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

upgraded 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 (1113,232 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	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]	-----------	
	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 HCI 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 I [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 tire 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 riot 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 of 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 (104μg/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 A1203 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 x 10^{-5} percent of all anthropogenic CO_2 and only 5 x 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 x 10^7 kg/yr (17.6 x 10^7 lb/yr) of water to the troposphere while natural processes in the tropics account for the input of 1 x 10^{12} kg/yr (2.2 x 10^{l2} 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 manometers 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 1000 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 1510,000 1 (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 I; 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 oil 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).

<u>Groundwater</u>

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 I (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 I; 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 I [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 I (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, HCI 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 HCI 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 HCI 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 HCI 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 (5 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 (11 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 HCI, 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 HCI 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 HCI 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 longterm 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 (1600,000 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 al 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 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 front 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% Median Mean 95%	4.9×10^{-5} 2.4×10^{-4} 4.4×10^{-4} 1.3×10^{-3}	5.3×10^{-5} 2.6×10^{-4} 4.6×10^{-4} 1.5×10^{-3}	3.7×10^{-5} 2.5×10^{-4} 5.9×10^{-4} 2.3×10^{-3}	1.6×10^{-3} 8.3×10^{-3} 1.1×10^{-2} 3.0×10^{-2}	1.1×10^{-2} 2.8×10^{-2} 3.2×10^{-2} 6.6×10^{-2}	Not Applicable	1.9×10^{-2} 4.1×10^{-2} 4.5×10^{-2} 8.3×10^{-2}
Titan IV (SRMU) Fail-to-Ignite	5% Median Mean 95%	2.2×10^{-5} 4.5×10^{-4} 1.4×10^{-3} 5.8×10^{-3}	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	2.2×10^{-5} 4.5×10^{-4} 1.4×10^{-3} 5.8×10^{-3}
Centaur Tank Failure/Collapse[b]	5% Median Mean 95%	1.2×10^{-5} 5.1×10^{-5} 1.1×10^{-4} 3.9×10^{-4}	4.6×10^{-6} 4.4×10^{-5} 1.1×10^{-4} 4.1×10^{-4}	1.3×10^{-5} 1.2×10^{-4} 2.9×10^{-4} 1.2×10^{-3}	3.0×10^{-4} 9.5×10^{-4} 1.8×10^{-3} 6.5×10^{-3}	1.7×10^{-4} 1.3×10^{-3} 2.6×10^{-3} 9.7×10^{-3}	1.5×10^{-5} 1.1×10^{-4} 2.6×10^{-4} 9.0×10^{-4}	1.2×10^{-3} 3.7×10^{-3} 5.2×10^{-3} 1.5×10^{-2}
Inadvertent Reentry From Earth Orbit[b] (excluding Earth escape)	5% Median Mean 95%	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	3.4×10^{-4} 1.2×10^{-3} 1.7×10^{-3} 4.6×10^{-3}	3.4×10^{-4} 1.2×10^{-3} 1.7×10^{-3} 4.6×10^{-3}
Scenario Totals By Mission Phase[c]	5% Median Mean 95%	2.6×10^{-4} 1.0×10^{-3} 1.9×10^{-3} 6.9×10^{-3}	1.0×10^{-4} 3.6×10^{-4} 3.7×10^{-4} 1.8×10^{-3}	1.1×10^{-4} 5.0×10^{-4} 8.8×10^{-4} 3.1×10^{-3}	2.7×10^{-3} 1.0×10^{-2} 1.3×10^{-2} 3.3×10^{-2}	1.3×10^{-2} 3.1×10^{-2} 3.4×10^{-2} 7.0×10^{-2}	4.5×10^{-4} 1.5×10^{-3} 2.0×10^{-3} 4.8×10^{-3}	Not Applicable

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 o 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 JPLs 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 pressing 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 1.0×10^{-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]	4×10^{-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 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]		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 1 88, 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. El 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 (0.2 μCi/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.

<u>Potential Consequences for Phases 1 through 6 Accidents</u>

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} (2.97×10^{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 4-10. 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 $\mu Ci/m^2$)
		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 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. 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 $\mu Ci/m^2$)
	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)				Maximum Individual Dose, Sv (rem)	Land Area km2 (mi2) Above 7.4 x 103 Bq/m2 (0.2 µCi/m2)
	Without De Minimis	With De Minimis	Without De Minimis	With De Minimis		
Shallow-E1[d]	1.25 x 10^{5}	2.92 x 10^{2}	4.38 x 10^{3}	1.02 x 10^{1}	2.61 x 10^{-1}	5.71 x 10^{3}
	(1.25 x 10^{7})	(2.92 x 10^{4})			(2.61 x 10^{1})	(2.20 x 10^{3})
Shallow-E2[e]	1.53 x 10^{5}	3.64 x 10^{2}	5.36 x 10^{3}	1.27 x 10^{1}	3.25 x 10^{-1}	5.73 x 10^{3}
	(1.53 x 10^{7})	(3.64 x 10^{4})			(3.25 x 10^{1})	(2.21 x 10^{3})
Steep-E1[f]	6.40 x 10^{4}	4.34 x 10^{2}	2.24 x 10^{3}	1.52 x 10^{1}	5.03 x 10^{-1}	1.54 x 10^{3}
	(6.40 x 10^{6})	(4.34 x 10^{4})			(5.03 x 10^{1})	(5.95 x 10^{2})
Steep-E2[g]	1.03 x 10^{5}	4.83 x 10^{2}	3.60 x 10^{3}	1.69 x 10^{1}	3.90 x 10^{-1}	2.26 x 10^{3}
	(1.03 x 10^{7})	(4.83 x 10^{4})			(3.90 x 10^{1})	(8.73 x 10^{2})
Expectation-E1[h]	7.07 x 10^{4}	4.18 x 10^{2}	2.48 x 10^{3}	1.46 x 10^{1}	4.76 x 10^{-1}	2.00 x 10^{3}
	(7.07 x 10^{6})	(4.18 x 10^{4})			(4.76 x 10^{1})	(7.72 x 10^{2})
Expectation-E2[i]	1.30 x 10^{5}	4.19 x 10^{2}	4.56 x 10^{3}	1.47 x 10^{1}	3.55 x 10^{-1}	4.13 x 10^{3}
	(1.30 x 10^{7})	(4.19 x 10^{4})			(3.55 x 10^{1})	(1.59 x 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 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).
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 1 0 (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)	Effective Dose Equivalent[a] 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 x 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 5.46×10^4 person-Sv (5.46×10^6 person-rem) for a steep angle reentry, and about 9.93×10^4 person-Sv (9.93×10^6 person-rem) for a shallow reentry. The expectation collective dose would be about 6.58×10^4 person-Sv (6.58×10^6 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 El 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 x 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 x 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 nonrespirable 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] Without De Minimis	Radiological Consequences, Health Effects[a,b] With De Minimis	Mission Risks, Health Effects[a,c,d] Without De Minimis	Mission Risks, Health Effects[a,c,d] With De Minimis
1	Command Shutdown & Destruct	1.7×10^{-4}	7.24×10^{-4}	-	1.2×10^{-7}	-
	Titan IV (SRMU) Fail-To-Ignite	9.1×10^{-4}	3.36×10^{-4}	-	3.1×10^{-7}	-
	Centaur Tank Failure/Collapse	4.2×10^{-5}	7.28×10^{-4}	-	3.1×10^{-8}	-
				Mission Risk Contribution: Phase 1	4.6×10^{-7}	-
5	Command Shutdown & Destruct	4.6×10^{-4}	1.51×10^{-4}	4.38×10^{-5}	6.9×10^{-8}	2.0×10^{-8}
	Centaur Tank Failure/Collapse	3.7×10^{-5}	1.51×10^{-4}	4.38×10^{-5}	5.6×10^{-9}	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	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: 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 1.0×1.0^{-5} Sv (1.0×1.0^{-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 El 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 105 to 106 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 El 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 x 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 4-1 8 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 1 3 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^{-3}, 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:

$$(\text{Average individual risk})_i = (\text{Mission risk contributions} / (\text{Exposed population at risk})_i$$

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] Without De Minimis	Health Effects[b] With De Minimis	Conditional Probability	Short Term Total Probability	Average Individual Risk[c] Without De Minimis	Average Individual Risk[c] 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}
VEEGA						Overall	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 x 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 x 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 x 10^{-11} or a chance of about 1 in 1 6 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 x 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 1000 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 x 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	2.2×10^{-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 mil 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 x 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 x 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 x 10^{-11} (1 in 100 million) for each of these accident cases. This is at least 1 0,000 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 & Destruct	107×10^{-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}	4.3×10^{-7} (4.3×10^{-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 1 9 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 [1 64,050 ft]).

Exhaust products in the exhaust cloud are typically dispersed within about 14 km (9 mi) of the launch complex (Pad 39A or 3913), with the heaviest deposition of A1203 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/m2 (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 7,1 00 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 ($A1_2O_3$) and HCl near the launch pad, similar to a Titan IV (SRMU) launch. As the Shuttle is launched, about 3,300,0001 (863,000 gal) of deluge and washwater is used. An unknown amount of the 1,938,0001 (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 (1,238,8001 [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 WPL 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 19781, 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 1 988a, 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 1 988 Shuttle Databook (NASA 1988a) used for the Ulysses FSAR, which has been updated with initiating accident probabilities (DOE 1 990a).

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 1 994b, Halliburton NUS 1994b).

Shuttle Phase 0

During Phase 0, none of the accident scenarios or environments identified for prelaunch 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 + 1 28 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 1 994b). 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 1 994b).

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 1994, 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 + 1 28 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).

<u>Short-Term Inadvertent Reentry/ During Earth Swingby</u>

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) Fireball	Ground-Level	At Altitude	Altitude, m (ft)[a]	Remarks
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 la, 1b, or 1c expectation source terms (Table 4-24), the highest collective dose would be about 1 x 10^{-1} person-Sv (l x 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] Without De Minimis	Collective Dose With De Minimis	Health Effects[d] Without De Minimis	Health Effects With De Minimis	Maximum Individual Dose, Sv (rem)	Land Area, km² (mi²), Above 0.2 µCi/m²
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 condition 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 7×10^{-6} SV (7×10^{-4} rem) from expectation case source terms. Comparing these doses with individual doses received from natural background radiation (about 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/YrD (see Table 4-14) for a total 50-year effective dose commitment of about 1.82×10^{-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 (4.0×10^{-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 1.2×10^{-4} Sv (1.2×10^{-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 5.6×10^{10} Bq (1 .5 Ci) and would result in a 50-year collective dose of about 1.97×10^{-2} person-Sv (1.97 x 100 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 5.4×10^{-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 4-1 4). 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 SOL 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 la, lb, and 1c) accident with a release could "impact" the local CCAS/KSC area only, while a late Phase 1 (Phase ld and le) 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 km2 (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 1 999 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 1 994b) and the *Accident Assessment for Shuttle Launch of Cassini* (Martin Marietta Astro Space 1 994b) 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 1 999 Shuttle mission alternative.

<u>Mission Risk</u>

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 1 00,000 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 1 994b). 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

Mission Phase	Period, s	Accident Scenario Description	Total Probability	Radiological Consequences, Health Effects[a,b] Without De Minimis	Radiological Consequences, Health Effects[a,b] With De Minimis	Mission Risks, Health Effects[a,b,c,d] Without De Minimis	Mission Risks, Health Effects[a,b,c,d] With De Minimis
1a	0-10	SRB Case Rupture	1.02×10^{-5}	4.68×10^{-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 the de minimis dose level were considered, the estimated health effects would be approximately 15 (excess latent cancer fatalities) with either VEEGA E1 or E2.
c. Expectation of incremental latent cancer fatalities.
d. The mission risk contribution due to a given accident scenario (i) is: $(\text{Mission risk contribution})_i = (\text{Total Probability})_i \times (\text{Consequences})_i$.

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] Without De Minimis	Mission Risks, Health Effects[a,b] With De Minimis	Exposed Population at Risk[c]	Average Individual Risk, Health Effects[a,b,c,d] Without De Minimis	Average Individual Risk, Health Effects[a,b,c,d] 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}
VEEGA					Subtotal	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^{-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 data.
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 longterm 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 t 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 nonrenewable 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.

Executive Summary

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Chapter 8

Appendix A

Appendix B

Appendix C

Appendix D

Appendix E