action and recreational use of the water bodies (e.g., swimming, boating, and fishing), as well as by the feeding activity of various marine and aquatic species. Particles of PuO_2, 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 (NASA 1990).

PuO_2 entering into a water/sediment system would be preferentially taken out of solution and bound in saturated sediments in amounts on the order of 100,000 times greater than the amounts that would remain in the associated water column (NASA 1990).

Studies have indicated that the bioaccumulation in marine organisms can range from 2 to 3,000, depending on the type and density of seafood impacted (e.g., freshwater fish, saltwater fish, mollusca), the amount of radioactive material released, and the deposition area.

Parameters used for estimating the uptake from harvesting and consumption of agricultural products have been measured (Baes et al. 1984, Rupp 1980, Yang and Nelson 1984). These and similar agricultural and food consumption parameters and plutonium ingestion parameters (ICRP 1979) are used as the basis for estimating human doses via ingestion. For example, an analysis of Pu-238 contamination of orange trees shows that a total of only 1 percent of the plutonium intercepting the plants would be transported from field to market during the following 12 months of harvesting (Pinder et al. 1987). Most of this plutonium would adhere to the fruit's peel and would be removed prior to ingestion; uptake to the orange itself would be extremely small or nonexistent.

C.4 TRANSPORT AND DEPOSITION OF PLUTONIUM DIOXIDE IN THE HUMAN BODY

Plutonium dioxide that enters the human body by ingestion or inhalation has many possible fates, all of which have been studied in detail (ICRP 1979, ICRP 1986). The inhalation route is found to be approximately 1,000 times as effective as ingestion in transporting plutonium to the blood, due to the short time of residency, the chemical properties of plutonium, and the physiological environment of the GI (gastro-intestinal) tract (ICRP 1979).

Ingested plutonium dioxide will quickly pass through the digestive system and be excreted with only a small quantity being absorbed via the mucosa into the blood stream. The fractional absorption of PuO_2 is estimated to average about 10^{-5} (i.e., about 1 part in 100,000 ingested would be absorbed) (ICRP 1979, ICRP 1986). The fractional absorption is based on the average individual. PuO_2 in the environment could become more soluble with time due to the use of fertilizers in gardening, chlorination in drinking water, and soluble forms in seawater. Dietary and physiological factors, such as fasting, may increase or decrease the fractional absorption.

Inhaled plutonium dioxide is transported to one or more portions of the respiratory system depending on the particle size. Generally, most particles larger than 5 micrometers are intercepted in the nasopharyngeal region and either expelled or swallowed to pass through the digestive tract; what is not absorbed, is then excreted. Particles smaller than about 5 micrometers are transported to and remain in the trachea, bronchi, or deep lung regions. Particles reaching the deep lung are cleared from the body much more slowly than those not entering the lung. For example, 1.4-micrometer particles are typically cleared from the lung at the rate of 40 percent in the first day and the remaining 60 percent are cleared in 500 days (ICRP 1979). Particles captured in the mucous lining of the upper respiratory tract are moved more rapidly to the pharynx, where they are swallowed. Once swallowed, they behave as if ingested.

Plutonium dioxide remaining in the lung will continuously irradiate lung tissue, and a small fraction will be transported over time directly to the blood or to lymph nodes and then to the blood. The fraction of plutonium transferred directly from lung tissues to the blood is believed to be about 1 percent of the amount retained in the lungs, depending on the size distribution of ultra-fine particles. Smaller particles are likely to form over time from larger particles due to the natural fragmentation processes associated with radioactive decay and may also be transferred to the blood. Approximately 15 percent of the plutonium initially deposited in the lungs will be transferred to the lymph nodes, and up to 90 percent will eventually be transferred to the blood (ICRP 1986).

Once PuO_2 has entered the blood via ingestion or inhalation, it circulates and is deposited primarily in the liver and skeletal system. It is currently accepted that plutonium transported by the blood is distributed to the following organs: 45 percent in the liver, 45 percent in the skeletal system, 0.035 percent in testes in males, and 0.011 percent in ovaries in females with a non-measurable amount crossing the placenta of pregnant women and entering the fetus. The remaining 10 percent of the activity in the blood is excreted through the kidneys and colon or deposited in other tissues (ICRP 1979, ICRP 1986).

The resident times in the liver, skeletal system, and gonads are quite long. Current estimates for 50 percent removal times for plutonium are 20 years for the liver, 50 years for the skeleton, and an infinite retention time for the gonads.

C.5 CANCER INDUCTION AND GENETIC EFFECTS

Several possible outcomes to the ejection of an alpha particle from a decaying Pu-238 nucleus may occur to a nearby cell:

1. The alpha particle entirely misses the cell and has no damaging effect.

2. The alpha particle strikes the cell but does not strike critical components within the cell, and the cell survives.

3. The alpha particle strikes a critical component of the cell and quickly kills it. The same may be true of striking and chemically changing water molecules, which act to damage critical cell structures.

4. The alpha particle or reaction products strike a portion of a chromosome within the cell, modifying the chromosome but not killing the cell. Most chromosome damage is correctly repaired, but a small fraction is incorrectly repaired (a mutation).

Generally, the last outcome, which has an extremely low probability of occurrence, is the most potentially harmful. This process may lead to the induction of cancer or genetic effects, which may be passed on to offspring (ICRP 1990). Damage may occur at any time following large uptakes of plutonium, and the detrimental effects may occur immediately or be delayed years after the initiating event in cell DNA. Because of the very small amount of activity ingested or inhaled by the average exposed individual and transported to internal tissues where effects may occur, however, the probability of this outcome for all accident scenarios is exceedingly small.

APPENDIX D

RESPONSES TO PUBLIC REVIEW COMMENTS

APPENDIX D

RESPONSES TO PUBLIC REVIEW COMMENTS

The U.S. Environmental Protection Agency (EPA) published a Notice of Availability for the Cassini mission Draft Environmental Impact Statement (DEIS) in the Federal Register on October 21, 1994. The public review and comment period closed on December 20, 1994. Timely comments were received from organizations and individuals listed in Table D-1.

Where no extension of the comment period was requested or otherwise authorized by NASA, untimely comments were considered if received before March 3, 1995 (see Table D-2). As of March 3, 1995, 25 letters were received after the comment period closed, and are included in this Appendix.

This Appendix provides specific responses to the comments received from the individuals and organizations listed in Tables D-1 and D-2. Copies of the comment letters are presented in the following pages. The relevant issues in each comment letter are marked and numbered for identification along with the National Aeronautics and Space Administration's (NASA's) response to each issue. Where changes in the text were appropriate, such changes were noted in the comment response.

The majority of the public comments received raised the following issues on the Environmental Impact Statement (EIS):

- the use of plutonium in space
- the status of solar technology for deep space missions
- the properties of plutonium
- the radiological consequence and risk analyses.

Information on these topics may be obtained in the following sections of the EIS:

The use of plutonium in space—Section 2.2.4 of the EIS describes the plutonium-containing radioisotope thermoelectric generators (RTGs) and radioisotope heater units (RHUs) in detail, including the testing and verification data to ensure containment of the plutonium dioxide fuel under most accident environments. In addition, Section 2.6.3.1 compares the physical properties and the attendant production requirements of alternative radioisotopes to plutonium-238. Section 2.6.3.2 discusses the limitations of the potential alternative conversion technologies to the thermoelectric converter used on the RTGs that would potentially result in the use of less plutonium.

The status of solar technology for deep space mission—Section 2.6.3.4 discusses the level of development of solar technology and the various solar design options that were evaluated for the Cassini mission.

The properties of plutonium—Appendix C of the EIS briefly describes the properties of plutonium-238 and the environmental effects of plutonium dioxide used in the RTGs and RHUs.

The radiological consequences and risk analysis—Section 4.1.5 of the EIS presents: the radiological consequence methodologies, the postulated accident scenarios and the associated probabilities of their occurrence, and the potential source terms. The potential radiological consequences from postulated accidents are described in Sections 4.1.6.2 and 4.2.6 in two ways: the land areas that could be contaminated above the EPA screening level of 7.4×10^3 Bq/m^2 (0.2 μCi/m^2), and health effects (excess latent cancer fatalities). The risk analyses for the mission are presented in Sections 4.1.8 and 4.2.8 from three perspectives: contribution by mission phase/scenario to mission risk (expressed as health effects mission risk); average individual risks; and the risk to the maximum exposed individual.

TABLE D-1. LISTING OF COMMENTORS

Commentor Number	Date of Comment	Organization	Individual Presenting Comments
1	11/29/94	Florida Coalition for Peace & Justice	Bruce K. Gagnon
2	12/5/94	Private Citizens	Mr. & Mrs. Puchstein
3	12/9/94	Private Citizen	Horst A. Poehler, Ph.D
4	12/10/94	Private Citizen	Dorothy Scott Smith
5	12/14/94	Private Citizens	Harvey G. and E. Lois Baker
6	12/14/94	Private Citizen	Ronald J. Balogh
7	12/14/94	Private Citizen	Arnie Welber
8	12/15/94	Southern Rainbow Education Project (SREP)	Gwendolyn M. Patton
9	12/15/94	Private Citizen	Anna B. Pilson
10	12/16/94	Florida Coalition for Peace & Justice	Donna Ellis
11	12/16/94	South Dakota Peace and Justice Center	Jeanne Koster
12	12/17/94	Private Citizen	Phil Seligman
13	12/17/94	Private Citizens	Warren and Olive Wilson
14	12/18/94	Private Citizen	Dr. Mary Ann Lawrence

TABLE D-1. LISTING OF COMMENTORS (Continued)

Commentor Number	Date of Comment	Organization	Individual Presenting Comments
15	12/19/94	National Space Society	Glenn Harlan Reynolds
16	12/19/94	Committee to Bridge the Gap	Daniel Hirsch
17	12/19/94	Private Citizen	Beth Raps
18	12/19/94	Women's International league for Peace and Freedom	Jennie Baer
19	12/19/94	Private Citizen	Kathleen Kelly
20	12/20/94	Florida Coalition for Peace & Justice	Sylvia Torgan with 24 additional petitioners
21	12/20/94	Private Citizens	Ruth E. and Jack Snyder
22	12/20/94	Private Citizen	Richard H. Hiers, Ph.D, J.D.

TABLE D-2. LISTING OF COMMENTORS RESPONDING AFTER CLOSE OF THE PUBLIC COMMENT PERIOD

Commentor Number	Date of Comment	Organization	Individual Presenting Comments
23	12/21/94	Private Citizens	Mr. & Mrs. Harry Kernes
24	12/22/94	Private Citizen	Rea D. Ward
25	12/22/94	Private Citizen	Georgia Van Orman
26	12/22/94	Private Citizen	Arthur Draving
27	12/25/94	Private Citizen	John P. Ferrell
28	12/26/94	Private Citizen	Ingeborg F. Roberts
29	12/26/94	Private Citizen	Geraldine Jenara Amato
30	12/28/94	Pikes Peak Justice and Peace Commission	Mary Sprunger-Froese
31	12/28/94	Private Citizen	Harvey Wasserman
32	12/30/94	Private Citizen	Edward Dierauf
33	12/30/94	Private Citizen	Margery D. McIntire
34	12/31/94	Private Citizen	Nancy Strong
35	1/1/95	Private Citizen	Karen McFadyen
36	1/1/95	Private Citizen	Linda Bermann
37	1/2/95	Private Citizen	Merilyn Hiller

TABLE D-2. LISTING OF COMMENTORS RESPONDING AFTER CLOSE OF THE PUBLIC COMMENT PERIOD (Continued)

Commentor Number	Date of Comment	Organization	Individual Presenting Comments
38	1/3/95	Private Citizens	Sidney and Olive Manuel
39	1/3/95	Private Citizen	Ronald P. Reed
40	1/4/95	Private Citizen	V. Lee Fuqua
41	1/8/95	Private Citizen	Robert R. Holt, Ph.D.
42	1/16/95	Private Citizen	Bob Ellenberg
43	1/23/95	Private Citizens	Martina and John Linnehan
44	2/12/95	Private Citizen	Ruth Putz
45	2/19/95	Private Citizens	Carole and Frank Hyneman
46	2/24/95	Private Citizen	Mrs. Fran Collier
47	2/27/95	Religious Education for the Catholic Deaf & Blind	Rev. René Robert

FLORIDA COALITION FOR PEACE & JUSTICE
P.O. Box 90035 • Gainesville, Florida 32607 • (904) 468-3295

November 29, 1994

Action Network for Social Justice (Tampa)
Affirmation Lutheran Church (Boca Raton)
Boca Citizens for Social Responsibility
Brevardians for Peace & Justice
Broward Citizens for Peace & Justice
Catholic Diocese of St. Augustine, Office of Peace & Justice (Jacksonville)
Center for Advancement of Human Cooperation (Gainesville)
Deerfield Progressive Forum
Delray Citizens for Social Responsibility
Environmental & Peace Education Center (Ft. Myers)
Florida Southwest Peace Education Coalition (Venice)
Freedom Coalition (Gainesville)
Grace Contrino Abrams Peace Education Foundation (Miami)
Grandmothers for Peace (St. Augustine)
Greens of Alachua County
Jacksonville Coalition for Peace & Justice
Metanoia (St. Marys, GA)
Miami Peace Center
Orlando Big Mountain Support Group
Orlando Friends Meeting
Palm Beach County Committee for Social Responsibility
Patriots for Peace (Ft. Walton Beach)
Pax Christi Florida
Peace & Justice Subcommittee, Presbytery of Tampa Bay
Peace Coalition (Lake Worth)
Peace of Highlands County
Peace Place (Ft. Lauderdale)
Peacemaking Committee of Central Florida Presbytery
Peacemaking Group (Naples)
Physicians for Social Responsibility (South Florida)
Polk County Citizens for Peace & Justice
Social Concerns Committee of St. Margaret Mary Catholic Church (Winter Park)
Southeastern Yearly Meeting
South Florida Peace Network
Tallahassee Peace Coalition
Tallahassee Society of Friends
Tampa Bay Peace Education Program
Treasure Coast Citizens for Peace & Justice
Unitarian Social Action Network (Clearwater)
Unitarian Social Concerns Committee (Boca Raton)
Unitarian Social Concerns Committee (Gainesville)
Unitarian Social Concerns Committee (Jacksonville)
Unitarian Social Concerns Committee (Melbourne)
Unitarian Social Concerns Committee (DeLand)
Unitarian Social Concerns Committee (West Volusia)
Unitarian Social Responsibility Committee (Vero Beach)
Unitarian Universalist Church of Sarasota
Vets for Peace (Gainesville)
Volusians for a Peaceful World (Daytona Beach)
Westminster United Presbyterian Church (Lakeland)
Women's Int'l League for Peace & Freedom (WILPF) (Palm Beach County)
WILPF (Tallahassee)
WILPF (Tampa)
WILPF (Treasure Coast)
Winter Park Friends Meeting

Dr. Peter B. Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington DC 20546

Dear Dr. Ulrich:

This letter is to comment on the Cassini Draft Environmental Impact Statement (DEIS) prepared by NASA. In it I could find no date that comments were due by.

We are glad to see that NASA has incorporated some our our concerns from Galileo and Ulysses into the Cassini DEIS. For example, Table 2-2 acknowledges that there have been accidents in the past. It was my personal experience during the campaigns against Galileo and Ulysses that NASA spokespersons frequently told the media that there had never been any accidents in the past. I have in my files the same table but it lists the inventory of Pu at launch (curies). We'd like to see that make it back into the table in the final EIS.

— 1A

You also do much more on alternatives in this DEIS except you still come to the same conclusion that you did in the past. Only now you use alot more mathmatics to come to the conclusion that "the spacecraft requires the use of RTG's to satisfy the mission electrical power needs."
I'm enclosing a European Space Agency (ESA) press release dated April, 1994 that announces that European industry has recently developed high efficiency solar cells and that they won't need RTG's for "future demanding deep-space missions." I ask that the press release be made part of our official comments.

— 1B

It is clear to us that NASA and DoE much to easily dismiss the use of a solar alternative. The political will is lacking and pressure from the nuclear power industry is a certain factor for the lack of effort. Or instead of saying that the nuclear industry pressures NASA and DoE, maybe we should just say that they have taken over the decision making process.

— 1C

We still maintain that one of the problems with nuclear power in space is that it is contaiminating people before it ever leaves the earth -- during the fabrication process that happens at Savannah River, Los Alamos, Oak Ridge, Mound Labs and Martin Marietta. You didn't spell

— 1D

RESPONSES TO COMMENTS
Commentor No. 1: Florida Coalition for Peace & Justice
(Bruce K. Gagnon)

Response to Comment 1A:

The Cassini Environmental Impact Statement (EIS) now contains an updated version of the corresponding table from the Ulysses mission Tier 2 EIS (NASA 1990). The plutonium inventories on U.S. spacecraft previously launched have been included in Table 2-2.

Response to Comment 1B:

Solar cells recently developed under laboratory conditions by European Space Agency (ESA) have demonstrated desirable characteristics for missions traveling about two-thirds of the distance to Saturn. For research and development purposes, Deutsche Aerospace and CISE (Milan, Italy) have produced a small quantity of Low-Intensity, Low-Temperature (LILT) silicon solar cells for potential use on space missions such as ESA's Rosetta comet mission. The cells thus far, have tested favorably under simulated environments for use at nearly 6 astronomical units (AUs). (Cassini will need to operate at 9 to 9.3 AU while at Saturn). Calculations suggest that operation at Saturn conditions may subject silicon cells to low temperature freeze out, significantly reducing their performance. However, in view of the margin of error, Jet Propulsion Laboratory (JPL) has assumed that optimum cell performance would be available in all Cassini array studies. The ESA LILT cells are relatively thick compared to other cells evaluated for potential use on the Cassini spacecraft and have low resistance to radiation damage compared to the conventional thin silicon and gallium arsenide space solar cells previously assumed in the array sizing studies. Analysis by JPL spacecraft electrical power systems engineers shows that the improved performance of the LILT cells (25 percent efficiency instead of less than 20 percent achieved by most other cells) would be offset by their increased mass and greater radiation sensitivity (S. Strobel and K. Bogos et al. [In Print] "Si and GaAs Solar Cells for Low Intensity, Low Temperatures Operations," in the Proceedings of 1st World Conference on Photovoltaic Energy, Hawaii, December 5-9, 1994). As with other solar power options studied for the Cassini spacecraft, the extremely large mass of even the lightest solar configuration is beyond the lift capability of the Titan IV (Solid Rocket Motor Upgrade [SRMU])/Centaur launch vehicle. Even if a heavy-lift booster and a suitable upper stage could be made available, the severe field-of-view problems, greatly increased turn times, and greater operational complexity and programmatic risk associated with an all-solar Cassini design makes such a design, from both mission engineering and scientific perspectives, infeasible.

RESPONSES TO COMMENTS
Commentor No. 1: Florida Coalition for Peace & Justice
(Bruce K. Gagnon)
(Continued)

Even if the solar cells discussed in the ESA press release become available for future application in deep space, these ESA solar cells would not necessarily be applicable for all future deep space missions due to the limitations discussed above. Therefore, radioisotope thermoelectric generators (RTGs) are likely to remain the more feasible power source for certain missions.

Response to Comment 1C:

The RTGs that would be onboard the Cassini spacecraft are not a product of or directed by the nuclear power industry. RTGs were developed by the Department of Energy (DOE) in response to the need for a compact, reliable source of small amounts of electrical power for U.S. deep space missions.

Response to Comment 1D:

This EIS addresses the impacts of preparing for and implementing the Cassini mission. The environmental, safety and health impacts associated with RTG and radioisotope heater unit (RHU) manufacturing processes at DOE facilities are the subject of separate National Environmental Policy Act documentation and are not within the scope of this EIS. For more detailed information, see the reference, *Environmental Assessment for Radioisotope Heat Source Fuel Processing and Fabrication* (DOE 1991).

out in the DEIS any of the consequences of this process. Instead you made reference to a 1991 DoE study. It should be printed as part of the EIS. The burden of proof is on NASA. If this isn't a crucial part of the environmental impact study then what in the world is? I enclose an article from the Albuquerque Journal dated 2/26/94 for the record. —1D

The "Monte Carlo Simulation" computer model that you use to calculate risk assessment and contamination probabilities is totally suspect in our opinion. You put garbage into a computer and you get garbage out. We know that you rig the figures so that everyone can say that the risk is "acceptable". Again, our experience during Galileo and Ulysses showed how the figures changed as often as one changes socks.

For example, the DEIS claims that in an accident after take-off debris would fall on Africa and plutonium might be released on impact resulting in "less than one excess cancer." During the earth swing-by a reentry accident that released plutonium into the atmosphere would be "shared" among 5 billion people causing only 2,300 cancers over 50 years. These numbers are truly pure garbage. We refer you to Dr. John Gofman's study of the 1964 Snap-9A accident and its long term implications on worldwide cancer rates. —1E

Also unacceptable to us is the language that you use to down-play the health risks of pu-238 and pu-239. You make it sound like a Sunday picnic. Again we urge NASA to look at Dr. John Gofman's work on the subject and include that in the final EIS. —1F

There is not enough documentation in the DEIS about the consequences of contamination of the land in the event of any accident. If pu-238 and pu-239 was spread over parts of Africa how much land would have to be removed? What would be done with it? The buildings? The plant life, animals, the people? Spell it out. It could happen. —1G

NASA once again claims that it must rush to meet the October, 1997 launch schedule and that any delay would harm science objectives. It is our contention that a delay is absolutely necessary because proof exists that a solar alternative <u>does exist</u> despite the claims in the DEIS to the contrary.

The entire Cassini program should go back to square one and a serious solar alternative must be developed. —1H

We can assure NASA that if there is ever an accident with plutonium on a space mission, during any stage, the future of nuclear power missions would be over. But most importantly the agency itself would face total dishonor before the people of the world. —1I

RESPONSES TO COMMENTS
Commentor No. 1: Florida Coalition for Peace & Justice
(Bruce K. Gagnon)
(Continued)

<u>Response to Comment 1E:</u>

The risk analysis presented in the EIS is deterministic. Monte Carlo simulations, however, were performed in the estimation of the launch phase initiating accident scenario probabilities and the Earth-Gravity-Assist (EGA) inadvertent reentry probabilities. The Monte Carlo technique is appropriate when evaluating functional relationships involving probability distributions. As part of the launch approval process, DOE will be preparing a more in-depth evaluation of the potential environmental consequences as part of the Final Safety Analysis Report (FSAR). Monte Carlo simulations will be applied in the FSAR.

The Systems for Nuclear Auxiliary Power (SNAP)-9A RTG, which used plutonium (Pu-238) fuel in the metallic form, was designed for reentry burnup. Following the SNAP-9A reentry burnup, the particles associated with the plutonium (Pu-238) had a measured arithmetic mean particle size of 10 μm with a range of 5 to 58 μm. Contacts with Dr. Gofman through his organization have failed to yield any indication that he evaluated the SNAP-9A accident.

<u>Response to Comment 1F:</u>

The results of the accident analysis have been factually stated in the EIS in terms of 1) the total probability of release, 2) the radiological consequences of such a release, and 3) the risk. Appendix C discusses the environmental and health risks associated with plutonium (Pu-238) dioxide in greater detail. See also, <u>Johnston</u> v. <u>U.S.</u>, 597 F. Supp. 374, at 409-415 (U.S.D.C., D. Kan., 1984).

<u>Response to Comment 1G:</u>

Tables 4-10 and 4-11 of the EIS present the estimated area of land contamination from potential accidents where plutonium could be released. Section 4.1.6.2 deals with the radiological consequences to the land.

A Phase 5 accident occurring during the 8 seconds the instantaneous impact point is over Africa would lead to spacecraft breakup during reentry. Reentry heating would by design melt the RTG converter housing and release the individual aeroshell modules, which would then reenter separately. General purpose heat source (GPHS) modules are designed to remain intact

RESPONSES TO COMMENTS
Commentor No. 1: Florida Coalition for Peace & Justice
(Bruce K. Gagnon)
(Continued)

under these reentry conditions. Individual reentering GPHS modules impacting rock could lead to fueled clad failures and release of fuel (an average of 5.5×10^{10} Bq [1.5 curies]). No releases would be expected from soil or water impacts. The total probability for such a release is estimated to be around 5.0×10^{-4} for the Proposed Action. Should such a release occur, the maximum individual dose is estimated to be 1.24×10^{-4} Sv (1.24×10^{-2} person-rem) and the collective dose is estimated to be 4.32×10^{-3} Sv (4.32×10^{-1} person-rem), resulting in 1.51×10^{-4} health effects.

A review of Tables 4-10 and 4-11 of the EIS reveals that the estimated area of land contamination based upon a U.S. Environmental Protection Agency screening level of 7.4×10^3 Bq/m^2 (0.2 μCi/m^2) for a Phase 5 accident would be about 0.02 km^2 (0.008 mi^2) in the expectation source term case, and about 0.1 km^2 (0.04 mi^2) in the maximum source term case (Command Shutdown and Destruct Scenario). It should be noted that these estimates would apply to an accident occurring during the 8-second period of Phase 5 when the GPHS modules could impact the African continent. Even then, the modules would have to impact rock for a release to occur. The amount of land that would have to be remediated, if any, would be determined by an assessment of the impact location. For accidents occurring outside the United States or its territorial jurisdictions, the State Department and diplomatic channels would be employed in accordance with pre-arranged procedures and support elements would be dispatched as appropriate.

Response to Comment 1H:

NASA has followed the technical progress in power source technology worldwide for many years. Indeed, a substantial portion of the work in the area of solar arrays has been funded by NASA. While improvements have been made in solar technology, significant breakthroughs are still required to support a mission like Cassini. Recent international conferences on space power provided no reports of technical breakthroughs that would suggest changing the proposed approach to powering the Cassini spacecraft. The availability of the solar power option was discussed in response to Comment 1B.

RESPONSES TO COMMENTS
Commentor No. 1: Florida Coalition for Peace & Justice
(Bruce K. Gagnon)
(Continued)

Response to Comment 1I:

NASA places the highest priority on assuring the safe use of radioactive materials in space. Thorough and detailed safety analyses are conducted prior to launching NASA spacecraft with RTGs, and many prudent steps are taken to reduce the risks involved in NASA missions using RTGs. In addition to NASA's extensive internal safety requirements and reviews, missions that carry nuclear material also undergo an additional safety review involving detailed verification testing and analyses.

We are presently running an international petition campaign calling for an end to the Cassini mission as long as nuclear power is used on-board.

We urge NASA to rethink its severe opposition to solar in deep space, especially when the Cassini mission partner ESA, now acknowledges that RTG's are not needed for deep space missions. —1J

Our opposition to nuclear power in space will only deepen as NASA explores the use of such power for the moon colony or the Mars exploration mission. As the public learns more about this issue as they have since Galileo they too will begin to pay a closer look at who is running the show down at NASA and DoE when it comes to making these decisions. And we can assure you that people are becoming less intimidated by the so-called science experts as they see technology fail time after time. The taxpayer is footing the bill and is being asked to assume the risk of contamination from missions that do not need to be a threat. —1K

If NASA wants to do pure science they had better start getting out of bed with the nuclear industry that is in it for pure profit. We will continue to shine a light on this unholy alliance.

In peace,

Bruce K. Gagnon
State Coordinator

RESPONSES TO COMMENTS
Commentor No. 1: Florida Coalition for Peace & Justice
(Bruce K. Gagnon)
(Continued)

Response to Comment 1J:

NASA's primary choice of space power for planetary missions has historically been solar. For example, the Mars Observer, Viking Orbiters, Mariners 4, 6, 7 and 9 were solar-powered Mars missions. NASA continues to use solar power for missions when such technology is applicable. Future missions to Mars such as Pathfinder and Mars Global Surveyor will be solar-powered, using the newest high efficiency GaAs/Ge cells. Mars Pathfinder lander and microrover represent the first use of photovoltaics on the Martian surface. However, NASA incorporates RTGs with spacecraft designs when solar power or other power technology is not feasible for the planned mission. The current state of the technology makes solar power infeasible for a mission like Cassini. See also response to Comment 1B.

Response to Comment 1K:

The availability of solar power technology for the Cassini mission has been addressed in response to Comment 1B. The total health effects mission risk to the public (considering all launch phases and the Earth-Gravity-Assist trajectory) for Cassini has been provided in Section 4.1.8 of the EIS, and is estimated to be small (about 1.8×10^{-3} health effects).

Press Information Note No:07-94

Paris, 29 April 1994

New solar cells with record efficiency

Under contract with ESA, European industry has recently developed high efficiency solar cells for use in future demanding deep-space missions such as the recently approved ROSETTA cometary mission. The new solar cells reach a 25% efficiency under deep space conditions. The efficiency is the ratio between the electrical energy produced by the cell and the incoming solar energy. The higher the efficiency, the "better" the solar cell.

Unlike telecommunications and Earth observation satellites which orbit near the Earth and are normally powered by solar cells arrays, spacecraft operating at very large distance from the Sun (typically deep-space probes) experience a solar intensity which is only about 5% or less of that near the Earth. This was the case for ESA's ULYSSES for instance which, before reaching the Sun's poles had first to travel to Jupiter at 780 million km from the Sun (Jupiter is five times further away from the Sun than we are!). Moreover, the equilibrium temperature of solar arrays at those distances goes down to about -100 °C. Current solar cells used all over the space world are not generally made to operate at these low temperatures and solar intensities. They allow for 10- to 20% efficiencies in near-Earth orbits but show anomalous behaviour at deep space conditions.

For this demanding environment deep-space probes have to use power sources other than solar panels, because their electrical performance degrades too much at these low light intensities and low temperatures. Until now, deep space probes had to use thermonuclear power generators, like the so called RTGs (Radioisotope Thermoelectric Generators).

There are also Public Relations offices at the following ESA establishments:

- ESTEC Noordwijk
Netherlands
Tel (31) 1719.83 006
Fax (31) 1719 17 400
- ESOC Darmstadt
Germany
Tel (49) 6151 90 2696
Fax (49) 6151 90 2961
- EAC Cologne
Germany
Tel (49) 2203 60 010
Fax (49) [illegible]
- [illegible]
Italy
[illegible]

As RTG's technology is not available in Europe, ESA therefore attempted to develop a power source based on very high-efficiency solar cells.

Under low-light low-intensity conditions, 25% efficiency has been achieved on 6x4 cm Silicon cells. The 25% mark represents the highest efficiency ever reached worldwide with Silicon cells without special optical concentration devices to increase the amount of sunlight collected to be converted into electricity. Another breakthrough had already been reached by ESA a little over one year ago with solar cells of a different technology, the Gallium Arsenide (GaAs) type, where 23% efficiency was reached on 2x4 cm cells.

This technology milestone in Silicon solar cells was reached by an industrial team led by DASA (Heilbronn, Germany) with CISE (Milano, Italy) as sub-contractor (CISE being also responsible for the development of high efficiency GaAs solar cells).

ESA expects that the new high performance Silicon solar cells could profitably be used in deep space missions for Europe and that this technology could also be of interest for near-Earth orbit space applications as well as for Earth based ones.

ALBUQUERQUE JOURNAL

Plutonium Lab Safety Questioned

By John Fleck 2/26/94
JOURNAL STAFF WRITER

Federal investigators have raised questions about safety procedures at Los Alamos National Laboratory's plutonium laboratory, where workers soon will begin making key parts for NASA's 1997 Cassini mission to Saturn.

Los Alamos and Department of Energy officials defended the lab's safety, and a NASA official said he doesn't think Cassini will be delayed.

The most serious dispute between investigators and the Department of Energy, which runs Los Alamos, is over whether a backup power generator used to power safety systems should be automatic or manually operated.

The investigation, done during the past year by the Defense Nuclear Facilities Safety Board, didn't find imminent threats to public or worker safety, according to board reports.

The board's staff did, however, find problems in procedures used to ensure safety at Los Alamos' Technical Area 55, the laboratory's main plutonium handling complex.

The board has called a hearing March 7 in Washington, D.C., to look into the problems.

One of those problems, an allegedly inadequate backup power supply, could allow dangerous plutonium to escape the building if there was a plutonium leak inside the building at the same time the power went out, according to a report by board investigators.

DOE officials say they believe a manually operated power generator is sufficient to prevent leaks.

The report also cited a "high frequency" of radiation leaks inside the Los Alamos plutonium complex — 51 during a 19-month period in 1992-93.

In addition, investigators found Los Alamos hasn't done the paperwork to demonstrate it complies with the 51 separate DOE nuclear safety-regulated regulations.

Officials at Los Alamos and the U.S. Department of Energy said Technical Area 55 is safe.

"If we thought that facility was unsafe, we would shut it down," said Jerry Bellows, manager of the department's Los Alamos Area Office.

Bellows acknowledged the problems, but said they involve compliance with bureaucratic regulations, not the actual safety of the plutonium complex.

Bellows attributed the number of reported radiation leaks to heightened safety attention by workers, who now report minor incidents that in the past might not have been mentioned.

Dana Christensen, deputy chief of the Los Alamos division that runs the plutonium complex, pointed out that the laboratory has built plutonium parts for U.S. spacecraft for more than two decades without danger to public or worker health.

The Defense Nuclear Facilities Safety Board is an independent federal agency with the legal authority to investigate safety issues and make recommendations to the U.S. Secretary of Energy, said spokeswoman Carol Morgan.

It doesn't have the authority to shut anything down. Past investigations, however, have led to work delays at other U.S. nuclear facilities.

Plutonium is a radioactive metal made in nuclear reactors and not found in nature.

Dangerous if inhaled, plutonium is only handled in sealed containers with glove-lined portholes allowing workers to work with it remotely.

Los Alamos' Technical Area 55 is the largest functioning plutonium-processing facility in the United States.

NASA uses plutonium to power spacecraft used on deep-space missions. Los Alamos is preparing to begin manufacturing the plutonium parts for NASA's $1.4 billion Cassini spacecraft.

Ron Draper, deputy manager of the Cassini project for NASA, said in a telephone interview that he didn't expect the problems at Los Alamos to cause any delays in Cassini's launch.

NEW MEXICO'S
LEADING
NEWSPAPER
ALBUQUERQUE JOURNAL

RESPONSES TO COMMENTS
Commentor No. 2: Mr. & Mrs. Puchstein

DATE: December 5, 1994

TO: Dr. Peter B. Ulrich
Code SLP
NASA Headquarters
Washington, D.C. 20546

FROM: Mr. & Mrs. Paul Puchstein
1733 Athens Court
Lakeland, Florida 33803

SUBJ: Draft Environmental Impact Statement for the Cassini Mission

NASA should choose the "no action" alternative and immediately cease plans to launch the Cassini Mission until the power sources of 32Kg (72 lb) of PU-238 are replaced.

Public confidence in NASA's ability to continue to administer our National aeronautics and space contracts is seriously jeopardized by your morally unconscionable and irresponsible propagation of the production, use and proliferation of non-strategic radioactive material. —2A

Exploration of the solar system must never unnecessarily risk impacting and contaminating the Earth's environment. —2B

Sincerely,

Paul Puchstein
Jean Puchstein

Paul and Jean Puchstein
1733 Athens Court
Lakeland, Florida 33803

COPY: Senator John Glenn

<u>Response to Comment 2A:</u>

Radioisotope thermoelectric generators (RTGs) are the only suitable power technology available for the Cassini mission to Saturn. Furthermore, there is no new technology presently available or on the horizon to replace the RTGs for the Cassini mission.

The United States has an outstanding record of safety in using RTGs on 23 missions over the past three decades (See Table 2-2). While RTGs have never caused a spacecraft failure on any of these missions, they have been on board three missions which experienced malfunctions for other reasons. In all cases, the RTGs performed as designed.

More than 30 years have been invested in the engineering, safety analysis and testing of RTGs. Safety features, demonstrated through extensive testing, have been incorporated into the RTG's design. See Section 2.2.4.2 of the Environmental Impact Statement for more detailed information. There is about 32.4 kg (71.4 lb) of plutonium dioxide in the three RTGs. Table 2-3 provides the isotopic composition of the fuel form used for the Cassini mission.

<u>Response to Comment 2B:</u>

NASA places the highest priority on assuring the safe use of radioactive materials in space. Thorough and detailed safety analyses are conducted prior to launching NASA spacecraft with RTGs, and many prudent steps are taken to reduce the risks involved in NASA missions using RTGs. In addition to NASA's extensive internal safety requirements and reviews, missions that carry nuclear material also undergo an additional safety review involving detailed verification testing and analyses.

p 1 of 3

400 4 Ave
Satellite Beach, FL
32937-5202
Dec 9, 1994

Dr. Peter B Ulrich
Chief, Flight Programs Branch
Solar Systems Exploration Division
Office of Space Science
Washington, DC, 20546

Dear Dr. Ulrich:

In accordance with your letter of Oct 14, and your following letter giving the submission date, I am submitting mg comments on the DEIS, as follows:

Economic impact discussions do not consider or discuss the impact losses to the homeowner in cases of a nuclear spill. All homeowner policies are void in case of nuclear contamination, as a result of the Price Anderson Act. The homeowners are left to assume the loss due to NASA's nuclear failure, —3A

The nuclear containment estimates are deficient in overstating the containment of the nuclear spills. The basic containment consists only of a minimum thickness 22 mil cover of iridium (a relatively soft metal) about the thickness of a fingernail. —3B

The DEIS fails to examine the Benefit/risk ration where nuclear spill may place five Florida counties with a population of over 1.5 million and their property values at risk. The expected additional scientific knowledge does not justify the potential risk to the health and property values of the inhabitants that may be exposed. —3C

The DEIS admits that other, safer electrical power supply generators could be developed. The rush to launch with plutonium is not justified. Delay the Cassini launch until safer generators can be developed. —3D

The boundaries of the Cape and KSC launch sites were laid out so that the surrounding civilian population would be free of any toxic releases from launch exercises. The launch of the Cassini missile with 72 pounds of plutonium oxide far exceeds the boundaries that were designed to provide safety to the surrounding population. NASA and the AF have a choice of either buying up the necessary surrounding real estate, or setting up a launch site in the remote Pacific for current and future nuclear launch missions that pose unacceptable dangers to surrounding populations. —3E

Of possible launch sites, French Guiana, Balkanur Russia, and NASA/KSC, only the NASA/AF launch site is surrounded by a large populatiom, (in excess of 1.5 million) within 50 miles. For launch safety, and to live up to NASA's motto "Safety First", it would pay for the United States to pay these foreign countries to launch Cassini and other nuclear-bearing missiles. After all, Cassini is an international undertaking.

RESPONSES TO COMMENTS
Commentor No. 3: Horst A. Poehler, Ph.D.

Response to Comment 3A:

Homeowners and other property owners would not be left with the financial responsibility for damages resulting from contamination as a result of an accidental release of plutonium associated with the Cassini mission. While it is true that individual homeowner insurance is generally not available for damages resulting from nuclear related activities, Congress has provided a mechanism for financial reimbursement for damages from a nuclear-related incident. The provisions of law that provide for this protection is known as the Price-Anderson Act. This Act is incorporated into the Atomic Energy Act.

The Price-Anderson Act, as amended, (42 U.S.C. Sec. 2210) governs liability and compensation in the event of a nuclear incident arising out of activities of the U.S. Department of Energy (DOE). A "nuclear incident" is defined under the Atomic Energy Act, "as any occurrence, including an extraordinary nuclear occurrence, within the United States causing, within or outside the United States, bodily injury, sickness, disease, or death, or loss of or damage to property, or loss of use of property, arising out of or resulting from the radioactive, toxic, explosive, or other hazardous properties of source, special nuclear or byproduct material..." [42 U.S.C. Sec. 2014(q)]. In the case of the Cassini mission, DOE retains title to the radioactive power systems at all times. The radioisotope thermoelectric generators (RTGs) would, therefore, be subject to the Price-Anderson Act provisions. In the unlikely event that an accident were to occur resulting in release of plutonium, affected homeowners would be eligible for reimbursement for loss of property due to contamination.

Response to Comment 3B:

The fuel containment approach taken in the RTG design is one of multiple barriers as described in Section 2.2.4.2 of the Environmental Impact Statement (EIS):

> "Each general purpose heat source (GPHS) module consists of a graphite aeroshell, two carbon-bonded carbon fiber insulator sleeves, two graphite impact shells (GISs), and four [iridium-encapsulated] fueled clads. The ... aeroshell... serves as the module's primary heat shield to protect the internal components from direct exposure to a reentry's thermal and aerodynamic environment.

> The two GISs contained in the GPHS module provide the primary resistance to impact and mechanical loads. ... The iridium shell protects and immobilizes the fuel. The iridium alloy is compatible ... with the plutonium dioxide fuel material ..., resists oxidation in air, and melts at 2,425°C (4397°F)."

The three key features that make the iridium useful are: its high melting temperature, its material compatibility with the plutonium dioxide fuel, and its resistance to oxidation in air. These features coupled with the reentry heating and impact protection provided by the graphitics of the GPHS module components limit the release potential for a wide range of accident environments.

A summary of the safety tests conducted to demonstrate the containment of fuel to a high degree of reliability under a range of accident environments is presented in Section 2.2.4.2 of the EIS.

The dimensions of all components of the GPHS-RTG assembly are given in the Reference Design Document, Volume I of the Ulysses Final Safety Analysis Report (FSAR) (U.S. Department of Energy, *Final Safety Analysis Report for the Ulysses Mission, Volume I Reference Design Document* ULS-FSAR-002, March 1990). The iridium clad is 0.56 mm (0.022 in) thick minimum. The plutonium fuel pellet is 27.56 mm (1.085 in) long and 27.53 mm (1.084 in) in diameter. The graphite impact shells have a minimum thickness of 4.24 mm (0.167 in). The graphite aeroshell has a minimum thickness of 4.70 mm (0.185 in).

Response to Comment 3C:

Aside from the multiple benefits being derived during mission planning, the Cassini mission to the Saturnian system would represent a rare opportunity to gain significant insights into major scientific questions about the formation of the solar system and the conditions that led to life on Earth, in addition to a host of questions specific to the Saturn system. See Section 1.4 of the EIS for further details.

Sections 4.1.6 and 4.2.6 of the EIS discuss the estimated consequences and potential impacts of radiological accidents that could occur during the Cassini mission. These sections provide analyses and information on the potential consequences and impacts on the Cape Canaveral Air Station (CCAS) regional area which is defined in Section 3 (Affected Environment) to include the six-county region surrounding CCAS and Kennedy Space Center (KSC). As discussed in Section 4.1.8 of the EIS, the population which could be affected by a launch accident (near the launch pad) would be the population in the vicinity of CCAS, estimated on the order of 100,000 people.

Response to Comment 3D:

NASA has invested in research and development of solar power technology. Additionally, DOE, the European Space Agency, and other agencies and research centers around the world have been investing in and improving upon solar power technology over the last decade. A number of solar power designs were investigated for the Cassini mission that would utilize unproven yet promising technology (e.g., the Advanced Photovoltaic Solar Array).

NASA studied many different solar, battery, and other power alternatives, including long life fuel cells, available for Cassini and found none that would meet the mission requirements. A Cassini spacecraft equipped with the highest efficiency solar cells available, or fuel cells, or batteries, or combination of these would make the spacecraft too massive for launching to Saturn. Even if a heavy-lift booster were available that could launch the Cassini spacecraft with a massive solar array, such large solar arrays would introduce insurmountable complexity to the mission and would severely jeopardize the chances for mission success. For fuel cells, even assuming the highest currently available energy fuel-per-unit mass and 100 percent efficient conversion (an idealistic assumption since only 60-70 percent is currently feasible), the resulting dry mass (before adding propellants for the spacecraft engines needed for maneuvers in space) would be about 16,000 kg (17.6 tons). It would not be possible to launch Cassini and place it on a trajectory to Saturn if it were that massive, i.e., it would exceed the launch capability of the Titan IV (Solid Rocket Motor Upgrade [SRMU])/Centaur by more than a factor of 2.

Though NASA continues to invest in research and development of solar power technology, the current state of the technology makes solar power infeasible for the Cassini mission to Saturn. See also responses to Comments 1B and 2A.

RESPONSES TO COMMENTS
Commentor No. 3: Horst A. Poehler, Ph.D.
(Continued)

Response to Comment 3E:

As discussed in Section 2.2.8 of the EIS, the Range Safety program must ensure that the launch and flight of space vehicles presents no greater risk to the general public than that imposed by the overflight of conventional aircraft. In addition, safety clearance zones and procedures to protect the public on land, on the sea, and in the air are established and controlled for each launch and launch vehicle at the facilities on the Eastern Range (this would include both CCAS and KSC). Safety control zones are established to protect personnel and resources. Consistent with our Nation's policies for outer space missions such as Cassini, a U.S. launch site is used.

Clearly, year after year, as time passes, larger and larger nuclear missiles will attempted to be launched at KSC/AF. In each case the argument will be the same, "The previous nuclear launches succeeded." Sooner or later, a catastrophic nuclear spill will occur. Its time that NASA build a population-safe nuclear launching site in the remote Pacific. —3E

No place on earth is safe from the reentry of a failed nuclear missile. What if it lands on a population center such as New York, Chicago, Los Angeles, Paris, Rome, London? What will NASA say?. How will they justify their benefit/risk calculation? —3F

How many TitanIV/Centaur missiles have been flown to date? How many were successful.With this paucity of successful launches how can NASA arrive at a realistic estimate of the launch risk ? —3G

The present Florida ground level of plutonium contamination is 0.001 microcurie/sq meter. In case of nuclear contamination by the Cassini launch, NASA proposes that a level of plutonium contamination some 200 times higher than the present level is safe, and harmless to health, for which no de-contaminattion is required. NASA leans back on the EPA, for support that this level will do no harm. One should recognize the element of self interest in such a pronouncement. The higher the level, the less money EPA has to spend to clean up the many nationwide sites that have already been contaminated by nuclear bomb tests, nuclear bomb manufacture, and nuclear power plants. —3H

The health consequences of a plutonium spill are underestimated. In particular the risk to children is not even discussed. Since effects from plutonium contamination may not appear for as long as 20 years. The legacy of NASA's experiment may not appear for decades in the productive life of the children —3I

No mention, or provision, is made of the distribution of respiratory masks for populations in the near vicinity, or the sheltering of schoolchildren indoors. At the time of the last nuclear launch, Galileo, the local media suggested that children and adults hold handkerchiefs to their faces. What a cruel hoax? NASA said nothing,and did not even provide their workers at KSC with respiratory masks.

NASA mentions, but is not deterred, from its own estimates of the following stated impacts, "Where areas of land cover used by man (e.g. buildings, roads, ornamental vegetation) are contaminated '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'" High range cost decontamination methods include, "removal and disposal of all vegetation, removal and destruction of topsoil, destruction of citrus and all other perennial growing stocks, banning of future agricultural land use , demolition of some or all structures, land use restrictions, permanent relocation of affected populations". —3J

RESPONSES TO COMMENTS

Commentor No. 3: Horst A. Poehler, Ph.D.

(Continued)

Response to Comment 3F:

Neither the Titan IV (SRMU)/Centaur nor the Cassini spacecraft can be considered a missile in the sense of nuclear weapon. If impact and release of fuel were to occur in the U.S., the emergency response plan developed specifically for the Cassini mission would be activated, and the extent of contamination would be assessed and appropriate measures taken. If the impact and release were to occur in a foreign country, the U.S. government would offer its technical expertise, if requested, to assess the level of contamination and the need for further mitigation actions.

As population density increases beyond the expectation values used in the analysis, the radiological consequences would increase accordingly. However, the higher potential consequences would be associated with a lower probability event. Therefore, risk defined as a probability weighted consequence (i.e., total probability times consequence) would be similar to that reported for the expectation case in the EIS. Furthermore, as a result of the launch approval process, DOE will be preparing a more in-depth evaluation of the potential environmental consequences as part of the FSAR. NASA will review the FSAR, when it becomes available, and will evaluate the information presented for differences, if any, concerning estimates of potential consequences.

Response to Comment 3G:

As of March 3, 1995, there had been three successful Titan IV (SRM)/Centaur flights. The reliability data for the Titan IV/Centaur, expressed as initiating accident probabilities, are discussed in Section 4.1.5.3 of the EIS. The data were developed using peer-reviewed state-of-the-art assessment methodologies developed by a panel of technical experts in the aerospace industry. The methodologies involved the combination of analytical and failure rate predictions with actual flight history using Bayes Theorem. The theorem allows analytical evaluations to be mathematically combined with observed evidence to develop the probability of failure during a single launch.

Response to Comment 3H:

The consequence and risk estimates reported in this EIS do not assume that cleanup of the contaminated lands occurs in the event of an accident with a release of plutonium. The reported doses, based on the expectation case, in terms of individual doses and doses to the exposed population as a whole, indicate that the estimated radiological dose impacts are small. Mitigation activities described in Section 4.1.9 of the EIS would be employed, where applicable, to reduce radiological impacts even further.

Estimates of land areas potentially contaminated are based on plutonium deposition above a screening level established by the U.S. Environmental Protection Agency of 7.4×10^3 Bq/m^2 (0.2 μCi/m^2). This is a risk-based value at which cleanup actions would be evaluated. It is established independent of prevailing background levels.

Response to Comment 3I:

The radiological consequences of postulated accident source terms in the EIS have been calculated based on internal dose conversion factors presented in International Commission on Radiological Protection (ICRP) Publication 30. As such, these factors apply to adult members of the population. Particle size and age-dependent internal dose conversion factors are treated as part of a model presented in its recently released publication, *Human Respiratory Tract Model for Radiological Protection: ICRP Publication 66, 1995.* ICRP-60 recommends a dose commitment period of 50 years for an adult, as in ICRP-30, and 70 years for children. These new internal dosimetry recommendations are being evaluated and will be implemented, as appropriate, in the radiological consequence analysis being performed for the Cassini FSAR.

Response to Comment 3J:

As discussed in Sections 4.1.9 and 4.2.9 of the EIS, a comprehensive radiological contingency plan would be developed, prior to the launch of the Cassini spacecraft, in accordance with the Federal Radiological Emergency Response Plan. Protective action guidelines and post-accident monitoring would be addressed as part of the contingency planning activities. This contingency plan would be developed through the combined efforts of NASA, DOE, EPA, Federal Emergency Management Agency, the State of Florida, and local organizations involved in emergency responses. Portions of the plan would be practiced to assure that the various organizations were prepared to support the launch.

As discussed in Section 4.1.6.3 of the EIS, an accident occurring in the CCAS regional area could result in up to 1.43 km^2 (0.55 mi^2) of land

RESPONSES TO COMMENTS
Commentor No. 3: Horst A. Poehler, Ph.D.
(Continued)

contaminated above the screening level of 7.4×10^3 Bq/m^2 (0.2 μCi/m^2). The appropriate decontamination or mitigation action would be taken upon further evaluation of the accident consequences.

NASA should poll the people in the area affected by the launch to ask them whether they would be willing to risk their health and property for the sake of increased scientific knowledge of the solar system (even if the risk is estimated by NASA to be exceedingly small). –3K After all, ours is a democracy. Tell the public the truth about the possible consequences of a failed nuclear launch. Only then can NASA hold its head high. –3L

The fatal flaw in NASA's risk assessment is the failure to allow for human error. The disasters of Chernobyl, Challenger, Bhopal, and Valdez were due to human error. A purely technical risk assessment, such as in the Casini DEIS would have said they could not happen. –3M

Horst A Poehler

Horst A. Poehler, Ph D
400 3 Ave , Satellite Beach, FL
32937
Decemberr 9, 1944

RESPONSES TO COMMENTS
Commentor No. 3: Horst A. Poehler, Ph.D.
(Continued)

Response to Comment 3K:

NASA has estimated that the risk to the population near CCAS/KSC would be exceedingly low. The total health effects mission risk to the public (considering all launch phases and the Earth-Gravity-Assist trajectory) for Cassini is provided in Section 4.1.8 of the EIS, and is estimated to be small (about 1.8×10^{-3} health effects).

The National Environmental Policy Act process has afforded the population in the area of the launch the opportunity to convey their concerns regarding possible risks to the public and the environment stemming from the proposed Cassini mission. NASA has given serious consideration to all public comments concerning the Cassini draft EIS.

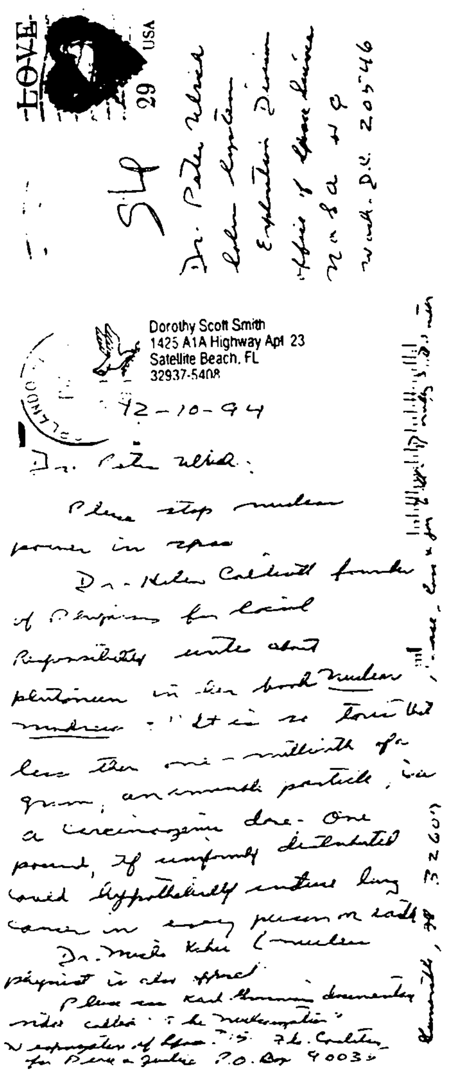
Response to Comment 3L:

Using widely accepted methodologies and best available information, NASA has provided analyses of the consequences associated with a potential launch accident in EIS Sections 4.1.6 and 4.2.6. The analyses indicate that the estimated consequences would be very small.

Response to Comment 3M:

The risk assessment includes the allowance for contributions from human error in several ways. The estimations of the launch failure rates were based in part on historical experience with both the Titan and STS (Shuttle) launch vehicles and in part on estimates of failure sequences that could lead to a severe accident. Human error was an integral consideration in the development of the Titan IV failure probabilities, (i.e. the initiating accident probabilities described in Section 4.1.5.3 of the EIS).

The estimation of the probability of an inadvertent reentry during an Earth swingby also included human error. The estimates are based on historical failure experience with interplanetary spacecraft and their components and on failure sequences that could lead to loss of control of the spacecraft.



S14

Dr. Peter Ulrich
Solar System
Exploration Division
Office of Space Science
NASA HQ
Wash. D.C. 20546

Dorothy Scott Smith
1425 A1A Highway Apt 23
Satellite Beach, FL
32937-5408

12-10-94

Dr. Peter Ulrich:

Please stop nuclear power in space

Dr. Helen Caldicott founder of Physicians for Social Responsibility wrote about plutonium in her book Nuclear Madness: "It is so toxic that less than one-millionth of a gram, an invisible particle, is a carcinogenic dose. One pound, if uniformly distributed could hypothetically induce lung cancer in every person on earth"

Dr. Michio Kaku (nuclear physicist) is also opposed.

Please see Karl Grossman documentary video called "The Nuclearization & Weaponization of Space" Fla. Coalition for Peace & Justice P.O. Box 90035

[illegible], FL 32601

-4A

-4B

RESPONSES TO COMMENTS
Commentor No. 4: Dorothy Scott Smith

Response to Comment 4A:

See response to Comment 2A.

Response to Comment 4B:

The citation on Dr. Helen Caldicott's book, *Nuclear Madness*, reads:

> "...it [plutonium] is so toxic that less than one-millionth of a gram (an invisible particle) is a carcinogenic dose.
>
> One pound, if uniformly distributed, could hypothetically induce lung cancer in every person on earth." (Caldicott, Helen M., *Nuclear Madness What You Can Do*, W. W. Norton & Company, Inc., New York, 1994).

As used in the Cassini mission, the fuel is a high-fired oxide, a stable and relatively insoluble ceramic material. Plutonium is radiologically toxic if deposited in sensitive tissues, such as the lungs. However, it must first be reduced to particle sizes small enough to deposit in the deep lung region. Typically, deep deposition of particles in the lungs requires particle sizes nominally 3 μm and less, equivalent to the 10 μm respirable particle of unit density used by ICRP (ICRP 1979). Larger inhaled particles are removed in the nasopharyngeal and tracheobronchial regions, and can never reach the lung.

The "invisible particle" of one-millionth gram of plutonium referred to by Dr. Caldicott would be, in fact, a single 60 μm diameter plutonium dioxide particle and cannot reach the deep lung region. This "invisible" one-millionth gram actually represents a large number of particles to inhale from the atmosphere if they are to reach the deep lung region. An independent analysis based on the amount of plutonium in human populations around the world resulting from the 6,350 kg (14,000 lb) of plutonium released to the atmosphere from weapons tests, estimated that only about 0.25 g (0.00055 lb) had deposited in the worldwide population (Richmond, Chester R., 1976, "Review of John W. Gofman's Reports on Health Hazards from Inhaled Plutonium," Oak Ridge National Laboratory, ORNL/TM-5257, February 1976). This estimate would be representative of plutonium or plutonium dioxide in a vapor-like state. From these data and a world population of 3 billion at the time, an average uptake factor of 1.3×10^{-17} grams inhaled per gram of plutonium released to the atmosphere can be estimated from atmospheric weapons tests. To achieve a uniform distribution of one pound of plutonium in the world population, equivalent to one ten-millionth (1 x 10^{-7}) not one-millionth (1 x 10^{-6}) gram of plutonium, as stated in Dr. Caldicott's book requires almost 2,000 times the cumulative release of plutonium from all past nuclear weapons tests conducted in the atmosphere. To achieve Dr. Caldicott's one-millionth gram for each person on earth would require about 140,000,000 kg (154,320 tons) of plutonium being released to the atmosphere.

When larger particle sizes are considered, then, in principle, fewer plutonium particles deposited in the deep lung region are required to achieve Dr. Caldicott's one-millionth gram. For example, about 8,400 particles of 3 μm diameter must be deposited in the deep lung region to cause a plutonium lung burden of one-millionth gram. Here again, nature conspires against Dr. Caldicott's assertion in two ways; first, radiological toxicity decreases from "hot particle" effects, and second, it is extremely difficult for a person to breathe and deposit one-millionth gram of plutonium in deep lung tissue. As stated by a leading expert in health physics and radiation biology: "There is no scientific evidence to support the allegation that one millionth of a gram of Pu in 'an invisible particle' will cause lung cancer. Theoretically, a single alpha particle could cause a cancer, but because of the random probabilistic nature of the carcinogenic process, the probability is too remote to calculate. Studies on 'hot particles' have shown them to be less carcinogenic than the same amount of radioactivity diffusely distributed in the tissue." (Declaration of Dr. Marvin Goldman, at paras. 6 and 12, October 5, 1989). The second point relates to the lung's physiology, which limits the fraction of inhaled particles that reach and become deposited in deep lung tissue as the size is increased. On the average only about one in twenty-five (0.04) inhaled 3 μm particles reach and deposit in deep lung tissue (ICRP 1979).

PU1-1214

December 14, 1994

Dr Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA Headquarters
Washington, D.C. 20546

Re: SOLAR v. PLUTONIUM

Dear Sir:

Much thanks for our DRAFT Environmental Impact Startement for the Cassini Mission, received 10/18/94, and for the supplemental memo dated 11/29/94 extending comments deadline.

How can you, as a scientist, go forward in the program to send into space 73 pounds of plutonium 238 and 239 when YOU know (and admit) how "horribly" toxic this substance is? We urge you to forego your pet project! —5A

You infer that it will be quite safe, but just look at the danger if an accident should happen. You surely know a shower of plutionum onto any parts of the Earth would be environmentally devastating (including all peoples' health)! —5B

You also infer that SOLR WOULD BE MORE SAFE than would plutonium. Consider:

A similar expenditure toward perfecting solar power use for space exploration will offer much more beneficial "fallout" toward widespread solar power use by billions of us on earth — than would "safe cantainers" for plutonium, the most dangerous material known.

If you have children and grand children you should be more concerned with solar benefits toward the good health, schools, education, pure water, air and food for future **tax payers to fund** more exploration! —5C

Please redraft or amend the Draft Statement.

Respectfully,

E. Lois + Harvey G Baker

Harvey G. and E. Lois Baker
538½ Magnolia Avenue
Daytona Beach 32114

RESPONSES TO COMMENTS
Commentor No. 5: Harvey G. and E. Lois Baker

Response to Comment 5A:

See response Comment 2A.

Response to Comment 5B:

The radioisotope thermoelectric generators (RTGs) and radioisotope heater units (RHUs) to be used on the Cassini spacecraft have been designed and safety tested to ensure containment of the plutonium (Pu-238) dioxide fuel under most accident environments. The ceramic plutonium (Pu-238) dioxide minimizes the generation of small respirable particles and exhibits a low potential for vaporization in thermal environments in the event some of the fuel is released during an accident. This ceramic fuel form also has a low solubility and is relatively immobile in the environment.

As part of the launch approval process, the Department of Energy (DOE) will be preparing a more in-depth evaluation of the potential radiological consequences as part of the Final Safety Analysis Report (FSAR). NASA will review the FSAR, when it becomes available, and will evaluate the information presented for differences, if any, in the estimation of the potential consequences.

Response to Comment 5C:

NASA is actively studying several future alternate space power sources, including solar cells, and power antennas. NASA has invested substantially in the research and development for such advanced power sources and is continuing to research more efficient technologies. Additionally, the DOE, the European Space Agency, and other agencies and research centers around the world have been investing in and improving upon solar power technology. Historically, NASA's primary choice of power source for planetary missions has been solar, and it continues to use solar power for missions when such technology is applicable. However, the current state of the technology makes solar power infeasible for a deep space mission such as Cassini. See also response to Comment 1B and 1K.

442 Brightwaters Drive
Cocoa Beach, FL 32931
December 14, 1994

Dr. Peter B. Ulrich
Solar System Exploration Division
Office of Space Science
NASA Headquarters
Washington, DC 20546

Dear Dr. Ulrich:

I am responding to the Draft Environmental Impact Statement for the Cassini Mission. I would like to start by saying that I wrote a letter on the subject of the Cassini mission over three years ago, to Howard Wright Cassini Program Manager, expressing my concerns over the use of plutonium as a fuel source. The letter also requested that NASA search for a solar alternative as a fuel source for Cassini and all other missions that would require plutonium RTGs.

When Galileo was launched NASA argued that the solar option was no option, claiming that the technology did not yet exist for deep space probes. At the time of my letter in April, 1991 I reminded NASA that the next mission requiring a plutonium RTG was not until 1995-96. This time should have been used to develop a solar alternative. The fact is that while NASA has tested the Advanced Photovoltaic Solar Array (APSA), no flight testing has been undertaken or even planned. this does not seem like a serious attempt to remove the risk of plutonium contamination for the people of East Central Florida or of the world as a whole (DEIS) 2-55.

–6A

I have spent long hours reading thousands of pages of text over the past several years trying to find the reason for why NASA finds it necessary to put people and the environment under the risk of plutonium contamination. The only reason I have found is a weak one at best. Read from your own Executive Summary/Purpose And Need For The Action (DEIS)V. " With the launch of the Galileo spacecraft in 1989; the program began its transition to exploration-type missions to the outer planets using orbiters and atmospheric probes. The Cassini spacecraft would make remote and close-up measurements of Saturn, its atmosphere, rings, moons, and magnetosphere. This information could also provide significant insights into the creation of the solar system and the conditions that led to life on Earth."

RESPONSES TO COMMENTS
Commentor No. 6: Ronald J. Balogh

Response to Comment 6A:

NASA has invested in research and development of solar power technology. Additionally, the U.S. Department of Energy, the European Space Agency, and other agencies and research centers around the world have been investing in and improving upon solar power technology over the last decade. A number of solar power designs were investigated for the Cassini mission, including designs that would utilize unproven yet promising technology (e.g., the Advanced Photovoltaic Solar Array).

NASA studied many different solar, battery, and other power alternatives, including long life fuel cells, available for Cassini and found none that would meet the mission requirements. A Cassini spacecraft equipped with the highest efficiency solar cells available, or fuel cells, or batteries, or combination of these would make the spacecraft too massive for launching to Saturn. Even if a heavy-lift booster were available that could launch the Cassini spacecraft with a massive solar array, such large solar arrays would introduce insurmountable complexity to the mission and would severely jeopardize the chances for mission success. For fuel cells, even assuming the highest currently available energy fuel-per-unit mass and 100 percent efficient conversion (an idealistic assumption since only 60-70 percent is currently feasible), the resulting dry mass (before adding propellants for the spacecraft engines needed for maneuvers in space) would be about 16,000 kg (17.6 tons). It would not be possible to launch Cassini and place it on a trajectory to Saturn if it were that massive, i.e., it would exceed the launch capability of the Titan IV (Solid Rocket Motor Upgrade [SRMU])/Centaur by more than a factor of 2.

Though NASA continues to invest in research and development of solar power technology, the current state of the technology makes solar power infeasible for the Cassini mission to Saturn. See response to Comment 1B.

Lets look at the purpose for the mission:

The Goal: Again from Executive Summary/Purpose And Need For The Action (DEIS) V. " The goal of the program is to understand the birth and evolution of the solar system."

Well, I quess that can't wait a few years longer to be discovered. If that information is out there it has been for over four and one half billion years, and will be for another four and one half billion years. There is a chance that NASA may have the time to get serious and develop a solar alternative after all. —6B

I will close by asking two things of you. First that you go with the No-Action alternative on Cassini until an alternate fuel source for this mission is ready; solar or any other non-nuclear. —6C Second, only because I do not believe that you will, I request a hearing on the subject where myself and others can intelligently debate the merits of this mission against the risks. —6D

Very truly yours,

Ronald J. Balogh

Enclosures: Letter to Mr. Wright dated April 12, 1991
Letter of request for comment extension to December 20, 1994

RESPONSES TO COMMENTS
Commentor No. 6: Ronald J. Balogh
(Continued)

Response to Comment 6B:

NASA has followed the technical progress in power source technology worldwide for many years. Indeed, a substantial portion of the work in the research and development of solar arrays has been carried out under NASA funding. Historically, NASA's primary selection of a power source for planetary missions has been solar-based, and NASA has continued to use solar power when feasible. While improvements have been made in solar technology, significant breakthroughs are needed to support a mission such as Cassini. Recent international conferences on space power provided no reports of technical breakthroughs that would suggest changing the proposed approach to powering the Cassini spacecraft. The solar power options for Cassini has been extensively reviewed and rejected for this EIS because no U.S. launch vehicle exists with the required lift capacity to conduct a solar powered mission to Saturn using available solar power technologies.

Response to Comment 6C:

See response to Comment 2A.

Response to Comment 6D:

NASA appreciates expression of your views and has considered your comment. If you have any new information or additional pertinent data, which would improve the analysis in the Environmental Impact Statement, please let us know.

442 Brightwaters Drive
Cocoa Beach, FL 32931
April 12, 1991

Mr. Howard Wright
CRAF/Cassini Program Manager,
Office of Space Science & Applications
Code SL, NASA
Washington, D.C. 20546

Dear Mr. Wright:

I am writing to you to express my concerns over the use of plutonium as a fuel source for the CRAF/Cassini Mission and any future missions which would use plutonium as a fuel source.

I live in the City of Cocoa Beach, Florida, and have for the past 19 years. I consider the Kennedy Space Center to be my neighbor and as such would prefer a friendly peaceful coexistence with them.

Currently I find this proposition of peaceful coexistence to be impossible because NASA and the Department of Energy choose on their own accord, to subject my family and myself, my community and environment to a calculated risk of plutonium contamination. These same risks were placed on my community and myself during the Galileo and Ulysses Missions. I did not understand then nor do I now, how NASA has the right to put me or anyone else, man, animal, or natural environment under a calculated risk of the effects of PuO_2.

The simple truth to this matter is that NASA, The Dept. of Energy, or the Federal Government itself does not have this right. This is a great injustice to everyone and everything concerned. I cannot accept this action by NASA. It is arrogance of the highest degree.

The facts to support these calculated risk factors can be found in the Final Environment Impact Statement for the Ulysses Mission (Tier 2), Section 4-33. Section 4-33 (Urban Areas) states and I quote, "If mitigation actions were necessary, temporary relocation of the population from their homes and workplaces my be required." It also states the "Deposition could also have a long-term effect on future investigations at any archaeological site. Archaeological digs, by their very nature, disturb the soil surface with digging and shifting operations, which could expose workers and others to PuO_2." What about our own back yards, does this apply to gardening or planting flowers?

Under <u>Inland Water and Ocean</u>, again Section 4-33, it states "some of the waters surrounding Merritt Island are considered Outstanding Florida Waters. These waters are disignated to receive protection which supercedes any other water classifications and standards, and as such prohibits any activity which reduces water quality paramaters below existing ambient water quality conditions. An ascent phase accident leading to a release could deposit sufficient amounts of PuO_2 to result in violation of this protection standard." This is a prime example of NASA's arrogance in its risk assessment. It knew full well that it might violate this protection and launched Ulysses anyway. In light of what is in NASA's own Environmental Impact Statement, it should be clear why I feel NASA is no longer a neighbor in good standing. They have violated my trust, they have elevated themselves to playing God with my life and where I live. Subjecting me and others to risks, however small, if actualized would be catastrophic.

NASA has argued that the solar option was no option, that the technology did not yet exist for these Deep Space Probes. While that in itself may be arguable, the fact that NASA now has until 1995-96 to develop a solar alternative is not. I implore you to plan solar power as the fuel source for this and all future missions where plutonium RTG's would be used.

Please remember that an individuals rights stop where they infringe on anothers, and this should be true for NASA too.

Sincerely,

Ron Balogh

Ron Balogh

442 Brightwaters Drive
Cocoa Beach FL 32931
December 14, 1994

Dr. Peter B. Ulrich
Solar System Exploration Division
Office of Space Science
NASA Headquarters
Washington, DC 20546

Dear Dr. Ulrich:

I request by way of this letter to extend my comment date to that of December 20, 1994.

Thank You.

Very truly yours,

Ronald J. Balogh

Ronald J. Balogh

RESPONSES TO COMMENTS
Commentor No. 7: Arnie Welber

ARNIE WELBER
9710 N.W. 7 [illegible] CIRCLE
[illegible]
PLANTATION, FLORIDA 33324 U.S.A.

Dec 14, 94

Dr Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Wash., DC 20546

Dear Dr Ulrich,

I have a request. Please suspend plans to launch Cassini space probe to Saturn as long as any plutonium is scheduled to be on board. —7A

My request is in accordance with risk of accident is not worth gamble. —7B

Further use of alternative on-board power sources such as solar energy and long-life fuel cells for all future deep space missions —7C

→

Over

Response to Comment 7A:

See response to Comment 2A.

Response to Comment 7B:

The total health effects mission risk to the public (considering all launch phases and the Earth-Gravity-Assist trajectory) for Cassini has been provided in Section 4.1.8 of the Environmental Impact Statement (EIS), and is estimated to be small (about 1.8×10^{-3} health effects). See Section 1.4 in the EIS for details on the multiple benefits being derived during mission planning. The Cassini mission to the Saturnian system would represent a rare opportunity to gain significant insights into major scientific questions about the formation of the solar system and the conditions that led to life on Earth, in addition to a host of questions specific to the Saturn system.

Response to Comment 7C:

See response to Comment 6A.

Your cooperation is essential.

Sincerely

Mr. Arnold J Welber

SOUTHERN RAINBOW EDUCATION PROJECT(SREP) --- "A FREE-STANDING, MULTI-RACIAL, MULTI-ISSUE COALITION DEDICATED TO THE PRINCIPLE THAT GRASS-ROOTS PEOPLE CAN ACT ON THEIR OWN BEHALF AS THEIR OWN ADVOCATES."
COORDINATING COMMITTEE POLICY, 1989

United Church of Christ
COMMISSION FOR RACIAL JUSTICE - SOUTHERN REGIONAL OFFICE

FAX # (205)262-0932(Please Call First) • Correspond To: (205) 288-5754
46 E. Patton Avenue • Montgomery, Alabama 36105

December 15, 1994

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, D.C. 20546

Dear Dr. Ulrich:

It is irrational to think that 73 pounds of plutonium 238 and 239 on board a space craft will not be dangerous. To discuss accident "probability" is an admission of its dangers. —8A

We urge you to read Dr. Caldicott's NUCLEAR MADNESS. She states: "It (Cassini--Titan 4 rocket) is so toxic that less than one-millionth of a gram, an invisible particle, is a carcinogenic dose. One pound, if uniformly distributed, could hypothetically induce lung cancer in every person on Earth." —8B

Does science care about human beings and other inhabitants on the earth? We urge you to desist in moving forward with this deadly project. This is not progress; this is destruction. —8C

Sincerely yours,

Gwendolyn M. Patton

Dr. Gwendolyn M. Patton, SREP Program/Field Director

RESPONSES TO COMMENTS

Commentor No. 8: Southern Rainbow Education Project (SREP) (Gwendolyn M. Patton)

Response to Comment 8A:

See response to Comment 2A.

Response to Comment 8B:

See response to Comment 4B.

Response to Comment 8C:

NASA and the Department of Energy take very seriously the possibility that an action that they take could potentially result in human fatalities or harm to the environment. Therefore, both agencies have gone to great lengths to reduce the potential for such events, both through design of the radioisotope thermoelectric generators and through design and operation of the spacecraft and its mission. As a result of these designs, the risks of fatalities or harm to the environment from the Proposed Action are considered to be very low. See Sections 4.1.5.2 and 4.2.5.1 of the Environmental Impact Statement for more details on launch phase accident scenarios.

RESPONSES TO COMMENTS
Commentor No. 9: Anna B. Pilson

Dec 15, 1994

Dr. Peter Ulrich
Solar Systems Exploration Division
Office of Space Science
NASA HQ
Washington DC 20546

Dear Dr Ulrich:

To help make the future safer for this, and future generations, of *your* family, mine and the rest of ~~inocent~~ innocent members of the human family, as well as yours, *STOP* the *plans* ~~of~~ of the Cassini plutonium mission. –9A

Even now there has been too much JUNK blasted into *our* space.

No MORE PLUTonium to be free, in the only space shared by all living beings.

I have children and grandchildren, and worry about yours. Don't you? –9B

Sincerly
Anna B. Pilson

ANNA B. PILSON
1479 OLD KINGS RD.
HOLLY HILL, FL 32117-1927

Response to Comment 9A:

We appreciate your concern in taking the time to read and comment on the Draft Environmental Impact Statement (EIS). See response to Comment 2A.

Response to Comment 9B:

NASA and the Department of Energy take very seriously the possibility that an action that they take could potentially result in human fatalities or harm to the environment. Therefore, both agencies have gone to great lengths to reduce the potential for such events, both through design of the radioisotope thermoelectric generators and through design and operation of the spacecraft and its mission. As a result of these designs, the risks of fatalities or harm to the environment from the Proposed Action are considered to be very low. See Sections 4.1.5.2 and 4.2.5.1 of the EIS for more details on launch phase accident scenarios.

CANCEL CASSINI
No Plutonium in Space

We, the undersigned, call upon NASA and our elected officials to suspend plans to launch the Cassini space probe to Saturn as long as any plutonium is scheduled to be on board. Presently, the project calls for 73 pounds of plutonium 238 to generate on-board electricity. The risk of an accident at launch or during its "slingshot fly-by" above the Earth is not worth the gamble. We urge the use of alternative on-board power sources such as solar energy and long-life fuel cells for all future deep space missions.

10A
10B
10C

NAME ADDRESS

1. Donna Jay Ellis/Rt 3-Box 159-2/Springtown Tx 76[illegible]
2.
3. Dear Dr Ulrich ——
4. I am a former VISTA VOLUNTEER — US Domestic Peace Corp —
5. I love my country, United States of America — The Best
6. Possible Nation To Live, we enjoy the most freedoms, more civil, human
rights than anywhere, we are truly a blessed people — But with our
rights + priviledges we have obligations as citizens to voice our
9. opinion to our public officials — ~~for~~ you — + others — to consider our
10. opinions + views as citizens of this country ——
11. Mine are ——
12. Suspend plans to launch Cassini space probe to Saturn with plutonium aboard
13. Our God-given earth — people — all creatures — are too precious to
14. all involved — including our God that created it for our use. —
15.
16. temporarily — to subject any involved — to such a risk! —— Ever!
17.
18. Thank you very much for listening + considering my opinions + views
19. on this — I fulfill my obligation as a responsible citizen here, +
20. respectfully request your comments + decision concerning this
21. situation — I await your response — eagerly —
22. Sincerely
23. Donna Jay Ellis —
24. December 16, 1994
25.

10D

Return to the Florida Coalition for Peace & Justice • P.O. Box 90035 • Gainesville, Fl 32607 • 904/468-3295

RESPONSES TO COMMENTS
Commentor No. 10: Florida Coalition for Peace & Justice
(Donna Ellis)

Response to Comment 10A:

See response to Comment 2A.

Response to Comment 10B:

See response to Comment 7B.

Response to Comment 10C:

See response to Comment 6A.

Response to Comment 10D:

NASA and the Department of Energy take very seriously the possibility that an action they take could potentially result in human fatalities or harm to the environment. Therefore, both agencies have gone to great lengths to reduce the potential for such events, both through design of the radioisotope thermoelectric generators and through design and operation of the spacecraft and its mission. As a result of these designs, the risks of fatalities or harm to the environment from the Proposed Action are considered to be very low. See Sections 4.1.5.2 and 4.2.5.1 of the Environmental Impact Statement for more details on launch phase accident scenarios.

We appreciate your concern in taking the time to respond to the draft Environmental Impact Statement.

South Dakota Peace and Justice Center

SOUTH DAKOTA PEACE AND JUSTICE CENTER

I want to see
a mighty flood of justice—
a torrent of doing good
Amos 5:24

P.O. Box 405
Watertown, SD 57201
(605)882-2822

December 16, 1994

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, DC 20546

Dear Dr. Ulrich,

In the minds of so many Americans, the cost of space programs is justified chiefly because of the spinoff of technologies that can help our nation and the world realize a better life.

Let us pose the question: which technology development would advance the quality of life—development of plutonium power systems for deep space probes or development of solar-powered systems for deep space probes?

Given that plutonium is fiendishly toxic and carcinogenic and given that solar-powered systems are well within technical reach for space probes and could spin off into sustainable energy technology that the earth is literally dying for want of, the answer to the question is obvious. —11A

Why no serious commitment to solar power for the 1997 Cassini mission to Saturn? I can assure you that the 700 plus members statewide of the South Dakota Peace & Justice Center will be vigorously lobbying against funding for NASA projects, such as a plutonium-powered Cassini mission, which fly in the face of common sense at the least and may even be said to demonstrate a death wish for our culture and our living world. —11B

Sincerely,

Jeanne Koster

Jeanne Koster, staff

copies to Sen. Pressler, Sen. Daschle,
Rep. Tim Johnson, Bruce Gagnon

Printed on recycled paper ♻

RESPONSES TO COMMENTS
Commentor No. 11: South Dakota Peace and Justice Center
(Jeanne Koster)

Response to Comment 11A:

NASA continues to invest in solar and other technologies for space applications. NASA's investment along with that of other Federal research and development programs has yielded advances in solar technologies that are in widespread use today. See also response to Comment 3D.

Response to Comment 11B:

NASA has estimated the risks from plutonium (Pu-238) dioxide onboard the Cassini spacecraft and has found the risks to the world population and our planet to be very low. The risks from the launch of Cassini would be lower than many of the risks that we face in our everyday lives (see Table 4-20 in the Environmental Impact Statement). A wide range of potential accident scenarios was evaluated. See also response to Comment 1K.

RESPONSES TO COMMENTS
Commentor No. 12: Phil Seligman

4505 S.W. 89 Ave
Miami, Fl. 33165
12/17/94

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA Hq.
Washington, DC 20546

If indeed the Cassini space probe to Saturn plans to use of plutonium 238 to generate on-board electricity, I wish to register my most urgent entreaty to reconsider this most dangerous gamble with the potential for calamitous effects in the event of a space accident. —12A

Recent advances in development of high efficiency solar cells and long life fuel cells offer alternative source of power. —12B

Sincerely,
Phil Seligman

Phil Seligman

Response to Comment 12A:

NASA appreciates expression of your views. Please see response to Comment 7B for more information.

Response to Comment 12B:

See responses to Comments 3D.

RESPONSES TO COMMENTS
Commentor No. 13: Warren & Olive Wilson

5910 440th St.
Primghar, Ia
12-17, 1994

Dr. Peter Ulrich
Solar System Exploration Div.
Office of Space Science
NASA Headquarters
Washington, D.C. 20546

Dear Peter Ulrich:

You and the Department of Energy have indicated in the Impact Statement for the 1997 Cassini space mission to Saturn that the 73 pounds of plutonium 238 + 239 on board will be of little danger.

We urge you to restudy and realize the danger that <u>is</u> there. – 13A

Dr. Helen Caldicott writes about plutonium in her book <u>Nuclear Madness</u>. "It is so toxic that less than one-millionth of a gram, an invisible particle, is a carcinogenic dose. One pound, if uniformly distributed, could hypothetically induce lung cancer in every person on earth." – 13B

The risk of an accident at launch or during its "slingshot fly-by" above the Earth is not worth the gamble. – 13C

We urge the use of alternative on-board power sources such as solar energy and long-life fuel cells for all future deep space missions. – 13D

Warren & Olive Wilson

<u>Response to Comment 13A:</u>

NASA considers the risk analysis presented in the Environmental Impact Statement (EIS) to be the best estimate based on the available information at the time. As part of the launch approval process, the Department of Energy will be preparing a more in-depth evaluation of the risks as part of the Final Safety Analysis Report (FSAR). NASA will review the FSAR, when it becomes available, and will evaluate the information presented for differences, if any, in the estimates of the potential radiological consequences and risks.

<u>Response to Comment 13B:</u>

See response to Comment 4B.

<u>Response to Comment 13C:</u>

The total health effects mission risk to the public (considering all launch phases and the Earth-Gravity-Assist trajectory) for Cassini has been provided in Section 4.1.8 of the EIS, and is estimated to be small (about 1.8 x 10^{-3} health effects).

<u>Response to Comment 13D:</u>

See response to Comment 3D.

12/18/94

Dear Ulrich,

I am writing in protest of the Cassini plutonium mission.

① If the probe crashed to earth, about 2/3 of the plutonium would fall to the ground. — 14A

② Plutonium is so toxic that less than 1 millionth of a gram is a carcinogenic dose.

③ If uniformly distributed, one pound of plutonium could induce lung cancer in every person on earth. — 14B

Sincerely,

Mary Ann Lawrence

Dr. Mary Ann Lawrence
5951 SW 45th Way
Fort Lauderdale, FL 33314

RESPONSES TO COMMENTS

Commentor No. 14: Dr. Mary Ann Lawrence

Response to Comment 14A:

The inadvertent reentry accident during an Earth swingby is addressed in Section 4.1.5.4 and Appendix B of the Environmental Impact Statement (EIS). The analyses of this accident show that about one-third of the plutonium dioxide fuel will be released as particles at high altitudes. During the reentry of these particles, about 37 percent will be converted to vapor and small particle sizes, which remain and disperse in the atmosphere gradually reaching the ground over many years. The larger particles will reach the ground much faster under the influence of gravity. The unreleased two-thirds of the fuel is contained in GPHS heat source components that survive the atmospheric reentry. Intact modules will fail and release some fuel if they impact on hard rock and the graphite impact shells will fail and release some fuel if they impact land. Impacts on hard rock are expected to occur only 4 percent of the time and on land masses about 25 percent of the time. All these factors affecting the behavior of the RTGs in the unlikely event of an inadvertent reentry accident are considered in the information contained in the EIS.

Response to Comment 14B:

See response to Comment 4B.

NATIONAL
SPACE SOCIETY

December 19, 1994

Dr. Peter B. Ulrich
Solar System Exploration Div.
Office of Space Science
NASA Headquarters
Washington, DC 20546

RE: *Cassini Draft Environmental Impact Statement*

Dear Mr. Ulrich:

I am writing in response to the draft environmental impact statement for the *Cassini* mission. Before providing my comments, however, I wish to note that the National Space Society commented on many topics raised by the *Cassini* draft EIS in an earlier proceeding. That was the notice of February 27, 1991, published at 56 Federal Register 8219. The *Cassini* Draft EIS makes no reference to those comments, and does not seem to take them into account. That is frustrating; we are often told that the voices of grassroots space interests should be heard more, only to discover that when we talk, people at NASA aren't always listening. I am attaching a copy of the letter in question for your information. — 15A

Comments on the EIS

Our strongest complaint, echoing the comments that we made almost four years ago, is that the EIS understates the costs of a "no-action" alternative. As has consistently been the problem with NASA Environmental Impact Statements for deep-space missions (see, for example, the *Ulysses* and *Galileo* Statements), the *Cassini* draft EIS fails to recognize the very significant adverse *environmental* effects of a no-action alternative. Instead, the costs of cancelling the mission are characterized strictly in terms of lost scientific opportunities.

Although we agree that there would be substantial costs in terms of lost scientific knowledge, we do not believe that these are the only costs involved. The rather artificial and truncated scope of most Environmental Impact Statements tends to overstate the importance of risks, and understate the importance of benefits, in evaluating whether to proceed. NSS believes that the long-term environmental benefits stemming from a better understanding of our solar system, and the material and energy resources available there, are significant and should be weighed against the short-term environmental risks involved in undertaking the missions. — 15B

922 PENNSYLVANIA AVE., SE
WASHINGTON, DC 20003
202/543-1900
FAX 202/546-4189

RESPONSES TO COMMENTS
Commentor No. 15: National Space Society
(Glenn Harlan Reynolds)

Response to Comment 15A:

While not directly referencing the comments contained in the National Space Society letter of April 12, 1991, the Environmental Impact Statement (EIS) attempted to be responsive to the three concerns raised—optional power sources, Earth flyby architecture, and the No-Action alternative. Options for onboard power sources for electric power requirements are addressed in Section 2.6.3 of the EIS with supporting documentation prepared by the Jet Propulsion Laboratory (JPL) (see JPL 1994, *Cassini Program Environmental Impact Statement Supporting Study, Volume 2: Alternative Mission and Power Study*. JPL Publication D-11777, Pasadena, CA, July 1994). In addition, NASA's response to Draft EIS Comment 6A provides additional amplification on the issue of optional power sources. The Earth flyby architecture is discussed in detail in Sections 2.2, 2.4 and Appendix B with supporting documentation prepared by JPL (JPL 1993f, *Cassini Environmental Impact Statement Supporting Study, Volume 3: Cassini Earth Swingby Plan*. JPL Publication No. D-10178-3, Pasadena, CA, addendum dated August 1994). See response to Comment 15B for a discussion of the No-Action alternative.

Response to Comment 15B:

See Section 4.4 of the EIS for a discussion of the No-Action alternative. NASA agrees that the potential long-term environmental benefits from understanding the solar system and the material resources there, would be significant. Missions such as Cassini are a significant part of the U.S. space exploration program and afford an opportunity to gather data from both planned and unplanned activities. As with other NASA missions, history suggests that the ultimate value of such deep space exploration may well be in something we cannot envision at the current time—the serendipitous potential that makes exploration so exciting and full of discovery. Solar system exploration improves our understanding of the chemical and physical conditions needed to foster the development of life. The benefit society reaps from this new understanding is difficult to quantify, but it is notable that the study and understanding of many terrestrial problems (e.g., global climate change) have benefitted from techniques and theories arising from space exploration.

We believe that missions such as Cassini will play a vital role in helping us learn to identify resources that may later be exploited to the benefit of mankind. Over the long term, we believe that the entire solar system is a part of humankind's resource base, and that a key environmental goal is to move polluting industries -- including extractive ones -- off the earth's surface and out of its biosphere. In this way, the long term health of the earth's environment is entirely consistent with -- and in fact assured by -- a vigorous program of space exploration and settlement. (See our position paper, "Outer Space and the Global Environment," a copy of which is attached, for more detail on this topic). —15B

Such a program of space settlement has already been endorsed by President Clinton during the campaign, (and by his predecessor, President Bush, in his July 20, 1989 speech) and by Congress, in the Space Settlements Act of 1988, Pub. L. 100-685, 102 Stat. 4083 (1988). If we are to continue to lay the groundwork (so to speak) for later human expansion throughout the solar system, missions like Cassini play an essential role --just as early exploration missions, like those of Lewis and Clark or Zebulon Pike, played a vital role in the opening up of the American West for settlement.

Abandoning -- or even substantially delaying -- these missions of exploration would have significant costs in terms of impeding progress toward this important national goal, and a substantial portion of those costs would be environmental in nature. We believe that NASA has the responsibility -- both statutory and moral -- to weigh this cost in the balance in assessing the "no action" alternative. Therefore, we believe that the "no action" alternative should be invoked *only* when the risks of a mission are unacceptable beyond any reasonable doubt. —15C

For these reasons, we recommend the insertion of the following paragraph at section 4.4, Draft EIS page 4-103:

> A risk of the no-action alternative is that we will fail to develop the understanding of the dynamic processes governing climate and environment on other planets that will permit us to fully understand those processes on our own planet, with the concomitant risk that we may not recognize dangers to the earth's environment stemming from human activities in time to prevent significant environmental harm. A further risk of the no-action alternative is that a failure to lay the groundwork for a spacefaring civilization that makes use of off-earth resources will retard the creation of such a civilization, lengthening the period of time when human activities will impose a strain on the environment and resources of the earth.

An environmental impact statement that fails to recognize these costs of mission cancellation is inadequate.

The Politics of RTGs

Our discussion of the *Cassini* EIS would be incomplete without mentioning that NASA has come under substantial political pressure from antinuclear activists regarding its use of radioisotopic thermoelectric generators in various deep-space probes such as *Cassini*,

RESPONSES TO COMMENTS
Commentor No. 15: National Space Society
(Glenn Harlan Reynolds)
(Continued)

In preparing Section 4.4 of the Draft EIS, NASA attempted to confine itself to the more quantifiable impacts of the No-Action alternative. In doing so, NASA tended to be somewhat conservative. NASA therefore has revised the text of Section 4.4 to emphasize the loss of potential benefits and knowledge that would be gained from the Cassini mission, such as our understanding of Earth's processes.

Response to Comment 15C:

Council on Environmental Quality (CEQ) regulations require that NASA evaluate the environmental impacts of the No-Action alternative along with those of the Proposed Action and other reasonable alternatives.

Ulysses, or *Galileo*. In the case of the *Ulysses* mission, NSS participated as a friend-of-the-court in support of the mission, and we will likely do so with regard to *Cassini* if litigation ensues.

The opposition of antinuclear groups to RTG-powered deep space missions has more to do with publicity-seeking and direct-mail fundraising than with any real concerns about the safety of RTGs. In addition, some of these groups fear (against all reason) that such programs are simply stalking-horses for some kinds of massive nuclear-powered antimissile battle stations that they expect the Department of Defense to construct. While NSS neither supports nor opposes military uses of space as such, we consider these fears to be both absurd and irrelevant to the question of whether missions such as *Cassini* are safe. We remain concerned, however, as we were in our 1991 letter, that fear of political opposition from antinuclear groups may cause NASA in the future to adopt mission architectures or strategies that are driven by political, rather than engineering concerns. We stress that any mission design should be based on sound scientific and engineering judgment, not on political concerns. – 15D

Conclusion

We consider the *Cassini* draft EIS to be an adequate statement (if occasionally an overstatement) of the risks involved in the mission. Its chief deficiency lies in a failure to address the very real environmental consequences of a no-action alternative. We urge the revision of the *Cassini* draft EIS to reflect this important concern.

Sincerely,

Glenn Harlan Reynolds
Executive Chairman, National Space Society

attachments:
Comments to Howard Wright, 4/12/1991
NSS Environmental Position Paper
NSS Comments, *Ulysses* Draft EIS, 4/6/1990

Response to Comment 15D:

The design of the Cassini mission and the spacecraft will be based on engineering and environmental analyses taking into account scientific benefits, risk assessment and available resources.

April 12, 1991

Mr. Howard Wright
CRAF/Cassini Program Manager
Office of Space Science and Applications
Code SL
National Aeronautics and Space Admin.
Washington, D.C. 20546

RE: Outer Solar System Exploration Program, 56 FR 8219

Dear Mr. Wright:

In response to your notice of February 27, 1991, published at 56 Federal Register 8219, here are the views of the National Space Society regarding environmental issues associated with new outer solar system exploration programs. The National Space Society is a grassroots public interest organization, with over 120 chapters and over 30,000 members, dedicated to the creation of a spacefaring civilization. That goal underlies the character of our response.

In your notice, you listed three primary issues to be addressed in the CRAF/Cassini Environmental Impact Statement. These issues involve the feasibility and desirability of the following alternatives to the baseline mission plan: (1) use of alternative (non-nuclear) power sources; (2) use of trajectories involving planets other than earth for fly-by assists (or, in a more accurate formulation, a ban on earth gravity assists); and (3) the "no action" alternative. NSS' views are as follow.

Alternative Power Sources

NSS takes no position on whether alternative power sources are feasible; we consider that to be an engineering question which is far more thoroughly within NASA's competence than within our own. However, we believe that this question should continue to be treated as an engineering question. Notwithstanding political agitation by various antinuclear groups (whose real agenda seems more related to stopping the Strategic Defense Initiative than to improving civilian space mission planning), NSS believes that NASA should choose power sources based solely on engineering concerns: what configuration best assures that the mission will achieve maximum capability (including reliability) at minimum cost. NSS would <u>strongly oppose</u> the selection of an alternative nonnuclear power source purely for political reasons. We believe that if NASA were to do so, it would be violating its responsibility to taxpayers to produce the best mission at the least cost.

Having said this, we do believe that where solar power is just as suitable on an engineering basis as nuclear power, the safety concerns relating to the use of space nuclear power may appropriately serve as a tie-breaker. Although we consider the risks involved in using nuclear power onboard deep space probes to be minor, they are not zero, and are undoubtedly greater than those associated with the use of solar power.

Ban on Earth Flyby Architectures

NSS' views on the use of earth flyby assists are very similar to those expressed above. We believe that the risks associated with such endeavors are low, and do not believe that mission capabilities should be sacrificed, or missions canceled, solely in order to avoid an earth flyby. Once again, we believe that decisions on whether to use an earth flyby should be made solely on the basis of sound engineering and astrodynamical judgment. Where the the use of gravity assists involving planets other than earth is equally effective in terms of mission capabilities, we would favor avoiding an earth flyby, but again we regard the risk involved in such flybys to be so minor as to make it no more than a tie-breaker in deciding between otherwise comparable trajectories.

The "No Action" Alternative

NSS' views are strongest in regard to the question of how the "no action" alternative should be evaluated. The rather artificial and truncated scope of most Environmental Impact Statements tends to overstate the importance of risks, and understate the importance of benefits, in evaluating whether to proceed. NSS believes that the long-term environmental benefits stemming from a better understanding of our solar system, and the material and energy resources available there, are significant and should be weighed against the short-term environmental risks involved in undertaking the missions.

We believe that missions such as Cassini -- and, much more significantly, CRAF -- will play a vital role in helping us learn to identify resources that may later be exploited to the benefit of mankind. Over the long term, we believe that the entire solar system is a part of humankind's resource base, and that a key environmental goal is to move polluting industries -- including extractive ones -- off the earth's surface and out of its biosphere. In this way, the long term health of the earth's environment is entirely consistent with -- and in fact assured by -- a vigorous program of space exploration and settlement. (See our position paper, "Outer Space and the Global Environment," a copy of which is attached, for more detail on this topic).

Such a program of space settlement has already been endorsed by President Bush -- in his speech of July 20, 1989 -- and by Congress, in the Space Settlements Act of 1988, Pub. L. 100-685, 102 Stat. 4083 (1988). If we are to continue to lay the groundwork (so to speak) for later human expansion throughout the solar system, missions like CRAF and Cassini play an essential role --just as early exploration missions, like those of Lewis and Clark or Zebulon Pike, played a vital role in the opening up of the American West for settlement.

Abandoning -- or even substantially delaying -- these missions of exploration would have significant costs in terms of impeding progress toward this important national goal. We believe that NASA has the responsibility -- both statutory and moral -- to weigh this cost in the balance in assessing the "no action" alternative. Therefore, we believe that the "no action" alternative should be invoked <u>only</u> when the risks of a mission are unacceptable beyond any reasonable doubt.

<u>Conclusion</u>

The space mission-planning process seems to have been politicized in the wake of the <u>Ulysses</u> and <u>Galileo</u> launch controversies. NSS believes that this politicization is unfortunate, and that those antinuclear groups who have opposed such launches do not reflect the public interest, and in fact are themselves not particularly interested in the launches and missions in question except as an opportunity to open an additional front in their ongoing campaign against the Strategic Defense Initiative. NSS, as a group favoring the expansion of civilization into outer space, takes no position on the Strategic Defense Initiative. However, we would not wish to see programs that we <u>do</u> support become the victims of "collateral damage" from someone else's war. For this reason, we urge again that NASA make its decisions on mission power and architecture solely on the basis of sound engineering judgment, and that it not allow itself to be swayed by the political campaigns of policy entrepreneurs.

Sincerely,

Glenn Harlan Reynolds
Chair, NSS Legislative Committee
and Member, Board of Directors

Attachment:
NSS Environmental Position Paper

RESPONSES TO COMMENTS
Commentor No. 15: National Space Society
(Glenn Harlan Reynolds)
(Continued)

NATIONAL
SPACE SOCIETY

Outer Space and the Global Environment: An NSS Position Paper

> I viewed my mother quite differently when I was in the womb than I did after birth. Afterward, I was able to take more responsibility for her.
> -- Astronaut Russell Schweickart

Human activity in outer space has already had important ramifications for the Earth. As early as 1949, astronomer Fred Hoyle predicted that "Once a photograph of the Earth, taken from the outside, is available, a new idea as powerful as any in history will be let loose." And so it was, once Apollo astronauts brought back photographs of the Earth from hundreds of thousands of miles away. Among the ideas let loose was the concept of the Earth as a whole, as a system of interrelated parts in which national boundaries were of little importance. Our planet, seen as a small, fragile object amid a sea of blackness and emptiness, became widely known as (significantly enough) "spaceship Earth." It is no coincidence that the first Earth Day took place shortly after these photos became available, and used one of them as its symbol. The consequences of this change in attitudes continue to be played out.

That change would be colossally important even if it were the only impact of the space program on environmental matters. But it is not. On closer examination, it is clear that the creation of a spacefaring civilization and the preservation of Earth's environment are not only complementary, but are in many ways the same. In fact, over the long term, we believe that human expansion

922 PENNSYLVANIA AVE., SE
WASHINGTON, DC 20003
202/543-1900
FAX 202/546-4189

into space is not only essential to the preservation of Earth's environment, but in fact will play an important role in promoting the spread of life throughout the solar system and beyond, something that we regard as perhaps humankind's most important role. Following are some examples, in both the near term and the longer term, of how space activity is part of a sound strategy for preserving and restoring environmental quality here on Earth. And following those examples is a larger view of why both environmental preservation and human expansion throughout the solar system are important.

Near Term: Space as a Global Management Tool

Short of killing off the human species altogether, preserving the Earth's environment requires that we understand the impact that our activities have on our planet, and adjust our activities to minimize the harm that we do. This kind of understanding is hard to come by, but many space-related projects play a part.

First, satellite observation of the Earth is vital. It was a NASA satellite, Nimbus 7, that first verified the Antarctic ozone hole -- an observation that led to our understanding of how chlorofluorocarbons (CFCs) can lead to the depletion of stratospheric ozone, which in turn led to the beginning of efforts to bring CFC pollution under control. Similarly, LANDSAT and SPOT photos have dramatized the extent of deforestation in the Amazon, of desertification in Africa and Asia, and of ocean pollution in many areas. And, aside from spotting crisis situations, satellite imagery plays a vital part in the mundane-but-important process of managing farmland, forests, and public lands generally. The planned Earth Observing System, better known as "Mission to Planet Earth," will drastically expand the amount of data available, and, with it, our ability to understand the Earth in order to save it.

Second, the understanding we gain from observing other parts of the solar system also serves to increase our understanding of the Earth. Studies of the Martian climate by the Mariner and Viking probes were instrumental in the development of climatic models that were later used in assessing threats like global warming and nuclear winter. Studies of the solar climate by probes like Ulysses will shed additional light on global warming and ozone depletion, and give us some sense of the extent to which Earthly climate change is driven by solar variation. And studies of other planets in general -- from Venus, with its runaway greenhouse effect, to Mars, with not enough of one -- underscore the fragility of climate, and the preciousness of our Earth. Good planets, as we have learned, are hard to find.

Longer Term: Space as Safety-Valve

There are many -- perhaps too many -- people on Earth. For several decades, at least, their numbers are likely to expand. This large population puts enormous, and growing, stress on the Earth's biosphere and resource base. Yet, paradoxically, it is not the creation of too much wealth, but the creation of too much poverty, that has produced most of the Earth's environmental problems.

Poverty is bad for the environment. Poor people burn wood for fuel -- leading to deforestation and aggravating the greenhouse effect. Poor people cut down rain forests for farmland, and mediocre farmland at that, with the same results. Poor people have many children, increasing the pressure on resources further, and making it harder to break the cycle of poverty.

But this does not mean that the industrial nations are less to blame. For they, too, are poor, except by comparison with those worse off. They burn oil and coal for fuel, creating acid rain and contributing to global warming. They remove large quantities of resources from the Earth's crust -- so large that the poorer countries could never equal their living standards, even in the absence of other barriers, because there is not enough to go around. And their economies pollute the Earth so much that elevating the poorer nations to their standards of living, if it were possible at all, would be ruinous to the Earth's ecosystem.

In both cases, though, the reason isn't malevolence, or immorality. "Rich" and poor nations alike do the damage that they do largely because they have no other way to live -- because they lack the resources and knowlege needed to do better. Space programs can change that. If we draw on space resources, then we are not limited to the resources, whether of materiel or energy, locked in the Earth's crust, resources that will run out within a few centuries no matter how stringently they are conserved. Within a century, and perhaps much sooner, it will be practical to obtain many minerals from the Moon and asteroids, meaning that destructive and unsightly mining and smelting on Earth will no longer be needed. Energy, too, can come from space: from orbital solar power plants, from similar facilities on the Moon, or even potentially from fusion plants powered by lunar Helium-3, eliminating the use of fossil fuels.

Over the long term (meaning perhaps two human lifetimes), it will be possible to move most polluting industries off the Earth, and into space. And the industries that remain can be made far less polluting through the use of clean, inexpensive energy derived from space. If this is done, Earth can be returned to a level of environmental health not seen since the industrial revolution began -- and without the need to kill off humanity by the billions, or to condemn poor nations to poverty for eternity.

The Big Picture: Space and the Expansion of Life

> The Earth is the cradle of humanity -- but one cannot remain in the cradle forever.
> --Konstantin Tsiolkovsky

For as long as anyone remembers, humans have been wondering about their place in the world. Why are we here? And what makes us different from the rest of life on this planet?

For the past several decades, there has been at least one major difference. We are the only species that has the ability to leave. Space activists have not fully considered the environmental implications of this fact -- but then, neither have environmentalists.

There are two possible ways to view the environmental movement. In its misanthropic form, it may be seen as based on a Romantic hostility to humanity and its works. Space has nothing to offer those who hold this negative view. But in a broader form, the environmental movement can be seen as dedicated to the flourishing of life, both in quantity and diversity, as a primary good. In this more positive formulation, the works of humanity are good or bad depending on whether they contribute to the flourishing of life, or harm it.

The expansion of humanity into space has a lot to offer those who hold this view. As humanity settles space, it will carry parts of the Earth's biosphere -- plants and animals -- along with it. Perhaps this is humanity's real role. If one believes in the so-called <u>Gaia</u> hypothesis, under which all life on Earth can be viewed in a sense as one meta-organism, perhaps our role is that of meta-gametes, carrying the seeds of life throughout the solar system, and eventually beyond, thus spreading life to places where it could not have evolved on its own, and which it could not have reached in other ways. And even if one does not adhere to the <u>Gaia</u> hypothesis, the spreading of life seems a good thing in itself.

This is a vital role for the space program, but not just for <u>any</u> space program. To support the "greening of the solar system," we must have a robust, vigorous space program that does more than merely send robotic probes to distant planets. We must have a space program capable of fostering a true spacefaring civilization, one in which travel throughout the solar system -- and eventually beyond it -- is routine, and comparatively affordable. That is NSS' goal and it is, we think, one that is profoundly in accord with the true goals of the environmental movement.

NATIONAL
SPACE SOCIETY

April 6, 1990

Dr. Dudley G. McConnell
NASA Headquarters
Code EL
Washington, DC 20546
Via Express

RE: NSS Comments on Ulysses Draft EIS

Dear Dr. McConnell:

In response to NASA's request for public comments, 55 Fed. Reg. 6326 (February 22, 1990), the views of the National Space Society (NSS) follow. NSS is a nationwide grassroots organization dedicated to the exploration and development of outer space and to the creation of a spacefaring civilization. Formed by the merger of the National Space Institute and the L5 Society, NSS has tens of thousands of members nationwide, and affiliate organizations throughout the world. Furthermore, NSS' views generally represent those of the substantial majority of all Americans that strongly supports an expansive and ambitious space program.

Scope of Comments

Because NSS believes that NASA has examined the issues in more than adequate scope and detail, and because NASA possesses expertise and experience in dealing with missions of this kind that no private organization can possibly hope to equal, NSS will not engage in a detailed examination of the technical issues addressed in the Environmental Impact Statement, particularly as NSS would have little to add to NASA's already thorough treatment. Instead, NSS will stress items omitted from the EIS, or given inadequate treatment therein, that NSS believes should have an important impact on the decision whether to proceed with the mission. In short, NSS is of the opinion that the EIS takes inadequate cognizance of the importance of the Ulysses mission in terms of the benefits, as well as potential detriments, that the mission will involve for the earth environment.

922 PENNSYLVANIA AVE SE
WASHINGTON DC 20003
202-543-1900

The Ulysses Mission and Its Importance

The Ulysses mission is of vital importance for a variety of reasons, some connected with scientific information gathering in the abstract, others connected with more down-to-earth problems. Since Ulysses will gather information regarding previously unobserved solar regions (the poles), it is an essential part of gathering a meaningful understanding of how the Sun, and the solar climate, works. One would not, after all, expect to understand the earth's climate without understanding what goes on at the poles; indeed, most climatological theories today suggest that many important climatic processes take place only at the poles. Similarly, an understanding of what goes on at the Sun's poles is vital to understanding the solar climate, and Ulysses provides an essential first step.

Such understanding has importance from a purely scientific standpoint, of course. Solar scientists have a lot to learn, and the understanding that they achieve will also be of use in understanding other stars as well: the Sun, after all, is the only star we are currently able to observe at close range. In addition, understanding the solar climate will have important ramifications for our understanding of solar-driven events that spread throughout the solar system: the solar wind, various magnetic and plasma effects, solar flares, and so on.

It is worth stressing, however, that abstract scientific benefits are not the only ones likely from Ulysses. There are also many concrete benefits that will come from such knowledge, benefits with considerable down-to-earth importance. These include:

- Better understanding of the earth's climate: Since the Sun is the earth's primary source of heat, variations in solar output can have dramatic impact on the earth's climate. Existing climatological models are unable to take these into account in any significant way, because the mechanisms of solar variation are, to put it mildly, poorly understood. If we are to understand matters such as global warming and other forms of climatic change, we must have more information concerning the solar climate, of the sort that Ulysses can provide.

- Better understanding of the space environment: A key hazard to manned flight in outer space is excess solar radiation stemming from solar flares. Such flares also pose a hazard to some kinds of spacecraft, and when particularly severe even to earth-based radio communications. A better understanding of the solar climate may lead to an ability to predict solar flares, and to adapt operations to avoid the worst of them. This will be particularly important in the context of space station operations and long-duration manned flights such as the manned Mars mission planned by the President.

- Better understanding of the earth/space interface: The changing solar cycles interact substantially with the earth's magnetic field and with the highest reaches of the upper atmosphere, at an altitude of 100-300 miles, approximately. Expansion of the upper atmosphere during part of the cycle is an important mechanism for removing debris from low-earth orbits. Better understanding of this process will be important in determining ways of addressing the orbital debris problem, which as recent Congressional hearings made clear is of considerable importance already.

Of course, by stressing these concrete benefits NSS does not mean to suggest that abstract scientific knowledge is not important. Such "abstract" knowledge always turns out to have important concrete uses in the end, though often those uses are entirely unforeseeable at the time the knowledge is arrived at.

Adequacy of the Ulysses EIS

In General

Having reviewed the draft Ulysses Environmental Impact Statement, NSS is of the opinion that it is entirely adequate. NASA has reviewed and considered all relevant factors of importance, and in particular has examined the possibility of catastrophic failure resulting in release of radioactive material from the onboard Radiothermal Generators with considerable thoroughness.

Such examinations are of necessity imprecise and subject to dispute; if risks were entirely clear, and all possible modes of failure obvious, we would live in a very different world indeed. And any authoritative determination is nonetheless open to dispute -- even judicial opinions fail to convince everyone. However, within the limits of the real world, NASA has done a more than adequate job; certainly no one else has the expertise or experience to do better, and the excellent safety record of radiothermal generators in practice suggests that NASA's estimates cannot be too far off base. Some imponderables remain, of course, but that is the nature of risk assessment and it is foolish to pretend otherwise. Given that radiothermal generators are far less risky than nuclear reactors (with which they are often confused by the public) and given the lack of alternatives, NSS believes that the level of risk is acceptable, and that the EIS identifies and correctly analyzes all significant factors which can be determined in advance.

NSS also agrees that there are no reasonable alternatives to the use of radiothermal generators for the Ulysses mission. As correctly noted in the EIS, available alternative power sources pose unacceptable costs or risks to the mission -- and, in general, simply would not work at the distance from the Sun (that of Jupiter) at which most of the mission's important phases will (and must) take place.

Errors and Inadequacies in the EIS

NSS would, however, like to take issue with NASA's statement (Draft EIS at pp. v, 4-30) that "[t]here are no environmental impacts associated with the no-action alternative." While this statement may be true from the rather artificial perspective that seems inevitable in the context of an Environmental Impact Statement, it is in fact false. Pursuing a "no-action" alternative -- that is, scrubbing the mission -- would in the real world have negative consequences for the environment that could in fact be quite severe, and that NASA should take into account in determining whether to proceed with the mission.

These consequences would stem from the failure to acquire the information regarding the solar climate, and its interaction with the earth's climate and the earth/space interface, that was described earlier. In the absence of such information, earthbound climatological models will inevitably suffer, understanding of the extent of the (already severe) orbital debris problem will be reduced, and efforts to ameliorate environmental problems on the earth will be handicapped, perhaps severely. There are no planned missions duplicating (even in part) *Ulysses*' functions. Given the long lead-times present for Solar System Exploration, this means that a cancellation of *Ulysses* would result in a major and long-lasting gap in our knowledge of these important topics.

Furthermore, cancellation of *Ulysses* would result in a squandering of human and intellectual capital, and in very significant demoralization costs among the planetary science community. Leaving aside the specific benefits that *Ulysses* itself will provide, no one would disagree that space exploration and planetary science have been of enormous benefit to our understanding of the earth environment -- and, in fact, have been an enormous source of consciousness-raising regarding the importance of environmental issues in general. It is no accident that the first Earth Day took place shortly after the first pictures of the earth from the Moon became available (futurist Arthur C. Clarke predicted that such photos would have just such an impact as early as 1959), or that the environmental movement has adopted just those photos as an important symbol. Furthermore, knowledge gained by satellite observations -- both of the earth and of other planets -- has had dramatic impact on our understanding of specific problems such as the Antarctic ozone hole. Senator Albert Gore, Jr. recently discussed this issue, *see* Gore, *Outer Space, the Global Environment, and International Law: Into the Next Century*, 57 Tenn. L. Rev. 329 (1990), and a number of environmental commentators have made similar points. *See, e.g.,* Hartmann, *Space Exploration and Environmental Issues*, 6 Environmental Ethics 227 (1984), and Beyond Spaceship Earth: Environmental Ethics and the Solar System (Sierra Club Press, 1986): G. Reynolds & R. Merges, Outer Space: Problems of Law and Policy 195-98 (1989).

Cancelling the *Ulysses* mission would have a chilling effect on such enterprises in the future, as scientists would be reluctant to invest years of their time in a mission that might be cancelled at the last moment for environmental reasons. Thus, the losses to the environment from cancelling *Ulysses* might go far beyond those specific benefits promised by *Ulysses* itself.

In addition to the loss of these concrete benefits, the abstract knowledge gained from *Ulysses* would be lost. That is not only a loss to the scientific community, but also a loss of other concrete benefits (currently unforeseeable but no less important for that) likely to be derived from that knowledge. NSS understands that the nature of EIS drafting, and the assumptions and pressures inherent in the risk assessment process generally tend to lead to a discounting of such unquantifiable benefits (a problem known in the risk-assessment trade as the "dwarfing of soft variables"), but urges that NASA resist these pressures and take account of the substantial potential losses, both immediate and long-term, of adopting a "no action" approach.

For this reason NSS also believes that Section 4.8.2 of the EIS (Draft EIS at p. 4-31) should be revised. That section currently states:

> A potentially large benefit to be gained from successful completion of this project is a better understanding of Earth through exploration and study of the environments of other planets.

Obviously, NSS does not disagree with this statement. However, NSS believes that the importance of this aspect of the mission is drastically understated in the EIS and should be more fully reflected along the lines set out above.

Conclusion and Recommendations

Environmental Impact Statements, of course, do not make recommendations; their purpose is simply to set out costs and benefits. NSS has already explained why it believes that the *Ulysses* EIS is adequate in its statement of potential costs and risks, but inadequate in its treatment of the likely benefits of the mission. NSS recommends that the EIS be revised to take these benefits into account.

Regardless of the extent to which such revisions are made, NSS recommends as well that NASA take the benefits noted in these comments into account in making its decision whether to proceed with the *Ulysses* mission. It is not the function of an Environmental Impact Statement to determine whether a particular project is "too risky." Its function is solely to ensure that the agency to whom decisionmaking authority has been delegated (here NASA and, because radioactive materials are involved, the President) makes an informed decision after considering all relevant factors.

NSS believes that when all relevant factors are considered, the necessary conclusion is that the Ulysses mission is not only justified, but very important -- and that that importance stems not only from scientific factors, but from the very significant positive impact that Ulysses is likely to have on the earth's environment over the long term. For this reason, NSS supports a decision to go ahead with the Ulysses mission.

Sincerely,

Glenn Harlan Reynolds
Chairman, NSS Legislative
Committee, For the
National Space Society

RESPONSES TO COMMENTS
Commentor No. 15: National Space Society
(Glenn Harlan Reynolds)
(Continued)

COMMITTEE TO BRIDGE THE GAP
1637 BUTLER AVENUE, SUITE 203
LOS ANGELES, CALIFORNIA 90025
(310) 478-0829

19 December 1994

Dr. Peter B. Ulrich
Chief, Flight Programs Branch
Solar System Exploration Division
Office of Space Science
Code SL
NASA Headquarters
Washington, DC 20546

Re: Cassini Program Draft EIS
by fax

Dear Dr. Ulrich:

These are the comments of the Committee to Bridge the Gap on the Casini DEIS. By letter of 29 November you kindly extended the comment period to 20 December.

Our concerns focus on two primary areas: inadequate assessment of alternatives to the use of plutonium as the power source for the mission and inadequate assessment of potential environmental impacts of accident should plutonium indeed be used. These concerns are summarized below.

Inadequate Consideration of Alternative Power Sources

The purpose of the National Environmental Policy Act (NEPA) is to require agencies to take (1) a "hard look" at alternatives, and (2) to do so *prior* to making decisions that could significantly affect the human environment. In this case, NASA failed both standards. — 16A Its consideration of alternatives was *pro forma*, and its defense of plutonium as the supposed only feasible alternative is that the decision to use plutonium instead of solar as a power source had already been made and it is too late to change plans without delaying the mission. — 16B

In essence, the Draft EIS indicates alternative, environmentally superior power sources could perform the mission, but because NASA has already started work on acquisition of a plutonium-powered generator and chosen not to develop a solar-energy system, a solar device is assertedly not available and plutonium is supposedly the only alternative available. However, NEPA requires consideration of environmental impacts and alternatives at *the earliest possible time*, before a commitment of resources. Had NASA performed this review earlier, it could have chosen to develop the environmentally superior power source.

It is somewhat tiresome to see the same excuse raised time after time in NASA EIS's. Beginning with Galileo, then Ulysses, and now Cassini, for years NASA has claimed it must choose to use plutonium because it had failed to develop solar. NEPA is supposed to guide that decision, the decision not guide NEPA. — 16C

Inadequate Consideration of Environmental Consequences of Accidents

The DEIS severely underestimates potential risks of an accident involving a plutonium power source. The probability figures and consequence estimates are far below realistic levels. Once again, it appears that the EIS is viewed as a paper hoop to jump through rather than a — 16D

RESPONSES TO COMMENTS
Commentor No. 16: Committee to Bridge the Gap
(Daniel Hirsch)

Response to Comment 16A:

The Cassini Environmental Impact Statement (EIS) examines the range of mission alternatives available for accomplishing the Cassini mission objectives within a reasonable timeframe, as well as the No-Action alternative. A number of optional launch vehicles, mission trajectories to Saturn, and spacecraft power and heating sources were examined in detail.

Response to Comment 16B:

NASA has followed the technical progress in space power research and development worldwide for many years. NASA studied many different solar, battery, and other power alternatives, including long life fuel cells, available for Cassini and found none that would meet the mission requirements. A Cassini spacecraft equipped with the highest efficiency solar cells available, or fuel cells, or batteries, or combination of these would make the spacecraft too massive for launching on the Titan IV (Solid Rocket Motor Upgrade [SRMU])/Centaur to Saturn. Even if a heavy-lift booster were available that could launch the Cassini spacecraft with a massive solar array, such large solar arrays would introduce insurmountable complexity to the mission and would severely jeopardize the chances for mission success. For fuel cells, even assuming the highest currently available energy fuel-per-unit mass and 100 percent efficient conversion (an idealistic assumption since only 60-70 percent is currently feasible), the resulting dry mass (before adding propellants for the spacecraft engines needed for maneuvers in space) would be about 16,000 kg (17.6 tons). It would not be possible to launch Cassini and place it on a trajectory to Saturn if it were that massive, i.e., it would exceed the launch capability of the Titan IV (SRMU)/Centaur by more than a factor of 2.

NASA continues to invest in research and development of solar power technology. Indeed, a significant portion of the work in the area of solar arrays has been carried out under NASA funding. While improvements have been made in solar technology, significant breakthroughs are still required to support a mission such as Cassini (see response to Comment 1B). Recent international conferences on space power provided no reports of technical breakthroughs that would suggest changing the proposed approach to powering Cassini. Within the timeframe of the Proposed Action, no power source options other than radioisotope thermoelectric generators are capable of meeting mission requirements.

Response to Comment 16C:

As stated previously in response to Comment 16B, NASA continues its research and investment in electric power technology for space missions. Historically, NASA's primary choice of a power source for planetary missions has been solar power and it has continued to be used for missions when such technology is feasible. The solar power option for Cassini has been extensively reviewed and rejected for this EIS because no U.S. launch vehicle exists to conduct a solar powered mission to Saturn using available solar power technology (see response to Comment 1B). To wait for future development of solar power options suitable to meet the mission requirements would indefinitely delay the mission. NASA has proceeded as quickly as possible in providing a high quality and accurate EIS utilizing the best available information.

Response to Comment 16D:

See response to Comment 13A.

serious effort to face comparative risks from alternative decision pathways. The DEIS appears to presume that miniscule quantities of the plutonium source can be released as respirable particles, an assumption that is in error. — 16E Furthermore, the use of the *de minimus* assumption is in appropriate. No respectable radiation protection body believes it is appropriate to presume a threshold for radiation injury. — 16F

We urge NASA to go back and once and for all decide that where there is an environmentally superior alternative, to use it, and to wean itself from its addiction to plutonium power sources.

Sincerely,

Daniel Hirsch

Daniel Hirsch
President

RESPONSES TO COMMENTS

Commentor No. 16: Committee to Bridge the Gap
(Daniel Hirsch)
(Continued)

Response to Comment 16E:

The particle size distributions for the accident source terms used in the analysis are based on consideration of the plutonium (Pu-238) dioxide fuel form and its response to accident environments (explosion overpressure, fragment, fire, impact, and reentry) as determined by safety test data and analysis. The small fraction of respirable particles associated with a release particle size distribution reflects the ceramic nature of the fuel and its low potential for vaporization in thermal environments. Impact-related releases are expected to be largely non-respirable particles and chunks.

Response to Comment 16F:

The predicted health effects resulting from postulated accident source terms are presented both with and without the application of a *de minimis* dose. The EIS takes no position relative to the appropriateness of applying a *de minimis* dose in the determination of the radiological consequences.

December 19, 1994

605 K Street, NE
Washington, DC 20002-3529

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, DC 20546

Dear Dr. Ulrich:

Please know that I am categorically opposed to development of the Cassini plutonium mission.

Do not let the brevity of this letter dissuade you from thinking that my position is passionately held, and from realizing that I am utterly aghast at the mere notion that NASA could imagine Cassini to be safe. This is sheer nonsense, playing God and potentially lethal to life on this planet.

Please stop Cassini now; I am a taxpayer, concerned citizen and mother-to-be, and speak as such.

—17A

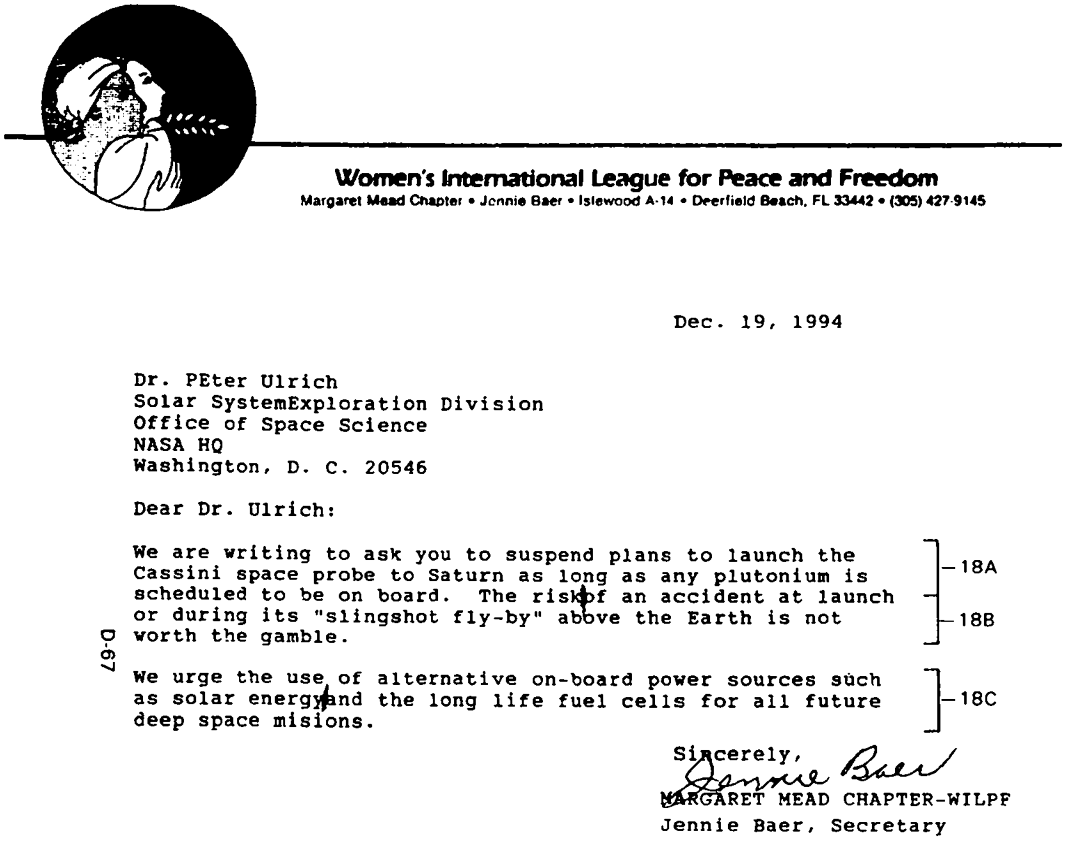
Beth Raps

Beth Raps

Response to Comment 17A:

NASA and the Department of Energy take very seriously the possibility that an action that they take could potentially result in human fatalities or harm to the environment. Therefore, both agencies have gone to great lengths to reduce the potential for such events, both through design of the radioisotope thermoelectric generators and through design and operation of the spacecraft and its mission. As a result of these designs, the risks of fatalities or harm to the environment from the Proposed Action are considered to be very low. See Sections 4.1.5.2 and 4.2.5.1 of the Environmental Impact Statement for more details on launch phase accident scenarios.

NASA appreciates your expressing your views and has considered your comment. Please see response to Comment 2A for further information on the use of plutonium dioxide for the Cassini mission.



Women's International League for Peace and Freedom
Margaret Mead Chapter • Jennie Baer • Islewood A-14 • Deerfield Beach, FL 33442 • (305) 427-9145

Dec. 19, 1994

Dr. PEter Ulrich
Solar SystemExploration Division
Office of Space Science
NASA HQ
Washington, D. C. 20546

Dear Dr. Ulrich:

We are writing to ask you to suspend plans to launch the Cassini space probe to Saturn as long as any plutonium is scheduled to be on board. The risk of an accident at launch or during its "slingshot fly-by" above the Earth is not worth the gamble. —18A —18B

We urge the use of alternative on-board power sources such as solar energy and the long life fuel cells for all future deep space misions. —18C

Sincerely,
Jennie Baer
MARGARET MEAD CHAPTER-WILPF
Jennie Baer, Secretary

RESPONSES TO COMMENTS

Commentor No. 18: Women's International League for Peace and Freedom (Jennie Baer)

NASA appreciates your expression of views. Your comments are similar to those raised by earlier commentors.

<u>Response to Comment 18A:</u>

See response to Comment 2A.

<u>Response to Comment 18B:</u>

See response to Comment 7B.

<u>Response to Comment 18C:</u>

See response to Comment 6A.

RESPONSES TO COMMENTS
Commentor No. 19: Kathleen Kelly

Kathleen F. Kelly
1460 West Carmen Avenue
Chicago, IL 60640

Dr. Peter Ulrich
Solar System Exploratin Division
Office of Space Science
NASA HQ
Washington, DC 20546

December 19, 1994

Dear Dr. Ulrich,

I am writing to protest plans to launch the Cassini space probe
to Saturn as long as any plutonium is scheduled to be on board. —19A
I understand that, presently, the project calls for 73 pounds of
plutonium 238 to generate on-board electricity. The risk you are
considering gambles with our lives. —19B

Please give more consideration to the use of a solar-powered —19C
alternative to the Cassini mission. I understand that current
plans call for production of the plutonium generator for Cassini
at the Savannah River Plant, Los Alamos Labs, Oak Ridge Labs, —19D
Mound Labs and Martin Marietta. Please do not seek ways to
maintain profits for these labs by developing nuclear power in
space.

Sincerely,
Kathleen Kelly
Kathleen Kelly

<u>Response to Comment 19A:</u>

See response to Comment 2A.

<u>Response to Comment 19B:</u>

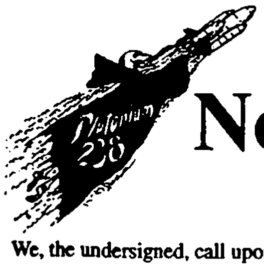
See response to Comment 7B.

<u>Response to Comment 19C:</u>

See response to Comment 6A.

<u>Response to Comment 19D:</u>

The Department of Energy provides radioisotope thermoelectric generators (RTGs) to NASA as an electrical power source for missions to explore the outer solar system. Such interagency cooperation is <u>not</u> for the profit of any laboratory.



CANCEL CASSINI
No Plutonium in Space

We, the undersigned, call upon NASA and our elected officials to suspend plans to launch the Cassini space probe to Saturn as long as any plutonium is scheduled to be on board. Presently, the project calls for 73 pounds of plutonium 238 to generate on-board electricity. The risk of an accident at launch or during its "slingshot fly-by" above the Earth is not worth the gamble. We urge the use of alternative on-board power sources such as solar energy and long-life fuel cells for all future deep space missions.

–20A
–20B
–20C

NAME ADDRESS

1. Sylvia Torgan 6237 Old Ct. Rd. Boca Raton Fla. 33433
2. Byron Youngman " " " " "
3. Elizabeth Barwen " " " " "
4. J.M. Howe Zeads 1737 SW 43 Ave Plantation FL 33317
5. Vivienne Williams 4811 SW 133 Ave. Ft Laud, Fl. 33330
6. Ola M. Iverson 2709 NW 47 Lane Laud. Lakes, FL 33313

Mary Kuner 2926 S. University Dr. #6201 Davie FL 33328

Dan Flora 8551 N.W. 48th st Lauderhill FL 33351

9. Susan Perry 10410 NW 7th Ct Plantation Fl 33324
10. Dorothy Morrison/192 S.W. 52 Ave; Plantation 33317
11. George Vorapke 2995 N. Dixie Hwy. Ft Laud. 3334
12. Melanie Pierre-Lerena 8201 NW 70 St Tamarac Fl 33321
13. Cynthia Smith 2900 N.W 83 Terr Sunr. FL. 33322
14. Sher Williams 760 E. Melrose Circle, Ft. Lauderdale, Fl 33312
15. Mary Kathleen 101 W 62 St. Hialeah Fla. 33012
16. [illegible] 8460 NW 28th Pl. Sunrise Fl 33322
17. Nancy Herman 1216 SW 30 Ave. Ft Lauderdale, FL 33312
18. Belinda White 320 Cambridge Dr. Ft. Lauderdale, Fl 33326
19. Abdul Salam 2995 N. Dixie Hwy Ft Lauderdale 33304
20. Diane Stoe 2330 Cypress Bend Pompano Bch FL 33069
21. Jacques Adams 4261 N.W 24 St Lauderhill Fl. 33313
22. Sandra Martin 3685 NW 28 CT Laud. Lakes 33311
23. Roy Sprenger 1415 SW 31 ST Ft Laud. FL 33315
24. Sherry Flournoy 3861 NW 6 PL Ft. Laud, 33311
25. Aida Melendez 6671 Fern St Mrgt 33063

Return to the Florida Coalition for Peace & Justice • P.O. Box 90035 • Gainesville, Fl 32607 • 904/468-3295

RESPONSES TO COMMENTS
Commentor No. 20: Florida Coalition for Peace & Justice
(Sylvia Torgan with 24 Additional Petitioners)

Response to Comment 20A:

See response to Comment 2A.

Response to Comment 20B:

See response to Comment 7B.

Response to Comment 20C:

See response to Comment 6A.

18102 Grove Avenue
Boca Raton, FL 33498-1624
December 20, 1994

Dr.Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, DC 20546

Dear Dr. Ulrich:

We urge you to suspend plans to launch the Cassini space probe to Saturn as long as any plutonium is scheduled to be on board. At present the project calls for 73 pounds of plutonium 238 to generate on-board electricity. —21A

The risk of an accident at launch or during its "slingshot fly-by" above the Earth is not worth the gamble. —21B

We urge the use of alternative on-board power sources such as solar energy and long-life fuel cells for all future deep space missions. —21C

Sincerely,

Ruth E. Snyder
Jack Snyder

Ruth E. Snyder

Jack Snyder

RESPONSES TO COMMENTS
Commentor No. 21: Ruth E. and Jack Snyder

NASA appreciates expression of your views. Your comments are similar to those raised by earlier commentors.

Response to Comment 21A:

See response to Comment 2A.

Response to Comment 21B:

See response to Comment 7B.

Response to Comment 21C:

See response to Comment 6A.

506 sw 40th terrace
Gainesville, FL 32607

December 20, 1994

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, DC 20546

I wish to comment on the DEIS for the 1997 Saturn Cassini space mission.

In particular, I am concerned about the utilization of plutonium 238 & 239 as fuels.

Two specific concerns.

(1.) I am not at all convinced that the DEIS correctly estimates the potential risks in the event of possible catastrophe scenarios. As you know well, the carcinogenic risks from **any** exposure to plutonium are very high. Whether in the event of explosion or crash at relatively low altitude levels, or explosion (or leakage) in upper or super atmospheric levels, the risk potential to humans and other terrestial life forms could be much higher than estimated--depending on circumstances. – 22A

(2.) Plutonium use at this point in history is going in the wrong direction. High efficiency solar cells, already developed in some other countries, are clearly the way to go. Not only will such cells cost less in dollar amounts (including externalized costs); they also eliminate the potential risk of plutonium exposure. – 22B The more plutonium-powered missions are launched, the greater the likelihood of accident resulting such exposure. We do not want to, nor do we need to go down that path. – 22C

I urge you to cancel planned use of plutonium in this and all other space missions. – 22D

Thank you for your attention to these concerns.

Sincerely yours,

Richard H. Hiers, Ph.D., J.D.

RESPONSES TO COMMENTS
Commentor No. 22: Richard H. Hiers, Ph.D., J.D.

Response to Comment 22A:

NASA considers the risk analysis presented in the Environmental Impact Statement (EIS) to be the best estimation based on the available information at the time. The results of the accident analysis have been factually stated in the EIS in terms of (1) the total probability of release, (2) the radiological consequences of such a release, and (3) the risk. As part of the launch approval process, the Department of Energy will be preparing a more in-depth evaluation of the risks as part of the Final Safety Analysis Report (FSAR). NASA will review the FSAR, when it becomes available, and will evaluate the information presented for differences, if any, in the estimates of the potential radiological consequences and risks.

Response to Comment 22B:

See response to Comment 1B.

Response to Comment 22C:

Comment noted. Please refer to Sections 4.1.5.3 and 4.2.5.2 in the EIS for a discussion of initiating accident probabilities.

The total health effects mission risk to the public (considering all launch phases and the Earth-Gravity-Assist trajectory) for Cassini have been estimated and are small (about 1.8×10^{-3} health effects). See Section 1.4 in the EIS for details on the multiple benefits already being derived from mission planning. The Cassini mission to the Saturnian system represents a rare opportunity to gain significant insights into major scientific questions about the formation of the solar system and the conditions that led to life on Earth, in addition to a host of questions specific to the Saturn system.

Response to Comment 22D:

See response to Comment 2A.

DAV
Harry Kernes
333 W. State St
Trenton, NJ 08618-5722

(Recycled) 12/21/94

Dear Dr. Ulrich;

Having Read Of The Project That Is To Send Uranium Into The Heavens I Have Felt It Is A Total Waste Of Our Resources And Money. Just One Little Mistake Can Cause An Eternity Of Problems.

I Urge You To Cancel The Cassini-So-called-Space Probe.

Respectfully Your
Harry Kernes
Harry Kernes

–23A

RESPONSES TO COMMENTS
Commentor No. 23: Mr. & Mrs. Harry Kernes

Response to Comment 23A:

The Cassini mission will use plutonium-238 dioxide in the radioisotope thermoelectric generators to generate onboard electrical power. The mission would commit human, material, economic and other resources (see Section 4.8 of Environmental Impact Statement [EIS]) to provide significant new scientific information to address some fundamental questions about the origins of life and our solar system. Significant technological benefits, as discussed in Section 1.4 of the EIS, have been achieved during the planning of the mission.

22 Dec 94

Dr Peter Ulrich
NASA

Dear Sir

In view of the alternatives available, please reconsider the use of plutonium for the Cassini mission. —24A

I share the concerns of the Florida Coalition for Peace + Justice which are based upon the possibilities noted in NASA's Draft Environmental Impact Statement. —24B

Cordially,

Rea D. Ward.

Rea D Ward
8440 Truman St
Englewood, FL 34224

RESPONSES TO COMMENTS
Commentor No. 24: Rea D. Ward

Response to Comment 24A:

NASA has invested in research and development of solar power technology. Additionally, the U.S. Department of Energy, the European Space Agency, and other agencies and research centers around the world have been investing in and improving upon solar power technology over the last decade. A number of solar power designs were investigated for the Cassini mission that would utilize unproven yet promising technology (e.g., the Advanced Photovoltaic Solar Array).

NASA studied many different solar, battery, and other power alternatives, including long life fuel cells, available for Cassini and found none that would meet the mission requirements. A Cassini spacecraft equipped with the highest efficiency solar cells available, or fuel cells, or batteries, or combination of these would make the spacecraft too massive for launching to Saturn. Even if a heavy-lift booster were available that could launch the Cassini spacecraft with a massive solar array, such large solar arrays would introduce insurmountable complexity to the mission and would severely jeopardize the chances for mission success. For fuel cells, even assuming the highest currently available energy fuel-per-unit mass and 100 percent efficient conversion (an idealistic assumption since only 60-70 percent is currently feasible), the resulting dry mass (before adding propellants for the spacecraft engines needed for maneuvers in space) would be about 16,000 kg (17.6 tons). It would not be possible to launch Cassini and place it on a trajectory to Saturn if it were that massive, i.e., it would exceed the launch capability of the Titan IV (Solid Rocket Motor Upgrade [SRMU])/Centaur by more than a factor of 2.

Though NASA continues to invest in research and development of solar power technology, the current state of the technology makes solar power infeasible for the Cassini mission to Saturn. See response to Comment 1B.

Response to Comment 24B:

The concerns of the Florida Coalition for Peace and Justice are addressed in responses to Commentor No. 1.

RESPONSES TO COMMENTS
Commentor No. 25: Georgia Van Ornam

P.O. Box 33074
Indialantic, Florida 32903
December 22, 1994

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, DC 20546

Dear Dr. Peter Ulrich:

I am one of America's citizens who wonders about the nescessity of placing 73 pounds of plutonium 238 and 239 on the 1997 Cassini space mission to Saturn.

Dr. Caldicott, founder of Physcians for Social Responsibility writes about plutonium "is so toxic that less than one-millionth of a gram,is a carcinogenic dose. One pound, if uniformly distributed, could hypothetically induce lung cancer in every person on Earth." —25A

NASA and the Department of Energy do have a cavalier approach that if the rocket explodes there will be just a few "excess cancers." For the poor schmuck (and this could be me) finds him/her self with an "excess cancer" cannot be happy about this casual attitude. —25B

European industry has recently developed high efficiency solar cells for use in future demanding deep-space missions. For goodness sakes, lets use solar energy! —25C

As a Floridan who lives in the Space Coast, I have seen several launches that have exploded, I certainly don't want a launch with plutonium on board!!

Yours truly,

Georgia Van Ornam
Georgia Van Ornam

Copy for my own records

Response to Comment 25A:

There is about 32.4 kg (71.4 lb) of plutonium dioxide in the three RTGs of which approximately 28 kg (62 lb) are plutonium isotopes. Table 2-3 provides the isotopic composition of the fuel form used for the Cassini mission. See also response to Comment 4B.

Response to Comment 25B:

See response to Comment 2B.

Response to Comment 25C:

See response to Comment 1B.

CANCEL CASSINI !

Dr. Dr. ULRICH

NASA SHOULD NOT SEND PLUTONIUM INTO OUTER SPACE. NEVER, NEVER, NEVER. IT IS TOO VOLATILE AND DANGEROUS. SOLAR POWER SHOULD BE UTILIZED. — 26A — 26B — 26C

ARTHUR DRAVING

4650 NW 10 PL B-104
PLANTATION, FL
33313

(305) 581-6544

RESPONSES TO COMMENTS
Commentor No. 26: Arthur Draving

NASA appreciates your comments on the use of plutonium on the Cassini mission to Saturn. Your comments are similar to those raised by earlier commentors.

Response to Comment 26A:

See response to Comment 2A.

Response to Comment 26B:

See response to Comment 5B.

Response to Comment 26C:

See response to Comment 6A.

John P. Ferrell
441 Madeira Avenue
Coral Gables, FL 33134

December 25, 1994

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, DC 20546

Dear Dr. Ulrich:

I am writing to express my vehement disapproval of your plan to allow 73 pounds of Plutonium to be launched from Florida. As a resident and voting citizen I urge you not to jeopardize the health of my family's state. – 27A

I hope you make decisions on such delicate matters in the future based on a short and long-term quality of life criteria instead of a short-term cost-benefit analysis. My daughter's quality of life cannot be described by numbers of dollars or "excess cancers." All cancers are excess and should be avoided. – 27B

Thank you for understanding and considering the concerns of your constituents and citizens in making your final decision on our quality of life.

Sincerely,

John P. Ferrell

RESPONSES TO COMMENTS
Commentor No. 27: John P. Ferrell

NASA appreciates your comments regarding the launch of the Cassini spacecraft to Saturn. Your comments are similar to those raised by earlier commentors.

Response to Comment 27A:

See response to Comment 2A.

Response to Comment 27B:

See responses to Comments 1I and 8C.

December 26, 1994

Dr. Peter Ulrich
Nasa Headquarters
Washington, DC.

Dear Dr. Ulrich:

Planning for nuclear weapons in space, starting with a launch of a rocket carrying 73 pounds of plutonium, is the scariest gamble with the earth's inhabitants. — 28A

There is no way to control any mishap involving the most toxic material known. — 28B

Compared to disasters in the past, any failure would be unimaginably worse. — 28C

Ethically, nuclear weapons on earth are no longer acceptable. How much less are they defendable in space?

The technology for powering space crafts by solar energy is sufficiently developed to be an alternative for exploration in space. — 28D

Very truly yours
Ingeborg F. Roberts

RESPONSES TO COMMENTS
Commentor No. 28: Ingeborg F. Roberts

Response to Comment 28A:

Cassini is a peaceful scientific mission being designed and developed by civilian agencies of the U.S. government and those of Europe. The plutonium fuel form used in the radioisotope thermoelectric generators (RTGs) is not weapons-grade material, and is used to generate electricity for the spacecraft and its scientific instruments.

Response to Comment 28B:

See response to Comment 5B.

Response to Comment 28C:

NASA has estimated the risks from plutonium (Pu-238) dioxide onboard the Cassini spacecraft and has found the risks to the world population and our planet to be very low. The risks from the launch of Cassini would be lower than many of the risks that we face in our everyday lives (see Table 4-20 in the Environmental Impact Statement). A wide range of potential accident scenarios was evaluated.

Response to Comment 28D:

See responses to Comments 3D.

DEC 26 1994 MONDAY

SIR: PETER ULRICH:
I WISH TO JOIN RANKS WITH
ALL CITIZENS OF OUR REPUBLIC
THAT OPPOSE THE USE OF
NUCLEAR POWER IN SPACE
PARTICULARLY, & I PRO-
TEST THE "CASSINI" PLUTONIUM
MISSION. KINDLY DO ALL
YOU CAN TO ADVANCE
PROPOSALS AND DECISIONS
TO SUBSTITUTE SOLAR
GENERATED POWER
FOR PLUTONIUM GENERATED
THE ENORMOUS RISKS
TO HUMAN HEALTH AND
ENVIRONMENTAL INTEGRITY
FAR OUT-PACE THE
PETTY PURPOSE OF
EXCESS PROFITS FOR A
FEW WHO SEE NO FURTHER THAN

—29A

—29B

—29C

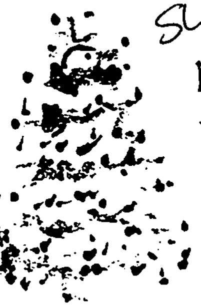
GERALDINE JENARA AMATO
P.O BOX 951
ALBUQUERQUE, NM 87103-0951
(OR)
610 MARBLE NE
87102-2433

HAPPY HOLIDAYS

SLP


USA 19

DR. PETER ULRICH
SOLAR SYSTEM EXPLORATION
DIVISION
OFFICE OF SPACE SCIENCE
NASA HQ
WASH DC
20546



THE NEXT YEAR'S
FINANCIAL PROFIT!
SHEETS
PRAYERFULLY

RESPONSES TO COMMENTS
Commentor No. 29: Geraldine Jenara Amato

Response to Comment 29A:

See response to Comment 2A.

Response to Comment 29B:

See response to Comment 6A.

Response to Comment 29C:

The Cassini mission is an international cooperative mission with the European Space Agency and the Italian Space Agency. There is no intent by NASA to generate excess profits for any organization.

Dec. 28, '94

Dear Dr. Ulrich!

Please cancel the Cassini plutonium mission. I support the campaign to stop nuclear power in space. 73 pounds of plutonium on a Titan rocket is a gamble you shouldn't take, and Americans shouldn't be subjected to. —30A

In April '94 the European Space Agency declared their industries have highly efficient solar cells available for deep-space missions. —30B

I only wish you and the DOE could be so thoughtful. Cassini is myopic, wasteful & dangerous. Cancel it! —30C

Mary Sprunger-Froese
235 E. Fountain Blvd.
Colo. Springs CO 80903

RESPONSES TO COMMENTS
Commentor No. 30: Pikes Peak Justice and Peace Commission
(Mary Sprunger-Froese)

NASA appreciates your comments regarding the Cassini mission to Saturn. Your comments are similar to those raised by earlier commentors.

Response to Comment 30A:

See response to Comment 2A.

Response to Comment 30B:

See response to Comment 1B.

Response to Comment 30C:

See response to Comment 7B.

GREENPEACE
1436 U Street NW • Washington DC 20009 • Tel (202) 462-1177
Tlx 89-2359 • Fax (202) 462-4507

Dr Ulrich—

No Pu in Space!! — 31A

Thanks

HARVEY WASSERMAN
735 EUCLAIRE AVE
BEXLEY OH 43209

RESPONSES TO COMMENTS
Commentor No. 31: Harvey Wasserman

Response to Comment 31A:

Please see responses to Comments 2A, 2B, and 8C.

553 15th avenue
San Francisco CA 94118
December 30, 1994

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington D.C 20546

Dear Dr. Ulrich;

Please consider solar alternatives for supplying energy to the 1997 Cassini space mission. It is wrong to embark upon a procedure using radioactive material that can impact upon man's health for thousands of years if something goes wrong in the launch.

–32A

–32B

Yours very truly
Edward Dierauf

Dierauf

RESPONSES TO COMMENTS
Commentor No. 32: Edward Dierauf

<u>Response to Comment 32A:</u>

See response to Comment 3D.

<u>Response to Comment 32B:</u>

See response to Comment 7B. The dominant isotope of the fuel, plutonium-238, has a half-life of 87.75 years. Because of radioactive decay and accounting for all the plutonium isotopes in the original fuel, the amount of plutonium remaining (without any mitigation actions) after 100 years would be 45 percent, after 500 years would be 2 percent, after 1,000 years 0.13 percent, and after 5,000 years would be 0.08 percent.

Margery D. McIntire
4600 A1A South, LP 2-1
St. Augustine, FL 32084

December 30, 1994

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Sciene
NASA HQ
Washingtoin DC 20546

Dear Dr. Ulrich;

It is fitting that I write to you on the last day of the year. I am 84. I may not be alive when the Cassini mission takes place.

According to Dr. Helen Caldicott, plutonium is "so toxic that one-millionth of a gram, an invisible particle, is a carcinogenic dose. One pound, if uniformly distributed, could hypothetically induce lung cancer in every person on Earth."

Okay. One pound of plutonium will not fall. If there should be an explosion, the debris would not be uniformly distributed. —33A

But, why chance it? Why use plutonium? Who not try solar-powered alternatives? —33B

I think I know why. You want to keep the nuclear power industry alive and well. —33C

I don't.

Or at least, not in use in space.

Please stop the Cassini launch if it uses nuclear power. —33D

Please give honest estimates of the danger to the planet should even the slightest accident occur. —33E

Use solar-powered cells, or tell me why you won't.

Thanks.

Margery D McIntire

RESPONSES TO COMMENTS
Commentor No. 33: Margery D. McIntire

NASA appreciates your comments on the Cassini mission to Saturn and your concern for the welfare of future generations. Your comments are similar to those raised by earlier commentors.

<u>Response to Comment 33A:</u>

See response to Comment 4B.

Response to Comment 33B:

See response to Comment 6A.

Response to Comment 33C:

See response to Comment 1C.

Response to Comment 33D:

See response to Comment 2A.

Response to Comment 33E:

See response to Comment 13A.

Nancy Strong · 120 S. Chancellor Street · Newtown, PA 18940

31 December 1994

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, D.C. 20546

Dear Dr. Ulrich,

I have long had a horror, as many have, over the destructive potential of nuclear power and of my nation's willingness to unleash it not once, but twice. It was not until the early '80s, however, that I became informed about the problem of nuclear waste and decided that we must forego nuclear power and seek alternatives in earnest. I was in correspondence at that time with Prof. Ruston Roy, a chemist at the University of Pennsylvania.

I urge that we NOT GO FORWARD WITH THE 1997 CASSINI SPACE MISSION TO SATURN, USING PLUTONIUM. –34A

If we must pursue space exploration – it grieves me that it is largely military in nature – then solar power must be used. –34B –34C

Sincerely,
Mrs. Nancy Strong

RESPONSES TO COMMENTS
Commentor No. 34: Nancy Strong

NASA appreciates your comments on the use of radioactive materials on the Cassini mission. Your comments are similar to those raised by earlier commentors.

Response to Comment 34A:

See response to Comment 2A.

Response to Comment 34B:

See response to Comment 28A.

Response to Comment 34C:

See response to Comment 6A.

2958 Oakisle Rd. N.
Jacksonville, FL 32257
January 1, 1995

Dear Dr. Ulrich:

I write to protest the Cassini plutonium mission planned for 1997.

I am not convinced that the DEIS recently released has realistic figures that even come close to that of other experts such as Dr. Helen Endicott. —35A

I think that the risks are much greater than NASA and the DOE would have us believe. —35B

I urge you to reconsider this planned launch.

Sincerely yours,

Karen McFadyen

Karen McFadyen

RESPONSES TO COMMENTS
Commentor No. 35: Karen McFadyen

Response to Comment 35A:

The results of the accident analysis have been factually stated in the EIS in terms of 1) the total probability of release, 2) the radiological consequences of such a release, and 3) the risk. Appendix C discusses the environmental and health risks associated with plutonium (Pu-238) dioxide in greater detail. See also response to Comment 4B.

Response to Comment 35B:

See response to Comment 13A.

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ.
Washington, D.C. 20546

Jan. 1, 1995

Dear Dr. Ulrich:

I'm writing with deep concern for the safety of the earth and all of us on it.

I'm writing to protest the CASSINI plutonium mission – a most dangerous project – at our expense!

Please don't allow Nuclear Power and weapons in space. We don't need this danger to our lives; the constant tension and worry in addition to our normal daily living.

—36A
—36B

Respectfully,

LINDA BERMANN Linda Bermann
2550 DANA ST. #7B
BERKElEy, CA 94704-2868

RESPONSES TO COMMENTS
Commentor No. 36: Linda Bermann

Response to Comment 36A:

Cassini is a peaceful scientific mission being designed and developed by civilian agencies of the U.S. government and those of Europe. The plutonium fuel form used in the radioisotope thermoelectric generators (RTGs) is not weapons-grade material, and is used to generate electricity for the spacecraft and its scientific instruments.

Response to Comment 36B:

NASA has estimated the risks from plutonium (Pu-238) dioxide onboard the Cassini spacecraft. The total health effects mission risk to the public (considering all launch phases and the Earth-Gravity-Assist trajectory) for Cassini is provided in Section 4.1.8 of the Environmental Impact Statement (EIS), and is estimated to be small (about 1.8×10^{-3} health effects).

The risks from the launch of Cassini are lower than many of the risks we face in our everyday lives (see Table 4-20 in the EIS).

46 D Pleasant St.
Provincetown, MA 02657
January 2, 1995

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington,DC 20546

Dear Dr. Ulrich:

The Cassini plutonium mission is a potentially deadly idea. Why must plutonium (aptly named after Pluto, lord of death) be used as an on-board power source when solar energy could be used instead? —37A

I resent mightily that my taxes are being used for such a misguided and risky plan. Are there not enough cancers growing already in our people that you must dream up still another "risk factor" to be added to an ever-growing list? —37B Stop this mission, re-think the use of plutonium, consider seriously using instead high efficiency solar cells recently developed in Europe. —37C

Sincerely,

Merilyn Hiller

(Ms.) Merilyn Hiller

cc: Rep. Studds
Sen. Kennedy
Sen. Kerry
Pres. Clinton

RESPONSES TO COMMENTS

Commentor No. 37: Merilyn Hiller

NASA appreciates your expression of views regarding the Cassini mission to Saturn. Your comments are similar to those raised by earlier commentors.

Response to Comment 37A:

See response to Comment 3D.

Response to Comment 37B:

See response to Comment 7B.

Response to Comment 37C:

See response to Comment 1B.

RESPONSES TO COMMENTS
Commentor No. 38: Sidney and Olive Manuel

Sidney Manuel
13672 Fern Trail Dr.
Fort Myers FL
33903-7202

January 3, 1994. Gentlemen: This household thinks putting plutonium into space by powering the Cassini probewith the substance is an act of criminality, and we would ask what gives the right to the Office of Space Science to subject humanity to the dangers inherent in such activity? —38A

Sincerely yours,
Sidney A. Manuel
Olive L. Manuel

Response to Comment 38A:

NASA believes that the Cassini mission to Saturn will be of great benefit to all people. Your comments about the use of plutonium in this mission are addressed in response to Comment 7B.

Ronald P. Reed
112 Behrends Avenue
Juneau, AK 99801-1414
(907) 586-1338

January 3, 1995

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington DC 20546

Dear Dr. Ulrich:

I am writing to you to express my alarm at the continuing plan to use toxic Flu-
tonium as the power source for the 1997 Cassini Saturn space mission. As a scien-
tist, you are doubtless aware of the dangers inherent in this project. Indeed, only
a few years ago the U.S. government was denouncing the Soviet Union for having
launched a nuclear-powered satellite which disintegrated in orbit and contaminated —39A
northern Canada.
There is certainly no guarantee that the mission contemplated will not end in
disaster; and the past practice of the Department of Energy's Nuclear Regulatory
Commission and its predecessor agency of deliberately understating dangers by magni- —39B
tudes of more than a hundred thousand in order to promote the use of nuclear power
inspires little trust in the figures now being bandied about.
Since the European Space Agency has recently stated that "European industry has
recently developed high efficiency solar cells for use in future demanding deep- —39C
space missions," there is no excuse for endangering the any of the planet's popula-
tion by using poison to launch a probe. The fact that you aim the launch in the gen-
eral direction of Africa rather than New York City or the continental U.S. is a ta-
cit acknowledgment of this danger; are African lives worth so much less than white —39D
ones?
Given that the launch is still two years away, I should think that you would have —39E
ample time to rethink your launch strategy, and retool the probe.

Sincerely,

Ronald P. Reed

RESPONSES TO COMMENTS
Commentor No. 39: Ronald P. Reed

Response to Comment 39A:

NASA places the highest priority on assuring the safe use of radioactive materials in space. Thorough and detailed safety analyses are conducted prior to launching NASA spacecraft with radioisotope thermoelectric generators (RTGs), and many prudent steps are taken to reduce the risks involved in NASA missions using RTGs. In addition to NASA's extensive internal safety requirements and reviews, missions that carry nuclear material also undergo an additional safety review involving detailed verification testing and analyses.

The Department of Energy has designed the RTGs with a number of safety features. First, the fuel is in the heat-resistant, ceramic form of plutonium dioxide, which reduces its chance of vaporizing in fire or reentry environments. This ceramic-form fuel is also highly insoluble, has a low chemical reactivity, and primarily fractures into large, non-respirable particles and chunks in the unlikely event that the RTGs are in an accident resulting in some released material.

Second, the fuel is divided among 18 small, independent modular units, each with its own heat shield and impact shell. This design reduces the chances of fuel release in an accident because all modules would not be equally impacted in an accident.

Third, multiple layers of protective materials, including iridium capsules and high-strength graphite blocks, are used to protect the fuel and prevent its accidental release. Iridium is a metal that has a very high melting point and is strong, corrosion-resistant and chemically compatible with plutonium dioxide. These characteristics make iridium useful for protecting and containing each fuel pellet. Graphite is used because it is lightweight and highly heat-resistant. See also response to Comment 2A.

Response to Comment 39B:

The U.S. Department of Energy and the U.S. Nuclear Regulatory Commission are two separate governmental agencies that evolved from the Atomic Energy Commission.

NASA considers the risk analysis presented in the Environmental Impact Statement (EIS) to be the best estimation based on the available information at the time. As part of the launch approval process, the Department of

RESPONSES TO COMMENTS
Commentor No. 39: Ronald P. Reed
(Continued)

Energy will be preparing a more in-depth evaluation of risks as part of the Final Safety Analysis Report (FSAR). NASA will review the FSAR, when it becomes available, and will evaluate the information presented for differences, if any, in the estimates of the potential consequences and risks.

Response to Comment 39C:

See response to Comment 1B.

Response to Comment 39D:

While the launch is not aimed at or targeted to Africa, there are several reasons why launch vehicles are generally directed eastward from Cape Canaveral Air Station/Kennedy Space Center. There are no land masses or populations threatened in the event of an early ascent launch accident. An eastward launch from the Cape puts a spacecraft on the proper course to travel toward other solar system bodies within the ecliptic plate, such as Saturn. In addition, from the Cape's location at 28.5 degrees north longitude, launch vehicles receive an extra 1,400-kilometer per hour (900-mile per hour) boost due to Earth's rotational velocity. This means less fuel is required for the launch vehicle to reach its destination.

For the Proposed Action, the instantaneous impact point would be over Africa for a brief period of 8 seconds in Phase 5 (see Section 2.2.7). Should an accident occur during this period, NASA has estimated that the total probability of a plutonium release would be very small with statistically indistinguishable health effects (see Section 4.1.8 of the Environmental Impact Statement).

Response to Comment 39E:

See response to Comment 2A.

Aloha Dr. Ulrich: I am writing to appeal to your sense of environmental and global justice.

I am disappointed but not surprised that NASA is continuing to resist the use of solar cells to power the 1997 Cassini space mission to Saturn. —40A

Instead NASA has chosen to put the human race at risk by shooting 73 pounds of Pu 238 and 239 into space. —40B

I know that your draft environmental impact statement seeks to assure us that "excess cancers" will be minimal. I am curious about the origin and basis of your "Monte Carlo Simulation" computer model which produced your accident probability and contamination figures. —40C

Hopefully you are familiar with the work of Dr Helen Caldicott who says that plutonium "... is so toxic that less than one-millionth of a gram, an invisible particle, is a carcinogenic dose. One pound, if uniformly distributed, could hypothetically induce lung cancer in every person on Earth." —40D

In light of this and the fact that, according to the European Space Agency, high efficiency solar cells have been developed for use in deep-space missions, —40E it seems that the only reasons to persist in the use of nuclear energy in space are to keep the production of nuclear material profitable in the United States, and to provide a basis for weapons in space —40F

Neither is a good reason

Conversely, by using and developing solar energy in space a more job-intensive, less hazardous industry will be supported. —40G

I urge you to use solar cells and not plutonium in

RESPONSES TO COMMENTS
Commentor No. 40: V. Lee Fuqua

Response to Comment 40A:

Historically, NASA used solar power for missions when such technology was applicable. For example, the Mars Observer, Viking Orbiters, Mariners 4, 6, 7 and 9 were solar-powered Mars missions. Future missions to Mars such as Pathfinder and Mars Global Surveyor will be solar-powered, using the newest high efficiency GaAs/Ge cells. Mars Pathfinder lander and microrover represent the first use of photovoltaics on the Martian surface. However, NASA incorporates radioisotope thermoelectric generators (RTGs) with spacecraft designs when solar power or other power technology is not feasible for the planned mission. The current state of the technology makes solar power infeasible for a mission like Cassini. See also response to Comment 6A.

Response to Comment 40B:

See responses to Comments 2A and 1K.

Response to Comment 40C:

The risk analysis presented in the Environmental Impact Statement is deterministic. Monte Carlo simulations were performed in the estimation of the launch phase initiating accident scenario probabilities and the Earth-Gravity-Assist inadvertent reentry probabilities. The Monte Carlo technique is appropriate when evaluating functional relationships involving probability distributions. As part of the flight approval process, the Department of Energy will be preparing a more in-depth evaluation of the potential environmental consequences as part of the Final Safety Analysis Report (FSAR). Monte Carlo simulations will be applied in the FSAR.

Response to Comment 40D:

See response to Comment 4B.

Response to Comment 40E:

See response to Comment 1B.

RESPONSES TO COMMENTS
Commentor No. 40: V. Lee Fuqua
(Continued)

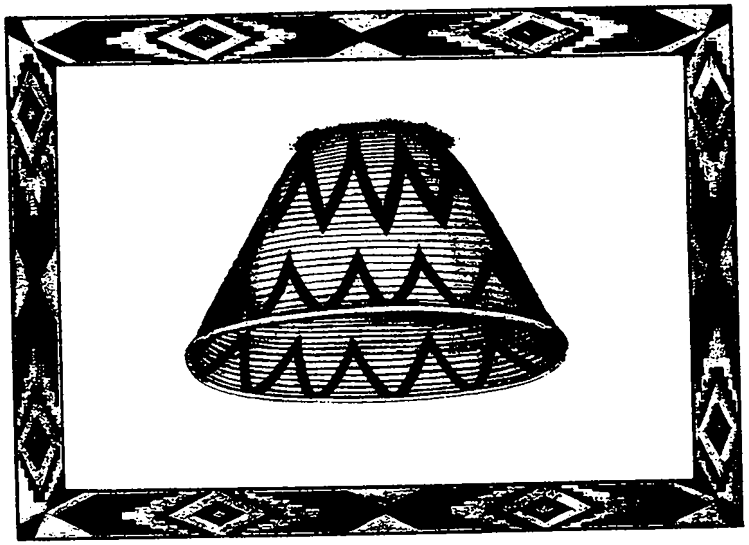
Response to Comment 40F:

Cassini is a peaceful scientific mission being designed and developed by civilian agencies of the U.S. government and those of Europe. The plutonium fuel form is not weapons-grade material, and is used to generate electricity for the spacecraft and its scientific instruments.

Response to Comment 40G:

NASA continues to invest in solar and other technologies for space applications. NASA's investment along with that of other Federal research and development programs have yielded advances in solar technologies that are in widespread use today.

RESPONSES TO COMMENTS
Commentor No. 40: V. Lee Fuqua
(Continued)



the Cassini mission
Thank you for your time.

Sincerely,
V Lee Fuqua
V LEE FUQUA
PO Box 1978
WAILUKU, HI
96793

POMA BASKET

Woven in the coil technique, this large conical carrying basket's typical geometric design was either reddish brown or black on a light ground or white on a brown ground.

200*4305
Printed in U.S.A.

RESPONSES TO COMMENTS
Commentor No. 41: Robert R. Holt, Ph.D.

January 8, 1995

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, DC 20546

Dear Dr. Ulrich,

I am writing to urge you, in the strongest terms, to delay the planned launch of the Cassini space mission to Saturn until its onboard energy system can be made non-nuclear. —41A Doubtless it is easier and cheaper to proceed with the plan to use plutonium in RTG's, but the risks to human life of doing so are simply unacceptable--especially because solar and fuel-cell options are feasible.

As a life member of AAAS and the former director of a research center at NYU, I am a strong advocate of using public funds to advance basic science, and hope that it will not be necessary to cancel the mission altogether, though in these times of new demands for budgetary stringency I would much rather see the required billions used to protect Medicare and Medicaid from threatened cuts. —41B The possible gains to knowledge from Cassini if everything goes well cannot in any way counterbalance the possible consequences of failure: damage to the health of countless thousands of human beings and death to many.

We have been lucky, so far, that there have not been worse disasters from the launching of so many space vehicles carrying radionuclides. It is high time to **stop that risky practice altogether**, surely not to try to launch the largest amount of plutonium ever sent into space. And using the notoriously unreliable Titan IV as the vehicle, to boot! —41C

NASA has the opportunity to get some favorable publicity, for a change, if it is announced that the mission is being delayed because a way has been found to eliminate dangers to human life. Such a delay might also make it possible to redesign it more economically. —41D

Sincerely yours,

Robert R Holt, PhD

Robert R. Holt
Professor of Psychology Emeritus
Box 1087 Truro, MA 02666-1087

Response to Comment 41A:

See response to Comment 2A.

Response to Comment 41B:

See responses to Comments 1K and 6A.

Response to Comment 41C:

The Titan family of launch vehicles has a flight history which spans more than three decades. They have been used for more than 320 launches including five launches of spacecraft with radioisotope thermoelectric generators and 10 launches carrying astronauts into space. See response to Comment 3G. Refer to Section 4.1.5.3 of the Environmental Impact Statement for more details.

Response to Comment 41D:

See response to Comment 1H.

January 16, 1995

Bob Ellenberg
1315 N.E. 9th St.
Gainesville, Fl. 32601
(904) 335-1856

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, D.C. 20546

Dr. Ulrich:

It has brought to my attention that as part of the Cassini space mission to Saturn, NASA is planning on sending a Titan 4 rocket from Kennedy Space Center with 73 pounds of plutonium on board as fuel. If one citizens opinion is worth anything, you have mine as totally opposed to fueling this mission with plutonium. Too, too risky, too many lives are potentially in jeopardy if anything should happen to the space ship and it came down anywhere on the planet with the possibility of radiation escaping from its container. Zero is the only acceptable figure for the loss of life, or for more cancers. As a health professional, I know we have enough cancer without creating more. —42A

I have read that the European space industry has been working with high efficiency solar cells that can send space ships into deep space. —42B Let us not continue to depend on such a deadly source of energy as plutonium. —42C

Please pay attention to the will of the people, our monies are paying for the project and we should have input. —42D

Thanks for you time,

Bob Ellenberg

Bob Ellenberg

RESPONSES TO COMMENTS
Commentor No. 42: Bob Ellenberg

NASA appreciates your comments about the use of plutonium in the Cassini mission to Saturn. Your comments are similar to those raised by earlier commentors.

Response to Comment 42A:

See response to Comment 7B.

Response to Comment 42B:

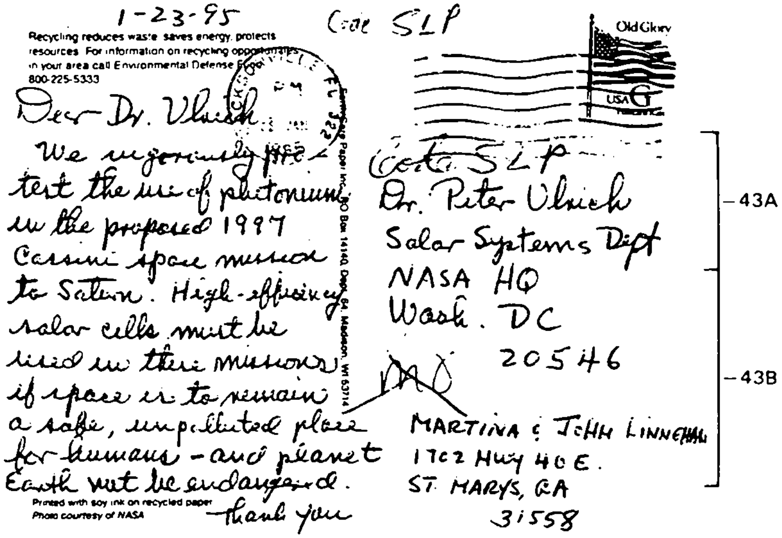
See response to Comment 1B.

Response to Comment 42C:

See response to Comment 5B.

Response to Comment 42D:

NASA appreciates your expression of views.



1-23-95 Cc: SLP

Recycling reduces waste, saves energy, protects resources. For information on recycling opportunities in your area call Environmental Defense Fund 800-225-5333

EarthCare Paper Inc., PO Box 14140, Dept. 64, Madison, WI 53714

Dear Dr. Ulrich,

We vigorously protest the use of plutonium in the proposed 1997 Cassini space mission to Saturn. High-efficiency solar cells must be used in these missions —43A

if space is to remain a safe, unpolluted place for humans - and planet Earth not be endangered. —43B

thank you

Printed with soy ink on recycled paper
Photo courtesy of NASA

Cc: SLP
Dr. Peter Ulrich
Solar Systems Dept
NASA HQ
Wash. DC
20546

MARTINA & JOHN LINNEHAN
1702 HWY 40 E.
ST. MARYS, GA
31558

RESPONSES TO COMMENTS

Commentor No. 43: Martina and John Linnehan

NASA appreciates your comments about the use of plutonium in the Cassini mission to Saturn. Your comments are similar to those raised by earlier commentors.

<u>Response to Comment 43A:</u>

See response to Comment 2A.

<u>Response to Comment 43B:</u>

See response to Comment 1B.

February 12, 1995

Dear Dr Ulrich,

Plutonium is so deadly, I do not understand why you want to use it in space. —44A

I think you should recheck your data and use a safer fuel — perhaps solar power with another back-up. —44B

Sincerely,
Ruth Putz
197 Kendal
Kennett Sq Pa 19348

RESPONSES TO COMMENTS
Commentor No. 44: Ruth Putz

NASA appreciates expression of your views. Your comments are similar to those expressed by earlier commentors.

Response to Comment 44A:

See response to Comment 2A.

Response to Comment 44B:

See response to Comment 6A.

920 Countryside
Columbus, In. 47201
Feb. 19, 1995

Solar System Exploration Div.
Office of Space Science
NASDA HQ
Washington, DC

Dear Dr. Ulrich,

We understand that the 1997 Cassini space mission to Saturn includes plans to use 73 lbs. of plutonium. We are opposed to this because of the terribly toxic nature of plutonium. We urge you to consider using a solar powered alternative. —45A

The European Space Agency, in 1994, released a statement saying that "European industry has recently developed high efficiency solar cells for use in future demanding deep-space missions."

Why would the DOE rather use deadly plutonium when there is a safe alternative? —45B

Respectfully yours,
Carole Hyneman
Frank Hyneman

RESPONSES TO COMMENTS
Commentor No. 45: Carole and Frank Hyneman

NASA appreciates expression of your views. Your comments are similar to those expressed by earlier commentors.

Response to Comment 45A:

See response to Comment 2A.

Response to Comment 45B:

See response to Comment 1B.

Fran Collier
3187 Windrush Bourne
Sarasota, FL 34235

Dr Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA HQ
Washington, DC 20546

Dear Sir:

This letter is to urge you to halt the Cassini plutonium mission and stop the use of nuclear power in space. —46A

NASA and DOE give little consideration to the use of a solar-powered alternative on the Cassini mission. However, in April 1994 the European Space Agency released a statement saying that "European industry has recently developed high efficiency solar cells for use in future demanding deep-space missions." —46B

How unfortunate that the nuclear power industry and the DOE continue producing plutonium generation in the Savannah River Plant, Los Alamos Labs, Oak Ridge, Mound Labs and Martin Marietta. These sites were mainstays in producing nuclear weapons. Now nuclear power in space might keep them profitable. —46C

Please use your influence to stop nuclear power in space and to develop solar energy for ALL purposes!

Sincerely,

(Mrs) Fran Collier

RESPONSES TO COMMENTS

Commentor No. 46: Mrs. Fran Collier

NASA appreciates expression of your views. Your comments are similar to those expressed by earlier commentors.

Response to Comment 46A:

See response to Comment 2A.

Response to Comment 46B:

See response to Comment 6A.

Response to Comment 46C:

See response to Comment 19D.

C.R.E.
F.S.D.B.

RELIGIOUS EDUCATION
FOR THE
CATHOLIC DEAF & BLIND
207 N. SAN MARCO AVENUE
ST. AUGUSTINE, FLORIDA 32084
(904) 823-4407 VOICE/TDD

February 27, 1995

Dr. Peter Ulrich
Solar System Exploration
Office of Space Science
NASA HQ
Washington, D.C. - 20546

Dear Dr. Ulrich:

Regarding the 1997 Cassini Space launch to Saturn, I greatly protest carrying plutonium on this mission. —47A

The possibility of an accident would endanger every living being. —47B

Again, I am against the Cassini plutonium mission.

Thank you.

Very truly yours,

Rev. René Robert

Rev. Rene' Robert

RR/mpf

Supported by the Knights of Columbus, Catholic Daughters and the Diocesan Fund.

RESPONSES TO COMMENTS

Commentor No. 47: Religious Education for the Catholic Deaf & Blind (Rev. René Robert)

<u>Response to Comment 47A:</u>

See response to Comment 2A.

<u>Response to Comment 47B:</u>

NASA has estimated the risks from plutonium (Pu-238) dioxide onboard the Cassini spacecraft and has found the risks to the world population and our planet to be very low. The risks from the launch of Cassini would be lower than many of the risks that we face in our everyday lives (see Table 4-20 in the Environmental Impact Statement). A wide range of potential accident scenarios was evaluated.

APPENDIX E

RESPONSES TO FEDERAL, STATE, AND LOCAL GOVERNMENT ORGANIZATIONS

APPENDIX E

RESPONSES TO FEDERAL, STATE, AND LOCAL GOVERNMENT ORGANIZATIONS

The U.S. Environmental Protection Agency published a Notice of Availability for the Cassini mission Draft Environmental Impact Statement in the Federal Register on October 21, 1994. The public review and comment period closed on December 20, 1994. Timely comments were received from the Federal, state and local government organizations listed in Table E-1.

Where no extension of the comment period was requested and granted, untimely comments were still considered if received before March 3, 1995 (see Table E-2). As of March 3, 1995, one letter was received after the comment period closed, and is included in this Appendix.

This Appendix provides specific responses to the comments received from the Federal, state and local agencies listed in Tables E-1 and E-2. Copies of the comment letters are presented in the following pages. The relevant issues in each comment letter are marked and numbered for identification along with the National Aeronautics and Space Administration's (NASA's) response to each issue. Where changes in the text were appropriate, such changes were noted in the comment response.

The comments received from the Federal, state and local government organizations related to the following issues in the Environmental Impact Statement (EIS):

- environmental impacts on groundwater near the launch site
- cumulative environmental impacts on the stratospheric ozone
- clarification of radiological impacts analyses

Information on these topics is addressed in the following sections of the EIS:

Groundwater impacts near the launch site—The description of the groundwater in the Cape Canaveral Air Station/Kennedy Space Center regional area is presented in Sections 3.1.5.3 and 3.1.5.4. In addition, Sections 4.1.2.6 and 4.2.2 discuss the environmental impacts on the hydrology and water quality from a normal launch.

Cumulative impacts on stratospheric ozone—The impacts on the upper atmosphere includes a discussion of the potential cumulative impacts on the ozone layer including those from other launches. The discussion is provided in Section 4.1.2.3 of the EIS.

Radiological impact analyses—Sections 4.1.5 through 4.1.8 and Sections 4.2.5 through 4.2.8 discuss the following: 'the methodologies used in the radiological assessments, radiological consequences, and risk analyses for the Cassini mission.

TABLE E-1. LIST OF COMMENTORS

Commentor Number	Date of Comment	Organization	Individual Presenting Comments
1	11/7/94	Brevard County Planning and Zoning Division	Peggy Busacca
2	11/10/94	U.S. Dept. of Health & Human Services Centers for Disease Control	Kenneth W. Holt
3	12/20/94	U.S. Environmental Protection Agency (EPA), Office of Federal Activities	Richard E. Sanderson

TABLE E-2. LIST OF COMMENTORS RESPONDING AFTER CLOSE OF PUBLIC COMMENT PERIOD

Commentor Number	Date of Comment	Organization	Individual Presenting Comments
4	12/23/94	State of Florida, Dept. of Community Affairs	Linda Loomis Shelley

BREVARD County
BOARD OF COUNTY COMMISSIONERS

FLORIDA'S SPACE COAST

PLANNING and ZONING DIVISION
2725 St. Johns St., Bldg. A Viera, Florida 32940

Telephone: (407) 633-2069

November 7, 1994

Dr. Peter B. Ulrich
Chief, Flight Programs Branch
Solar System Exploration Division
Office of Space Science
Code SL
NASA Headquarters
Washington, DC 20546

Dear Dr. Ulrich:

Thank you for the opportunity to review the Draft Environmental Impact Statement (DEIS) for the Cassini Mission. The Brevard County Planning and Zoning Division does not have any comments to make at this time regarding the above mentioned DEIS. However, the Planning and Zoning Division staff would like to be informed regarding any changes or updates that may be made to the DEIS. —1A

If you have any questions or need additional information, please contact Todd Corwin or me at (407) 633-2066.

Sincerely,

Peggy Busacca

Peggy Busacca, Director
Planning and Zoning Division

cc: Dean Sprague, Assistant County Administrator
Gary Ridenour, Director, Growth Management Department
Lisa Barr, Director, Natural Resources Management Division

RESPONSES TO COMMENTS

Commentor No. 1: Brevard County Planning and Zoning Division (Peggy Busacca)

<u>Response to Comment 1A:</u>

Comment noted. Thank you.

RESPONSES TO COMMENTS
Commentor No. 2: U.S. Dept. of Health & Human Services, Centers for Disease Control (Kenneth W. Holt)

DEPARTMENT OF HEALTH & HUMAN SERVICES
Public Health Service

Centers for Disease Control
Atlanta GA 30341-3724

November 10, 1994

Dr. Peter B. Ulrich
Chief, Flight Programs Branch
Code SL
NASA Headquarters
Washington, D.C. 20546

Dear Dr. Ulrich:

We have completed our review of the Draft Environmental Impact Statement (DEIS) for the Cassini Mission, National Aeronautics and Space Administration. We are responding on behalf of the U.S. Public Health Service.

In general, this DEIS addresses the public health concerns associated with each alternative. However, there are several suggested modifications offered by our reviewer that would improve the document. These comments are detailed in the attachment. If you should have any questions concerning these comments, you may contact Dr. Sanford Leffingwell at (404) 488-7091.

Thank you for the opportunity to review and comment on this draft document. Please ensure that we are included on your mailing list to receive a copy of the Final EIS, and future EISs which may indicate potential public health impact and are developed under the National Environmental Policy Act.

Sincerely yours,

Kenneth W. Holt

Kenneth W. Holt, M.S.E.H.
Special Programs Group (F29)
National Center for Environmental Health

Attachment

Comments on Draft Environmental Impact Statement for the Cassini Mission
National Center for Environmental Health, Centers for Disease Control and Prevention

Page/ Paragraph/ Line	Comment	
viii/3/7-9	The statement "Considering the extremely low probability of such an inadvertent reentry, NASA has estimated that normal worldwide cancer fatality rates could increase by approximately 0.0005 percent if such an accident were to occur" seems internally contradictory. The phrase "Considering the extremely low probability of such an inadvertent reentry" suggests that the 0.0005% increase is the product of the expected consequence and the probability of its occurrence, while the phrase "if such an accident were to occur" suggests that the 0.0005% worldwide increase is the consequence, untempered by probability of occurrence (the more usual way of presenting such considerations). This should be clarified.	2A
	Further, there needs to be a justification for use of worldwide incidence as an appropriate statistic rather than local incidence nearest the point of impact. An increase from a background rate of around 20% to a rate of 100% in a sufficiently small population would have a negligible impact on world incidence rates but would be catastrophic for the population affected.	2B
	Some information on the persistence of this elevation would also be helpful—would it last forever?	2C
	Finally, a term such as "background" might be better than "normal," since there is some controversy about how "normal" current cancer rates are.	2D
viii/4 ff	It might be helpful to include information about both the probability of occurrence and magnitude of consequence in the discussions of health effects risk.	2E
xxi-xxvii	This is a good location for the glossary of abbreviations and acronyms. Thanks.	2F
2-17	The table doesn't seem to balance. The weight percents at launch total to 97.89% and the total Bequerels at Launch for Pu-241 would appear to be 8.2×10^{13}, not 6.9×10^{13}. That should have no significant impact on the conclusions, but presence of a problem is often an indication of a need to review a section carefully, looking for errors which might be significant. (The published number for Pu-241 might even be correct for some reason inapparent to those of us uninitiated in the mysteries of nuclear physics.) In the table below, the first two columns were taken from Table 2-3; the third is the product of 10.8 kg and the percent-by-weight column; the fourth through sixth are taken from Table 2-3; the seventh and eighth are the product of column	2G

RESPONSES TO COMMENTS
Commentor No. 2: U.S. Dept. of Health & Human Services,
Centers for Disease Control (Kenneth W. Holt)
(Continued)

Response to Comment 2A:

The text on page viii has been clarified to note that if such an inadvertent reentry accident were to occur, the estimated numbers of resulting excess cancer fatalities would represent about 0.0005 percent of the normally observed cancer fatalities that would occur within the exposed population of about 5 billion people worldwide.

Response to Comment 2B:

Worldwide cancer incidence is an appropriate statistic to use when discussing potential exposures from a swingby accident since plutonium could be released in the upper atmosphere as vapor and/or small particulates. The vapor and/or particulates could then be transported and distributed worldwide by the wind circulation patterns in the upper atmosphere.

All releases could have local impacts. However, ground level releases resulting from accident scenarios in which plutonium-containing components of the radioisotope thermoelectric generators (RTGs) hit hard surfaces would be considered to have more of a local impact than a global (or worldwide) impact. Such ground-level releases would not be dispersed by upper atmospheric wind patterns. Localized low atmosphere or ground-level wind patterns would dominate the dispersal processes.

Tables C-5, C-6, and C-7 provide the fuel end states predicted for a plutonium release from an inadvertent reentry during an Earth swingby. The dominant contributor to the health effect impacts from both shallow and steep reentries would be from the vapor end state. The plutonium dioxide vapor and particulates are predicted to contribute about 99 percent of the estimated total health effects. Released at high altitude, the vapor/particulates would be transported and distributed worldwide by the wind circulation patterns in the upper atmosphere. Conversely, Tables C-5, C-6, and C-7 indicate a lesser health effect impact from ground level releases of plutonium dioxide. The health effect impact in the exposed population at risk from ground-level releases would be statistically indistinguishable from the normally observed cancer fatalities.

RESPONSES TO COMMENTS

Commentor No. 2: U.S. Dept. of Health & Human Services,
Centers for Disease Control (Kenneth W. Holt)
(Continued)

Response to Comment 2C:

The contamination resulting from an accident would not last "forever." The dominant isotope of the fuel, plutonium-238, has a half-life of 87.75 years. Because of radioactive decay and accounting for all the plutonium isotopes in the original fuel, the amount of plutonium remaining (without any mitigation actions) after 100 years would be 45 percent, after 500 years would be 2 percent, after 1,000 years 0.13 percent, and after 5,000 years would be 0.08 percent.

Response to Comment 2D:

Comment noted. Text has been clarified where appropriate.

Response to Comment 2E:

Comment noted. The probability of occurrence and magnitude of the consequences are discussed in detail beginning with Sections 4.1.5 through 4.1.8 and Sections 4.2.5 through 4.2.8 of the Environmental Impact Statement (EIS). The executive summary provides a synopsis of the analysis and the results obtained.

Response to Comment 2F:

NASA appreciates your comment. Thank you.

Response to Comment 2G:

A revised table has been included in the EIS. Please note that the total inventory is unchanged.

Page/ Paragraph/ Line	Comment	
2-17 (cont'd)	three and either column five or column six. Numbers below the line are column sums.	
2-19	This safety data is well-presented and impressive.	2H
2-28/5 (& elsewhere)	Does "to destruct" mean something different from "to destroy?" If so, perhaps it should be explained: if not, perhaps the plainer English form should be used (or utilized, if you must).	2I
2-64 & 65	The meaning of these numbers needs clearer explication. Did the low number of health effects (3.36 x 10^{-4}) result from the fact that no one lives in the .0718 square miles nearest the pad or from the fact that there is little likelihood of injury even if someone did spend a significant fraction of there time in that area? If the expected number of excess cancers is 3.36 x 10^{-4} and the average risk is 3.1 x 10^{-12}, the risk is apparently being distributed over 3.36 x 10^{-4}/ 3.1 x 10^{-12} or 1.8 x 10^{8} people. Surely there are not 180,000,000 people living in the .0718 square miles, so that interpretation must be wrong. What is the correct interpretation?	2J
2-66, footnote d	Again, a rationale for averaging exposure over the whole earth rather than some finite area near the point where containment failed (below, or even limited to a latitude band) should be given. If exposure estimates have assumed a more local distribution, then the text and notes should explain more clearly what the assumptions were and perhaps give sample calculations.	2K
4-101/2 & 3	These paragraphs are very helpful is addressing some of the questions raised earlier in the document. Adding a summarization of the calculations to the appropriate tables in section 2 would greatly facilitate reading, and similar inclusion in the text at an earlier point would also be useful. There are only 5 pages left in the document when this information is presented!	2L

RESPONSES TO COMMENTS
Commentor No. 2: U.S. Dept. of Health & Human Services, Centers for Disease Control (Kenneth W. Holt)
(Continued)

Response to Comment 2H:

Comment noted. Thank you.

Response to Comment 2I:

The correct verb is "destroy." "Destruct" is a common terminology employed by the aerospace community and denotes a human action undertaken to purposely destroy a vehicle, spacecraft, or other component.

Response to Comment 2J:

Table 2-7 indicates that the potential land area contaminated above the EPA screening level from a Phase 1 accident would be 1.86 x 10^{-1} km^2 (7.18 x 10^{-2} mi^2). The exposed population would not necessarily occupy the contaminated land area. The population exposures would occur largely as a result of airborne transport of released fuel dominated by local wind patterns. The estimated population at risk from a Phase 1 accident would be the population in the vicinity of CCAS, estimated to be 100,000 people.

Footnotes have been added to Tables 2-7 and 2-8 for clarification. The radiological consequences are presented for the phase/accident scenario combination with the largest contribution to the mission risk for the population in the indicated affected area. As shown in Tables 4-17 and 4-18, the total probability for a Phase 1/Titan IV (SRMU)/Centaur Fail-To-Ignite scenario would be 9.1 x 10^{-4} with an estimated 3.36 x 10^{-4} health effects. The product of these two numbers gives the mission risk contribution of 3.1 x 10^{-7} health effects. With an estimated population of 100,000 exposed to the release, the average individual risk would be 3.1 x 10^{-12}.

Response to Comment 2K:

See response to Comment 2B. The estimated average individual risk is reported in Table 2-8, as well as in Table 4-18. Also estimated, and reported in Section 4.1.8 and Table 4-19, is the average individual risk that a person within the reentry footprint could face if an inadvertent reentry accident occurred and the footprint was over land.

RESPONSES TO COMMENTS

Commentor No. 2: U.S. Dept. of Health & Human Services,
Centers for Disease Control (Kenneth W. Holt)
(Continued)

10.8 kg = Total Weight of fuel

Element	% by Wt.	Weight kg	Half-Life	Specific Radioactivity (Bequerel /gram)	Specific Radioactivity (Curies/ gram)	Total Radioactivity at Launch Bequerels	Total Radioactivity at Launch Curies
Pu-236	2.5E-6	0.0000	2.851	2.0E+13	531.3	5.40E+09	0.14
Pu-238	70.81	7.6475	87.75	6.3E+11	17.1	4.82E+15	130,771.91
Pu-239	12.86	1.3889	24,131	2.3E+09	0.062	3.19E+12	86.11
Pu-240	1.79	0.1933	6,569	8.4E+09	0.2267	1.62E+12	43.83
Pu-241	0.20	0.0216	14.4	3.8E+12	103	8.21E+13	2,224.80
Pu-242	0.11	0.0119	375,800	1.5E+08	0.00393	1.78E+09	0.05
Other	0.25	0.0270					
(O-16)$_2$	11.85	1.2798					
	97.87	10.5700				4.90E+15	133,126.83

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

DEC 20 [illegible]

OFFICE OF
ENFORCEMENT AND
COMPLIANCE ASSURANCE

Dr. Peter Ulrich
Solar System Exploration Division
Office of Space Science
NASA Headquarters
Washington, DC 20546

Dear Dr. Ulrich:

The Environmental Protection Agency (EPA) has reviewed the National Aeronautics and Space Administration (NASA) draft environmental impact statement (EIS) for the Cassini Mission. This review was conducted in accordance with our responsibilities under section 309 of the Clean Air Act and the National Environmental Policy Act (NEPA). We have classified this draft EIS as EC-2 (environmental concerns, insufficient information).

This rating primarily reflects our concerns for cumulative impacts. Under section 1508.7 of the Council on Environmental Quality (CEQ) NEPA Implementing Regulations, NASA is required to examine:

> ...the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. **Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.** (Emphasis added)

As EPA has commented before, we believe that cumulative impacts to the ozone layer from all launch activities need to be thoroughly examined in the near future. While any singular launch may have little impact, we do not know what the cumulative impacts to the stratosphere may be. —3A

EPA also would like to see effects of launch activities such as deluge, noise, fire suppression and washdown waters more thoroughly examined in the final EIS. While no data are presented in the document, EPA suspects that the groundwater in the vicinity of the three receiving percolation ponds is contaminated from runoff from this and other launches. —3B

RESPONSES TO COMMENTS
Commentor No. 3: U.S. Environmental Protection Agency (EPA), Office of Federal Activities (Richard E. Sanderson)

Response to Comment 3A:

Additional text has been added to Section 4.1.2.3 of the Environmental Impact Statement (EIS) to reflect the current state-of-the-science of the cumulative impacts on ozone due to rocket launches.

Response to Comment 3B:

Deluge, noise, fire suppressant and washdown water present after launch activities are temporarily held in the flame bucket. This water is released to the percolation ponds only when analytical results indicate that it satisfies permit criteria (State of Florida drinking water standards). Therefore, the release of this water should not adversely impact the groundwater system to any significant degree. Updated data from the U.S. Air Force groundwater monitoring wells at the Titan IV Launch Complexes 40 and 41 have been obtained and are included in Tables 3-3 and 3-4 of the EIS with updated text presented in Section 4.1.2.6.

In addition to our comments on the cumulative impacts associated with this and other launches, EPA has two other comments. First, the tracking of hazardous materials associated with the industrial type activities attendant to launches continues to pose administrative difficulties for both the regulatory and regulated agencies. Because of the many potential generators engaged in this effort, EPA suggests you consider the development of a pharmacy-style hazardous materials acquisition system similar to that at nearby Patrick Air Force Base. 3C

Secondly, the draft EIS states on page 3-13 that the Clean Air Act General Conformity Rules only apply to non-attainment areas. This is incorrect. The rules also apply to maintenance areas. While these rules may not be applicable to this project, EPA would like to correct this misinterpretation of the rules. 3D

Thank you for the opportunity to review and comment on the draft EIS. If you have any questions please call me at (202) 260-5053 or Pat Haman at 260-3358.

Sincerely,

Richard E. Sanderson
Director
Office of Federal Activities

RESPONSES TO COMMENTS
Commentor No. 3: U.S. Environmental Protection Agency (EPA), Office of Federal Activities (Richard E. Sanderson)
(Continued)

Response to Comment 3C:

NASA has and will continue to consider use of a pharmacy-style system on a Center-by-Center basis. Please note that Cape Canaveral Air Station is managed by Patrick Air Force Base and is a U.S. Air Force facility.

Response to Comment 3D:

Section 3.1.2.3 of the EIS has been modified to reflect corrections associated with the Clean Air Act (CAA) General Conformity Rules.

STATE OF FLORIDA
DEPARTMENT OF COMMUNITY AFFAIRS

2740 CENTERVIEW DRIVE • TALLAHASSEE, FLORIDA 32399-2100

LAWTON CHILES
Governor

LINDA LOOMIS SHELLEY
Secretary

December 23, 1994

Dr. Peter Ulrich
Chief, Flight Programs Branch
Solar System Exploration Division
Office of Space Science
Code SL
NASA Headquarters
Washington, DC 20546

RE: National Aeronautics and Space Administration - Draft Environmental Impact Statement - Cassini Mission - Kennedy Space Center, Brevard County, Florida
SAI: FL9410171068C

Dear Dr. Ulrich:

The Florida State Clearinghouse, pursuant to Presidential Executive Order 12372, Gubernatorial Executive Order 93-194, the Coastal Zone Management Act, 16 U.S.C. §§ 1451-1464, as amended, and the National Environmental Policy Act, 42 U.S.C. §§ 4321, 4331-4335, 4341-4347, as amended, has coordinated a review of the above-referenced project.

Based on the enclosed comments provided by our reviewing agencies, the state has determined that the above-referenced project is consistent with the Florida Coastal Management Program. —4A

Very truly yours,

Linda Loomis Shelley
Secretary

LLS/rk

Enclosures

Response to Comment 4A:

Comment noted. Thank you.

RESPONSES TO COMMENTS

Commentor No. 4: State of Florida, Dept. of Community Affairs
(Linda Loomis Shelley)
(Continued)

COUNTY: BREVARD

DATE: 10/31/94
COMMENT DUE DATE: 11/14/94
SAI#: FL9410171068C

STATE AGENCIES

- ___ Agriculture
- ___ Board of Regents
- ___ Commerce
- ___ Community Affairs
- ___ Education
- _X_ Environmental Protection
- _X_ Game & Fish Comm
- ___ Health & Rehab Srv
- ___ Highway Safety
- ___ Labor & Employmnt
- ___ Law Enforcement
- _X_ Marine Fish Comm
- ___ State Library
- ___ State
- ___ Transportation
- ___ Trans Disad. Comm
- ___ DEP District
- ___
- ___

LOCAL/OTHER

- ___ NWFWMD
- ___ SFWMD
- ___ SWFWMD
- ___ SJRWMD
- ___ SRWMD
- ___
- ___

OPB POLICY UNITS

- ___ Public Safety
- ___ Education
- ___ Environment/C & ED
- ___ General Government
- ___ Health & Human Srv
- ___ Revenue & Eco. Ana
- ___ SCH
- _X_ SCH/CON

Roy Williams
MARINE FISH COMMISSION

INTERDEPARTMENTAL

RECEIVED
NOV 14 1994
Florida C[illegible]
Managem[illegible]

RECEIVED
NOV 03 1994
MARINE FISHERIES
COMMISSION

The attached document requires a Coastal Zone Management Act/Florida Coastal Management Program consistency evalutation and is categorized as one of the following:

- ___ **Federal Assistance to State or Local Government (15 CFR 930, Subpart F). Agencies are required to evaluate the consistency of the activity.**
- _X_ **Direct Federal Activity (15 CFR 930, Subpart C). Federal Agencies are required to furnish a consistency determination for the State's concurrence or objection.**
- ___ **Outer Continental Shelf Exploration, Development or Production Activities (15 CFR 930, Subpart E). Operators are required to provide a consistency certification for state concurrence/objection.**
- ___ **Federal Licensing or Permitting Activity (15 CFR 930, Subpart D). Such projects will only be evaluated for consistency when there is not an analogous state license or permit.**

FOR CONSISTENCY PROJECTS, SEE REVERSE SIDE FOR INSTRUCTIONS.

To: **State Clearinghouse**
Executive Office of the Governor -OPB
Room 1603, The Capitol
Tallahassee, FL. 32399-0001
(904) 488-8114 (SC 278-8114)

Florida Coastal Management Director
Department of Community Affairs
Suite 305, Rhyne Building
Tallahassee, FL. 32399-2100
(904) 922-5438 (SC 292-5438)

EO. 12372/NEPA

☐ No Comment
☐ Comments Attached
☐ Not Applicable

Federal Consistency

☐ No Comment/Consistent
☐ Consistent/Comments Attached
☐ Inconsistent/Comments Attached
☒ Not Applicable

From:
Division/Bureau: Marine Fisheries Comm.
Reviewer: Roy Williams
Date: 11-9-94

RESPONSES TO COMMENTS
Commentor No. 4: State of Florida, Dept. of Community Affairs
(Linda Loomis Shelley)
(Continued)

COUNTY: BREVARD

DATE: 10/31/94
COMMENT DUE DATE: 11/14/94
SAI#: FL9410171068C

STATE AGENCIES

- __ Agriculture
- __ Board of Regents
- __ Commerce
- __ Community Affairs
- __ Education
- _X_ Environmental Protection
- _X_ Game & Fish Comm
- __ Health & Rehab Srv
- __ Highway Safety
- __ Labor & Employmnt
- __ Law Enforcement
- _X_ Marine Fish Comm
- __ State Library
- __ State
- __ Transportation
- __ Trans Disad. Comm
- __ DEP District
- __
- __

LOCAL/OTHER

- __ NWFWMD
- __ SFWMD
- __ SWFWMD
- __ SJRWMD
- __ SRWMD
- __
- __

OPB POLICY UNITS

- __ Public Safety
- __ Education
- __ Environment/C & ED
- __ General Government
- __ Health & Human Srv
- __ Revenue & Eco. Ana
- __ SCH
- _X_ SCH/CON

Susan Goggin
Dept of Env. Protection
MS 47
Interdepartmental

RECEIVED
NOV 3 1994
OFFICE OF
Intergovernmental Programs

RECEIVED
DEC [illegible] 1994
Florida Coastal
Management Program

The attached document requires a Coastal Zone Management Act/Florida Coastal Management Program consistency evalutation and is categorized as one of the following:

- __ Federal Assistance to State or Local Government (15 CFR 930, Subpart F). Agencies are required to evaluate the consistency of the activity.
- _X_ Direct Federal Activity (15 CFR 930, Subpart C). Federal Agencies are required to furnish a consistency determination for the State's concurrence or objection.
- __ Outer Continental Shelf Exploration, Development or Production Activities (15 CFR 930, Subpart E). Operators are required to provide a consistency certification for state concurrence/objection.
- __ Federal Licensing or Permitting Activity (15 CFR 930, Subpart D). Such projects will only be evaluated for consistency when there is not an analogous state license or permit.

FOR CONSISTENCY PROJECTS, SEE REVERSE SIDE FOR INSTRUCTIONS.

To: State Clearinghouse
Executive Office of the Governor -OPB
Room 1603, The Capitol
Tallahassee, FL. 32399-0001
(904) 488-8114 (SC 278-8114)

Florida Coastal Management Director
Department of Community Affairs
Suite 305, Rhyne Building
Tallahassee, FL. 32399-2100
(904) 922-5438 (SC 292-5438)

EO. 12372/NEPA

- ☐ No Comment
- ☐ Comments Attached
- ☐ Not Applicable

Federal Consistency

- ☒ No Comment/Consistent
- ☐ Consistent/Comments Attached
- ☐ Inconsistent/Comments Attached
- ☐ Not Applicable

From: FDEP
Division/Bureau: Intergovernmental Program
Reviewer: Susan Goggin
Date: 1 December '94