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FINAL

SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT FOR THE CASSINI MISSION

Office of Space Science
National Aeronautics and Space Administration
Washington, DC 20546

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ABSTRACT

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This supplement to the 1995 Cassini mission Environmental Impact Statement (EIS) focuses on information recently made available from updated mission safety analyses. This information is pertinent to the consequence and risk analyses of potential accidents during the launch and cruise phases of the mission that were addressed in the EIS. The type of accidents evaluated are those which could potentially result in a release of plutonium dioxide from the three Radioisotope Thermoelectric Generators (RTGs) and the up to 129 Radioisotope Heater Units (RHUs) onboard the Cassini spacecraft. The RTGs use the heat of decay of plutonium dioxide to generate electric power for the spacecraft and instruments. The RHUs, each of which contains a small amount of plutonium dioxide, provide heat for controlling the thermal environment of the spacecraft and several of its instruments.

Consistent with the commitment it made in the EIS, the National Aeronautics and Space Administration (NASA) has evaluated the information recently made available and has determined that preparation of this Supplemental Environmental Impact Statement (SEIS) for the Cassini mission will further the purposes of the National Environmental Policy Act (NEPA).

The planned Cassini mission is an international cooperative effort of NASA, the European Space Agency, and the Italian Space Agency to explore the planet Saturn and its environment. The Cassini mission is an important part of NASA's program for exploration of the solar system, the goal of which is to understand the system's birth and evolution. The Cassini mission would involve a four-year scientific exploration of Saturn, its atmosphere, moons, rings and magnetosphere. The scientific information gathered by the Cassini mission could help provide clues to the evolution of the solar system and the origin of life on Earth.

The Cassini EIS was made available to Federal, state and local agencies, the public and other interested parties on July 21, 1995. In addition to the No-Action Alternative, the 1995 Cassini EIS addressed, in detail, three alternatives for completing preparations for and operating the Cassini mission to Saturn and its moons. On October 20, 1995, utilizing the analyses in the 1995 Cassini EIS, along with other important considerations, such as programmatic, technical, economic, and international relations, the Record of Decision (ROD) selecting the Proposed Action was rendered.

The Proposed Action and preferred alternative addressed in this SEIS consists of completing preparation for and operating the Cassini mission to Saturn and its moons, with a launch of the Cassini spacecraft onboard a Titan IV (SRMU)/Centaur. The launch would take place at Cape Canaveral Air Station (CCAS) during the primary launch opportunity in October-November 1997. A secondary launch opportunity occurs in late November 1997-January 1998, with a backup opportunity in mid-March-April 1999, both using the Titan IV (SRMU)/Centaur. The primary launch opportunity would employ a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn; the secondary and backup opportunities would both employ a Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory. The Proposed Action would allow the Cassini spacecraft to gather the full science return desired to accomplish mission objectives.

EXECUTIVE SUMMARY

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

NASA completed development of the Cassini mission Environmental Impact Statement (hereafter denoted 1995 Cassini EIS) with distribution of the Final EIS to the public and other interested parties in July 1995. The Record of Decision (ROD) was rendered in October 1995. The 1995 Cassini EIS contained NASA's evaluation of the potential impacts of completing preparations for and implementing the Cassini mission, with particular emphasis on accidents that could potentially occur during launch and cruise phases of the mission, and which could impact human health and the environment. While the 1995 Cassini EIS analyses used the best information available at that time, the 1995 Cassini EIS noted that NASA and the U.S. Department of Energy (DOE) were continuing to analyze and evaluate additional accident scenarios specific to the Cassini spacecraft and its launch vehicle and trajectory. In both the 1995 Cassini EIS and the ROD, NASA made the commitment that, should significant differences arise between the results of the ongoing analyses and the 1995 Cassini EIS, NASA would evaluate the information and make a determination regarding the need for additional NEPA documentation, including supplementing the 1995 Cassini EIS. Updates of the safety analyses in support of the 1995 Cassini EIS were recently made available to NASA. NASA has evaluated those analyses accordingly, and has determined that the purposes of NEPA are furthered by preparation of this SEIS.

PURPOSE AND NEED FOR THE ACTION

The Cassini mission is an international cooperative effort of NASA, the European Space Agency (ESA), and the Italian Space Agency (ASI), to explore the planet Saturn and its environment. Saturn is the second-largest and second-most massive planet in the solar system, and has the largest, most visible, dynamic ring structure of all the planets. The mission is an important part of NASA's program for exploration of the solar system, the goal of which is to understand the system's birth and evolution. The Cassini mission involves a four-year scientific exploration of Saturn, its atmosphere, moons, rings and magnetosphere. The Cassini spacecraft consists of the Cassini Orbiter and the detachable Huygens Probe.

The Cassini mission represents an important step in the exploratory phase of planetary science, with the detailed data that would be obtained from the mission providing an important basis for continuing Earth-based studies of the planets. There are five major

areas of investigation planned for the Cassini Mission. An overview of each area of investigation follows:

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

- Titan is shrouded by dense clouds; therefore, little is known about its surface. Data collected by the instruments onboard the Cassini orbiter and the Huygens Probe would provide a better understanding of the abundance of elements and compounds in Titan's atmosphere, the distribution of trace gases and aerosols, winds and temperature, and surface state and composition. In particular, the spacecraft's radar would penetrate Titan's dense atmosphere and reveal the moon's surface characteristics. The Huygens Probe, carrying a robotic laboratory, would perform chemical analyses of Titan's atmosphere and clouds. As the Probe descends, the onboard instruments would measure the temperature, pressure, density, and energy balance through the atmosphere to the moon's surface. The surface properties would be measured remotely, and a camera would photograph the Titan panorama and relay the images to Earth via the Cassini Orbiter.

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

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

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

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

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

Implementation of the proposed action would also ensure that the spacecraft would complete its orbital tour before 2010, when Saturn's rings would present themselves nearly edge-on to the Earth and Sun, severely limiting the ability for detailed observations.

The Cassini spacecraft incorporates three (3) Radioisotope Thermoelectric Generators (RTGs) to provide onboard electric power for spacecraft operation and scientific instruments. The RTGs generate electric power by utilizing the heat from decay of radioactive material. The material is an isotopic mixture of plutonium in the form of dioxide, along with small amounts of long-lived actinides and other impurities. About 71 percent of the oxide mixture (by weight) is plutonium-238 (Pu-238). The three RTGs onboard the Cassini spacecraft contain a total of 32.7 kg (about 72 lb) of PuO_2, amounting to 1.49×10^{16} Bq (402,000 Ci). In addition, 129 Radioisotope Heater Units (RHUs) will be employed to regulate the temperature inside the spacecraft and for several instruments. Each RHU contains about 2.7 gm (0.006 lb) of mostly plutonium-238 dioxide, amounting to a collective total of about 0.35 kg (0.77 lb), or about 1.48×10^{14} Bq (4,000 Ci) of radioactive material in the 129 RHUs.

The 1995 Cassini EIS was made available to Federal, state and local agencies, the public and other interested parties on July 21, 1995. In addition to the No-Action Alternative, the 1995 Cassini EIS addressed three alternatives for completing preparations for and operating the Cassini mission to Saturn and its moons. On October 20, 1995, utilizing the impact analyses in the EIS, along with other important considerations such as

programmatic, economic, and international relations, the ROD selecting the Proposed Action was rendered.

ALTERNATIVES EVALUATED

The Proposed Action and preferred alternative consists of completing preparations for and operating the Cassini mission to Saturn and its moons, with a launch of the Cassini spacecraft onboard a Titan IV(SRMU)/Centaur. The launch would take place at Cape Canaveral Air Station (CCAS) during the primary launch opportunity of October 6 through November 15, 1997. A secondary launch opportunity occurs from late November 1997 through early January 1998, with a backup opportunity from mid-March to early April 1999, both using the Titan IV(SRMU)/Centaur. The primary launch opportunity would employ a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn; the secondary and backup opportunities would both employ a Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory. The Proposed Action would allow the Cassini spacecraft to gather the full science return desired to accomplish mission objectives.

Along with the No-Action Alternative, the 1995 Cassini EIS evaluated two other mission alternatives. The March 1999 Alternative would have used two Shuttle flights launched from Kennedy Space Center (KSC), with on-orbit integration of the spacecraft and upper stage, followed by injection of the spacecraft into a VEEGA trajectory to Saturn. The March 1999 Alternative is no longer considered reasonable at this time due to the long lead-time in developing and certifying the new upper stage that would be needed to implement this mission alternative. When combined with the significant additional costs associated with this alternative, the 1999 dual Shuttle alternative is no longer considered reasonable.

The other mission alternative evaluated in the 1995 Cassini EIS was the 2001 Alternative, which would use a Titan IV(SRMU)/Centaur to launch the spacecraft from CCAS in March 2001 using a Venus-Venus-Venus-Gravity-Assist (VVVGA) trajectory. A backup opportunity in May 2002 would use a VEEGA trajectory. The 2001 Alternative would require completing the development and testing of a new high-performance rhenium engine for the spacecraft, as well as adding about 20 percent more propellant to the spacecraft. Science returns from this alternative would meet the minimum acceptable level for the mission.

RADIOLOGICAL IMPACTS OF ACCIDENTS

Evaluation of the recently available safety analyses has indicated that the only parts of the previous Cassini EIS potentially affected are the analyses of the radiological consequences of accidents involving a potential release of plutonium dioxide (source term) from the RTGs and/or the RHUs onboard the spacecraft. The environmental impacts of completing preparations for the mission are unaffected by the updated analyses, and

remain as presented in the 1995 Cassini EIS. In addition, the analyses of the environmental impacts of both an incident-free launch and incident-free interplanetary gravity-assist trajectory are also unaffected and remain as presented in the 1995 Cassini EIS.

The EIS's and recently available analyses overall assessments of the Cassini mission's risk are similar. The updated assessment of individual mission segment accidents has identified higher risks for launch segment accidents and lower risks for the Earth gravity assist (EGA) swingby segment. Both the EIS and the updated analyses indicate that only a fraction of conceivable launch accidents are calculated to result in releases of PuO_2.

The ongoing safety analysis process is similar to the process used for the earlier Galileo and Ulysses missions and has resulted in incremental improvements in the modeling and analysis techniques. The potential source terms are determined by using simulations to evaluate the response of the RTGs, RTG components, and RHUs to the defined accident environments. The ongoing analyses utilize probabilistic risk assessment techniques with computer simulation and modeling of RTG responses to accident environments, and are based upon safety test and analysis studies performed by and on behalf of DOE. The safety test and analysis studies have been performed over the past 12 years on General Purpose Heat Source (GPHS) RTGs and materials, and RHUs. These tests provide a database of the performance response of the RTGs and RHUs to simulated accident conditions such as high-velocity impacts on hard surfaces, impacts from high-velocity fragments, and exposure to thermal and mechanical stresses such as would be encountered in a reentry from Earth orbit or exposure to burning solid rocket motor propellant. It must be emphasized that for a release of plutonium dioxide (PuO_2) to occur, the initiating accident must be followed by other events to create an accident environment that threatens the integrity of the RTGs and RHUs.

Since the issuance of the 1995 Cassini EIS, the refinements in the evaluation of accidents and estimation of their potential consequences have resulted in revised estimates. Comparison between the 1995 Cassini EIS results and the updated results are presented in this SEIS. The 1995 Cassini EIS reported point estimates of the "expectation" and "maximum" cases. The expectation case utilized source terms for each accident scenario that were probability-weighted, and was based upon a range of release conditions considered in the analysis. The maximum case utilized source terms that corresponded to either 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 $1x10^{-7}$ (1 in 10 million). The updated analyses used probabilistic risk assessment techniques similar to those used for the Galileo and Ulysses missions to generate updated estimates of consequences and risk.

The 1995 Cassini EIS utilized the concept of risk as one of the key measures in the accident analyses. Risk, for the purpose of the 1995 Cassini EIS and for this supplement, is defined as the total probability of an event occurring (i.e., a release from an RTG or RHU), multiplied by the mean consequence of the event (i.e., health effects described as latent

cancer fatalities over a 50-year period within the population potentially exposed by an accident). With respect to the Cassini accident analyses, the total probability of a release occurring is determined by multiplying the probability of the initiating accident that could threaten the RTGs and RHUs, times the conditional probability that the accident will result in a release. Risk estimates for the Cassini mission (expressed as health effects) have been developed for each mission phase/accident scenario and for the average exposed individual. The updated analyses report the best estimate of consequences and risks. While the overall probability of an accident that could threaten the RTGs or RHUs during the Cassini mission is 2.8×10^{-2}, or 1 in 36, the probability of an accident predicted to release PuO_2 is 2.8×10^{-3}, or less than 1 in 357. Such an accident could result in 0.089 mean health effects. This results in an overall mission risk of 2.5×10^{-4}, or 0.00025, health effects worldwide. This risk level is lower than the overall risk reported in the 1995 Cassini EIS (expected value of 1.7×10^{-3}, or 0.0017, health effects).

The total mission risk is distributed over four major mission segments--i.e., pre-launch (Phase 0), early launch (Phases 1 and 2), late launch (Phases 3 - 8) and Earth Gravity Assist (EGA). The pre-launch segment runs from 48 hours (T-48 hrs) prior to launch to T-0 seconds (s). The early launch segment starts with ignition of the SRMUs at T-0 s and extends through T+143 s when the SRMUs are jettisoned. The time period from T+143 s to T+206 s is not considered because there are no accidents that could result in a release of PuO_2 during this time period of the mission. The late launch segment starts at T+206 s and extends to the point where the spacecraft has escaped from Earth orbit. The EGA segment encompasses the period from Earth escape to completion of the Earth swingby.

Pre-launch accidents were not covered in the 1995 Cassini EIS because, at that time, none were postulated that could result in a release of PuO_2. However, information recently made available from the updated mission safety analyses indicates the total probability of a pre-launch accident that results in a release of PuO_2 is 5.2×10^{-5}, or about 1 in 19,200, and could result in 0.11 mean health effects and could contaminate 1.5 km^2 (0.58 mi^2) of land above 7.4×10^3 Bq/m^2 (0.2 $\mu Ci/m^2$) (the Environmental Protection Agency's [EPA's] guideline level for considering the need for further action).

The total probability of an early launch accident that results in a release of plutonium is 6.7×10^{-4}, or about 1 in 1,490, and could result in 0.082 mean health effects and could contaminate 1.6 km^2 (0.62 mi^2) of land above the EPA guideline level. In comparison to the 1995 Cassini EIS, this segment's mean mission risk is 0.000055 health effects, which exceeds the 1995 Cassini EIS estimate of 0.00000046.

The total probability of a late launch accident that results in a release of plutonium is 2.1×10^{-3}, or 1 in 476, and could result in 0.044 mean health effects and could contaminate 0.057 km^2 (0.02 mi^2) of land above the EPA guideline level. In comparison to the 1995 Cassini EIS, this segment's mean mission risk is 0.000092 health effects, which exceeds the 1995 Cassini EIS estimate of 0.00000037.

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The total probability of an EGA accident that results in a release of plutonium is 8.0×10^{-7}, or less than 1 in 1 million, and could result in 120 mean health effects and could contaminate 15 km^2 (5.8 mi^2) of land above the EPA guideline level. In comparison to the 1995 Cassini EIS, this segment's mean mission risk is 0.000098 health effects, which is less than the 1995 Cassini EIS estimate of 0.0017.

In addition to these new best estimate analyses, DOE has conducted a study of the uncertainty in the underlying test data and models used to estimate accident risks and consequences. This information is presented in Chapter 4 of this SEIS.

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LIST OF ACRONYMS

	A
ADS	Automatic Destruct System
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
AU	astronomical unit(s)
	B
Bq	Becquerel
	C
°C	degrees Centigrade (Celsius)
CBCF	carbon-bonded carbon fiber
CCAS	Cape Canaveral Air Station
Ci	curie
cm	centimeter
cm^3	cubic centimeters
CSD	Command Shutdown and Destruct
CSDS	Command Shutdown and Destruct System
	D
DCU	digital control unit
DEIS	Draft Environmental Impact Statement
DOD	Department of Defense
DOE	Department of Energy
	E
EGA	Earth-Gravity-Assist
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	European Space Agency
	F
FCO	Flight Control Officer
FSEIS	Final Supplemental Environmental Impact Statement
ft/s	feet per second
FTS	Flight Termination System
	G
g	gram
GaAs	gallium arsenide
GIS	Graphite Impact Shell
GPHS	General Purpose Heat Source

LIST OF ACRONYMS (continued)

H

H_2	hydrogen
ha	hectare
HNUS	Halliburton NUS
HTPB	hydroxyl terminated polybutadiene

I

ICRP	International Commission on Radiological Protection
IIP	instantaneous impact point

J

JPL	Jet Propulsion Laboratory, California Institute of Technology

K

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

L

LASEP-T	Launch Accident Scenario Evaluation Program-Titan IV/Centaur
lb	pound(s)
LEO	low earth orbit
LH_2	liquid hydrogen
LILT	low (insolation) intensity and low temperature
LIS	Laser Illumination System
LO_2	liquid oxygen
LWRHU	Light-weight Radioisotope Heater Units (same as RHUs)

M

MECO	Main Engine Cutoff
MET	mission elapsed time
mi	miles
mm	millimeter
MMH	monomethylhydrazine
mrem	millirem
m/s	meters per second
$\mu Ci/m^2$	µCi per square meter
µCi	µCi
$\mu g/m^3$	micrograms per cubic meter

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LIST OF ACRONYMS (continued)

N

N	Newton
N_2H_4	hydrazine
N_2O_4	nitrogen tetroxide (NTO)
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act
NO_2	nitrogen dioxide
NOI	Notice of Intent
NTO	nitrogen tetroxide (N_2O_4)

O

O_2	oxygen
O_3	ozone

P

PG	pyrolytic graphite
PLF	Payload Fairing
PMS	Propulsion Module Subsystem
POF	probability of failure
psi	pounds per square inch
Pt	platinum
Pu	plutonium
PuO_2	plutonium dioxide

R

rem	roentgen equivalent man
RHU	Radioisotope Heater Unit (same as LWRHU)
ROCC	Range Operation Control Center
ROD	Record of Decision
RSAS	Range Safety Advisory System
RTG	Radioisotope Thermoelectric Generator

S

s	seconds
SEIS	Supplemental Environmental Impact Statement
SRMU	Solid Rocket Motor Upgrade
Sv	Sievert
SV	Satellite Vehicle
SVDS	Space Vehicle Destruct System

LIST OF ACRONYMS (continued)

T

TBVD	Total Boost Vehicle Destruct
T	Time relative to ignition at launch

U

UDMH	unsymmetrical dimethylhydrazine
USAF	United States Air Force

V

VEEGA	Venus-Earth-Earth-Gravity Assist
VVEJGA	Venus-Venus-Earth-Jupiter-Gravity-Assist
VVVGA	Venus-Venus-Venus-Gravity-Assist

W

W	Watt

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Cassini Mission
Final Supplemental Environmental Impact Statement

Executive Summary

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Chapter 2

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SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT

1.0 PURPOSE AND NEED FOR ACTION

1.1 BACKGROUND

In July 1995, NASA completed and made available to the public and other interested parties, the Final Environmental Impact Statement, dated June 1995, for the Cassini mission to Saturn (hereinafter, denoted 1995 Cassini EIS) (NASA 1995). This was followed in October 1995 by the Record of Decision (Appendix A), in which NASA chose to implement the Proposed Action. Specifically, NASA chose to continue preparations for and implement the Cassini mission to collect scientific data from Saturn, its atmosphere, moons, rings and magnetosphere. The mission would be launched from Cape Canaveral Air Station (CCAS), onboard a Titan IV (SRMU or SRM)/Centaur at the primary launch opportunity from October 6 through November 15, 1997, and inserted into a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn. A secondary opportunity exists from November 27, 1997 through January 9, 1998, with a backup opportunity from mid-March to early April 1999, both using a Titan IV (SRMU or SRM)/Centaur launch vehicle and a Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory.

The Cassini spacecraft incorporates three (3) Radioisotope Thermoelectric Generators (RTGs) to provide onboard electric power for spacecraft operation and scientific instruments. The RTGs generate electric power by utilizing the heat from decay of radioactive material. The material is an isotopic mixture of plutonium in the form of dioxide (to be referred to as plutonium dioxide, or PuO_2) along with small amounts of long-lived actinides and other impurities. About 71 percent of the mixture (by weight) is plutonium-238. The three RTGs onboard the Cassini spacecraft contain a total of 32.7 kg (about 72 lb) of PuO_2, amounting to 1.49×10^{16} Becquerels (Bq) (402,000 curies [Ci]). In addition, 129 Radioisotope Heater Units (RHUs) will be employed to regulate the temperature for several instruments and inside the spacecraft. Each RHU contains about 2.7 gm (0.006 lb) of mostly plutonium-238 dioxide, amounting to a total of about 0.35 kg (0.77 lb), or about 1.48×10^{14} Bq (4,000 Ci) of radioactive material in 129 RHUs.

The EIS analyses indicated that continuing preparations for and implementing a normal Cassini mission would not adversely impact the human environment. The 1995 Cassini EIS determined that only in the event of an accident resulting in a release of plutonium dioxide was there any potential for substantial impacts to the human environment.

In evaluating the potential impacts associated with accidents for the 1995 Cassini EIS, NASA and its cooperating agency, the U.S. Department of Energy (DOE), using the best information available at that time, developed an array of four representative launch accident scenarios and the resulting accident environments. Accident scenarios identify the physical events that occur as a result of launch failures and the associated probabilities

of occurrence. Accident environments describe the various forces which impinge upon the RTGs. The four scenarios were representative of accidents that could potentially occur across all launch phases and could lead to a release of PuO_2. Accident scenarios and associated environments were also evaluated for an inadvertent reentry of the spacecraft into the atmosphere during an Earth swingby maneuver of the gravity-assist trajectory.

The four launch accident scenarios were evaluated across launch Phase 1 (Phase 1 is initiated at T minus zero seconds [T-0 s], with ignition of the SRMUs at the launch pad), through launch Phase 6 (insertion of the spacecraft into the planetary gravity-assist trajectory). No pre-launch Phase 0 accidents were identified that could cause a credible release. (For additional details regarding the accident scenarios and environments and the initiating probabilities, see Sections 4.1.5 and 4.1.6, respectively, of the Cassini EIS.) Releases from the RHUs were not considered significant when compared to potential releases from the RTGs.

NASA and DOE analyzed the representative accident scenarios with respect to the consequences and risks to human health (defined as excess latent cancer fatalities over a 50-year period, beyond those normally expected to occur, within the exposed population) and the environment. The results of those analyses were presented in Section 4.1 of the 1995 Cassini EIS. The 1995 Cassini EIS estimated the risk within each launch phase and for the Earth gravity-assist swingby to potentially affected human populations, as well as the overall mission risk (i.e., across all launch phases, including the Earth gravity-assist), to be small.

The 1995 Cassini EIS also indicated that NASA, DOE and the U.S. Air Force (USAF) were continuing to conduct mission safety analyses to determine the potential for release of PuO_2 in the event of an accident and the associated consequences and risks. In view of the ongoing mission analyses, NASA made a commitment in the 1995 Cassini EIS (see Section 4.6--Incomplete or Unavailable Information, item 2) and in the ROD (Appendix A). Specifically, this commitment noted that if the ongoing investigations resulted in risk greater than those presented in the 1995 Cassini EIS, NASA would evaluate the information and make a determination regarding preparation of additional NEPA documentation.

Results recently made available from the updated analyses are more refined and comprehensive than those in the 1995 Cassini EIS. Refined probabilistic risk assessment techniques, similar to those used for the Galileo and Ulysses missions, were used to assess the full range of accident scenarios and environments (including the four representative accident initiating events considered in the 1995 Cassini EIS) that could occur during launch of the spacecraft, as well as an inadvertent reentry during Earth swingby. The refined techniques used by the ongoing analyses specifically estimate the response of the Cassini RTGs and RHUs to the environments associated with each accident scenario possible for the Cassini mission. This SEIS provides the results of the updated analyses. As discussed in Chapters 2 and 4, while the overall best estimate of risk has not changed

appreciably for the mission, the variability in the updated analyses' results for individual mission segment accidents has prompted NASA's preparation of this SEIS.

1.2 PURPOSE OF THE PROPOSED ACTION

NASA, in an international cooperative effort with the European Space Agency (ESA) and the Italian Space Agency (ASI), proposes to conduct an extended investigation of the Saturnian system. The Cassini spacecraft would tour and study Saturn, its rings, moons and magnetosphere over a four-year period. Saturn is the second-largest and second-most massive planet in the solar system and has the largest, most visible, dynamic ring structure of all the planets. The mission is an important part of NASA's program for exploration of the solar system, the goal of which is to understand the system's birth and evolution. The Cassini mission involves a four-year scientific exploration of Saturn, its atmosphere, moons, rings and magnetosphere. The Cassini spacecraft consists of the Cassini Orbiter and the detachable Huygens Probe.

For several months, prior to its arrival at Saturn in July 2004, the spacecraft would perform scientific observations of the planet. The planned arrival date at Saturn provides a unique opportunity to have a distant flyby of Saturn's outer satellite, Phoebe. As the spacecraft maneuvers into its Saturn orbit, it will be at its closest distance to the planet during the entire mission. This offers a unique opportunity to observe the inner regions of Saturn's ring system and magnetosphere. About three weeks before Cassini's first flyby of Titan, Saturn's largest moon, the Huygens Probe would be deployed on its trajectory for later descent into Titan's atmosphere. The Probe would sample and determine the composition of Titan's atmosphere during its 2.5 hour descent and gather data on the moon's landscape. The Cassini Orbiter would then continue its tour of Saturn's system, making about 72 orbits of the planet over four years. The Orbiter would have about 35 encounters with Titan, about 6 encounters with icy moons of high interest such as Enceladus and Iapetus, and many more distant flybys of Saturn's other moons. The scientific information gathered by the Cassini mission could help provide clues to the evolution of the solar system and the origin of life on Earth.

For details of the goals and specific scientific observations that will be made by the Cassini Orbiter and the Huygens Probe, refer to Section 1.2 of the 1995 Cassini EIS.

1.3 NEED FOR THE ACTION

As stated in the 1995 Cassini EIS, conduct of the Cassini mission represents an important step in the exploratory phase of interplanetary science, with the detailed data that would be obtained from the mission providing an important basis for continuing Earth-based studies. Implementation of the proposed action would also ensure that the spacecraft would complete its orbital tour before 2010, when Saturn's rings would present themselves nearly edge-on to the Earth and Sun, severely limiting the ability for detailed

observations. Additional details regarding the need for action can be found in Section 1.3 of the 1995 Cassini EIS.

1.4 RESULTS OF PUBLIC REVIEW OF THE DRAFT SEIS

NASA published its Notice of Availability (NOA) for the Draft SEIS in the Federal Register on April 9, 1997 (62 Federal Register 17216), and mailed copies of the Draft SEIS and the supporting HNUS document to over 130 Federal, State and local agencies, organizations, and individuals. The U.S. Environmental Protection Agency (EPA) published its Notice of Availability in the Federal Register on April 11, 1997 (62 Federal Register 17810), initiating the 45-day review and comment period. Additional requests for the Draft SEIS and the supporting HNUS documentation subsequent to publication of the EPA NOA raised the total number of copies distributed to over 150.

The comment period for the Draft SEIS closed on May 27, 1997. A total of 16 response letters were received - 3 from Federal agencies, 12 from private individuals, and 1 from an organization. The comments ranged from "no comments" and questions regarding the ability of the RTGs and RHUs to survive reentry conditions; to questions regarding use of solar power, and emergency response planning.

Cassini Mission
Final Supplemental Environmental Impact Statement

Executive Summary

Chapter 1

Chapter 2

Chapter 3

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Chapter 6

Chapter 7

Chapter 8

Appendix A

Appendix B

Appendix C

Appendix D

Appendix E

2.0 PROPOSED ACTION AND ALTERNATIVES EVALUATED

The 1995 Cassini EIS, released in July 1995, examined mission alternatives available at that time for accomplishing the mission objectives within a reasonable time frame, as well as the No-Action Alternative. In the course of developing the mission alternatives, three major mission components (launch vehicles, mission trajectories to Saturn, and spacecraft electrical power sources) were examined in detail (JPL 1993a, JPL 1993b, JPL 1994). These three mission components remain the principal factors influencing the development of feasible mission designs (mission alternatives) and are also the factors determining the potential environmental impacts associated with each mission alternative under normal (incident-free) and accident conditions. Updated information regarding the evaluations of these three components and their availability in determining the mission alternatives is provided in this section.

The 1995 Cassini EIS examined in detail the feasible components that combined to form those mission alternatives; the Proposed Action (a 1997 Titan IV [SRMU or SRM]/Centaur launch), a 1999 Mission Alternative (a dual shuttle launch), a 2001 Mission Alternative (a Titan IV [SRMU] launch) and the No Action Alternative. The 1999 Mission Alternative would have involved dual Shuttle launches in 1999, with on-orbit assembly of the spacecraft and a specially-designed and developed upper stage. The launch site for this alternative would have been either Launch Pad 39A or 39B located at Kennedy Space Center (KSC) in Florida. The 1999 Mission Alternative is no longer being considered because of the insufficient time to develop and test the special upper stage, and associated cost.

Of the alternatives examined in the 1995 Cassini EIS, only the following are currently available to NASA:

- Proposed Action - The Proposed Action and preferred alternative consists of completing preparations for and operating the Cassini mission to Saturn, with a launch during either the primary (October-mid November 1997), secondary (late November 1997-January 1998), or backup (March-April 1999) opportunities. The SRM-equipped Titan IV/Centaur launch vehicle option that was considered in the 1995 Cassini EIS is no longer available. The SRMU is now fully flight-certified for use on the Titan IV. The first Titan IV(SRMU) mission was successfully launched by the Air Force on February 23, 1997.

- 2001 Mission Alternative - This mission alternative is to complete preparations for and operate the Cassini mission to Saturn in March 2001, or during the backup opportunity in May 2002. This alternative would utilize the Titan IV (SRMU)/Centaur launch vehicle.

- No-Action Alternative - Under the No-Action Alternative the mission would not be implemented.

A brief description of the Proposed Action is found in Section 2.1 of this SEIS. Changes in spacecraft design, the Earth swingby maneuver of the gravity-assist trajectory, and the range safety systems that have been made since completion of the 1995 Cassini EIS are highlighted.

Sections 2.2 and 2.3 of this SEIS provide brief additional details of the 2001 and No-Action Alternatives, respectively. The changes made in the spacecraft design, range safety system and Earth swingby maneuver noted for the Proposed Action also apply to the 2001 Mission Alternative. Additional details regarding the 2001 Mission and No-Action Alternatives can be found in Sections 2.4 and 2.5 of the 1995 Cassini EIS. For additional details of the Proposed Action, refer to Section 2.1 of the 1995 Cassini EIS.

2.1 DESCRIPTION OF THE PROPOSED ACTION

The following paragraphs summarize the basic elements of the Proposed Action that are pertinent to evaluating the results of the refined accident analyses and to comparing those results with the 1995 Cassini EIS analyses. Changes that have been made in the areas of range safety systems, spacecraft design, and in the design of the EGA trajectory are discussed where applicable.

2.1.1 Mission Design

The primary launch opportunity of the Proposed Action occurs within a 41-day launch period beginning October 6 and closing November 15, 1997 (JPL 1993a). Using the Titan IV (SRMU)/Centaur described in Section 2.1.6 of this Final SEIS, the spacecraft would be launched and injected into the 6.7-year VVEJGA interplanetary trajectory to Saturn, as shown in Figure 2-1.

After the spacecraft's launch and injection into the interplanetary trajectory in October 1997, it would swingby the planet Venus for the first time in April 1998, followed by a second Venus swingby in June 1999. The spacecraft would then fly on to Earth in slightly less than two months, where it would obtain its third planetary gravity-assist in August 1999. The spacecraft would obtain a fourth and final gravity-assist at Jupiter in December 2000, before proceeding to Saturn.

Cassini would arrive at Saturn in July 2004 and begin a four-year tour of the Saturnian system, after deploying the Huygens Probe on a trajectory for entry into Titan's atmosphere.

Changes in Mission Design Since the 1995 Cassini EIS: Two mission maneuvers have been altered. First, the swingby altitude for the Earth gravity assist maneuver has been increased from 500 km (310 miles) to 800 km (500 miles) or higher. Second, the last

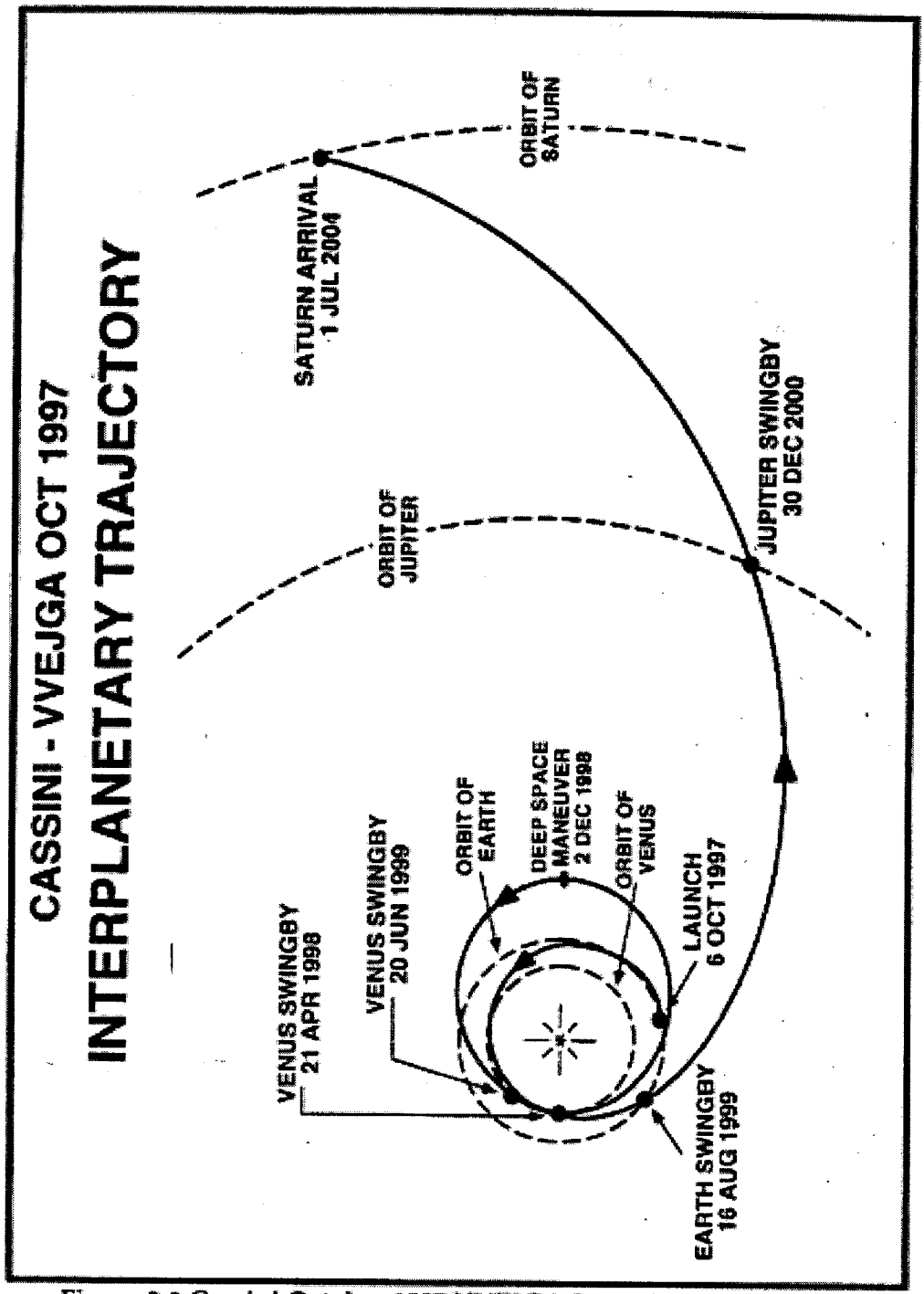

Figure 2-1 Cassini October 1997 VVEJGA Interplanetary Trajectory

trajectory correction before the Earth swingby has been delayed from ten days prior to swingby to seven days prior to swingby. This delay in the maneuver increases the biasing of the trajectory away from Earth during the period before the Earth swingby. Both of these changes work to keep the chances of an inadvertent Earth swingby reentry below one in one million.

2.1.2 Launch Opportunities

For the Proposed Action, the primary launch opportunity occurs during the 41-day period between October 6 and November 15, 1997. Problems with the launch vehicle or spacecraft or adverse weather conditions during this period could cause the loss of this primary launch opportunity.

Mission planners have identified secondary and backup launch opportunities from late November 1997, through early January 1998, and from mid-March to early April 1999, respectively, in the event such conditions arise. Both the secondary and backup opportunities would utilize a VEEGA trajectory to Saturn instead of the VVEJGA trajectory used with the primary launch opportunity.

Both the secondary and backup launch opportunities would have adequate allocations of propellant to meet the minimal science objectives. However, lower electrical power output available from the RTGs during the science portion of the mission due to the natural decay of the radioisotopes would result in fewer instruments being operated at a given time, or less engineering support given to some instruments (JPL 1993c). These mission constraints would reduce the science return from levels anticipated for the primary launch opportunity.

2.1.3 Spacecraft Description

The Cassini spacecraft, illustrated in Figure 2-2, is designed to be a three-axis stabilized probe-carrying orbiter for exploration of Saturn and its atmosphere, moons, rings and magnetosphere.

The components of the spacecraft relevant to an assessment of the potential for environmental impacts from the mission are the RTGs, RHUs, the propellants, and the propellant pressurant (helium). (RTGs and RHUs are addressed in Section 2.1.4 of this SEIS.) For propellants, Cassini would carry up to 132 kg (291 lb) of hydrazine for small maneuvers and attitude and articulation control, and about 3,000 kg (6,614 lb) of bipropellant (one tank each of monomethylhydrazine [MMH] and nitrogen tetroxide [NTO]) for larger maneuvers. Two high-pressure helium tanks are also used to provide pressure for the bipropellant and monopropellant tanks. The spacecraft (i.e., the Orbiter, the Probe and its supporting equipment, and the launch vehicle adapter), with propellants, would weigh 5,824 kg (12,840 lb) at launch (JPL 1993a).

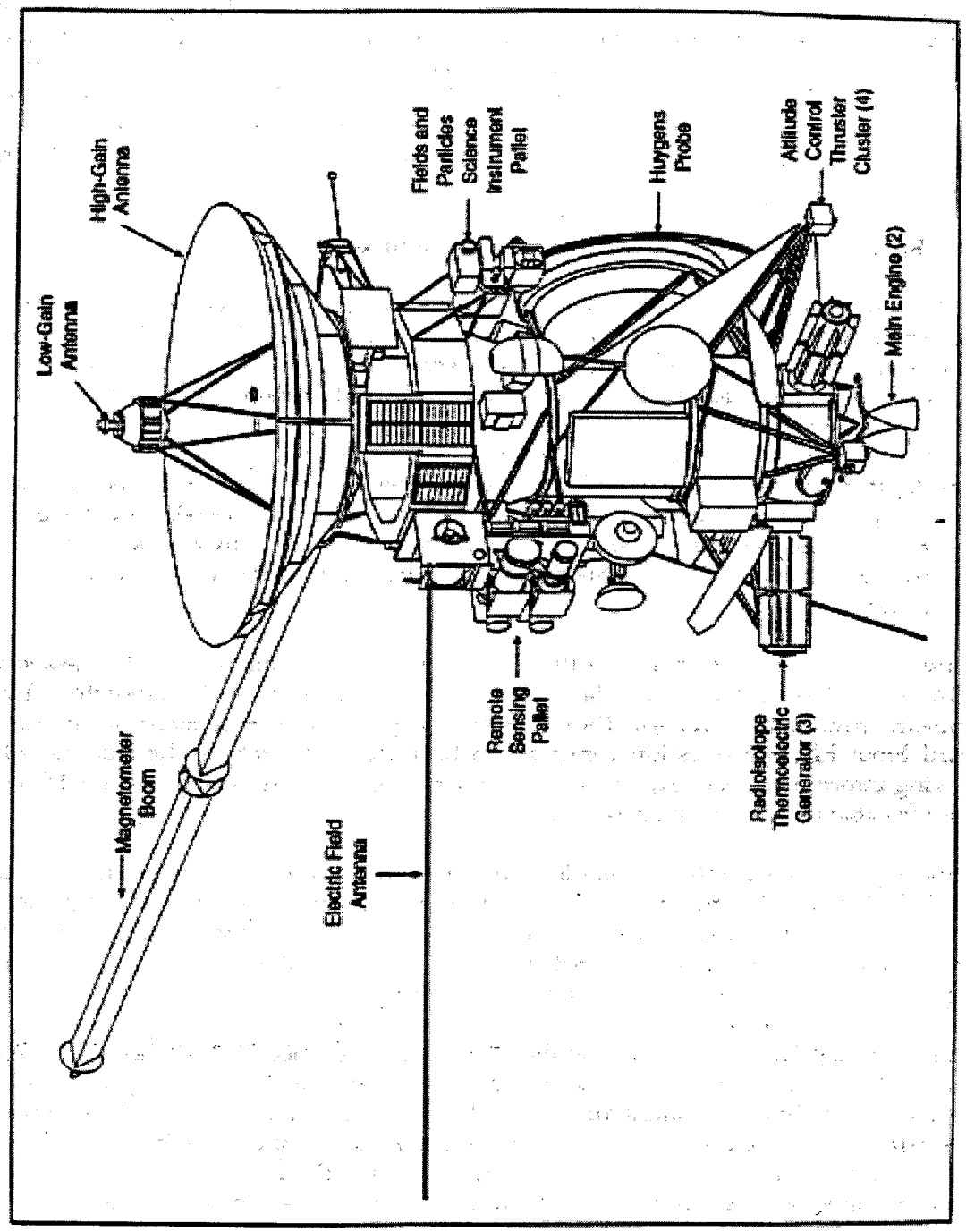

Figure 2-2 Diagram of the Cassini Spacecraft

Spacecraft Design Modifications Since the 1995 Cassini EIS: The spacecraft design has been modified in four places to improve the protection against micrometeoroid damage to the spacecraft propulsion subsystem. First, two layers of beta cloth (a woven fiberglass material more resistant to micrometeoroid damage than the multi-layer insulation material used for the spacecraft thermal blankets) were added to the core propulsion module. Second, stand-off beta cloth shields have been added around the helium and hydrazine tanks. Third, the thickness of the outer plate on the propulsion electrical box on the spacecraft bus was increased from 0.18 cm (0.070 in) to 0.89 cm (0.350 in). Fourth, a retractable main engine cover was added to protect the nozzles.

2.1.4 Spacecraft Electrical Power and Heating Sources

The Cassini spacecraft would use three RTGs to provide electrical power for its engineering subsystems and science payload and a maximum of 129 RHUs to regulate the temperature of various subsystems on the spacecraft and the Probe. The U.S. Department of Energy (DOE) provides the RTGs and RHUs and would retain title to them at all times. (See 1995 Cassini EIS Chapter 2 for details.)

An in-depth analysis of the available electrical power systems was performed to identify the most appropriate power source for the Cassini mission (JPL 1994). The use of RTGs was identified as the only feasible power system with the physical and operational characteristics compatible with achieving a high percentage of the science return from the Cassini mission.

During the comment period for the 1995 Draft Cassini EIS, some commentors asked why NASA is not using the new solar cells recently developed in the laboratory by the European Space Agency (ESA). Though NASA responded to these questions in the 1995 Cassini Final EIS, the question continues to be raised. Therefore, the purpose of the following information is to explain why solar arrays, even arrays using the new ESA cells, are not feasible for the Cassini mission.

For the Cassini spacecraft to complete the mission's science objectives, it must carry enough fuel to travel to Saturn, to brake and insert itself into orbit around the planet and to continue in orbit for four years. This amount of fuel is very heavy. Thus, in order to be light enough to launch, travel to Saturn and accomplish the science objectives of the mission, it is critical to keep the rest of the spacecraft as light as possible.

Another limiting factor in completing the mission science objectives is spacecraft electrical power. While orbiting Saturn and its moons, Cassini will use a variety of science instruments, singly or in combination, to collect many different types of data. Since the spacecraft has a limited amount of fuel and a limited amount of time in which to collect data at Saturn (four years), its power system must have the capability to simultaneously supply multiple science instruments, as well as continuously run the spacecraft itself.

Thus, a lightweight and highly-efficient method of providing electrical power becomes very important.

NASA has found that even with solar arrays containing the latest high-efficiency solar cells developed by ESA, it would not be possible to conduct the Cassini mission using solar power. The simplest and most immediate explanation for this is that the arrays, in order to meet Cassini's electrical power requirements, would have to be so large that the spacecraft as a whole would be too massive to launch.

ESA has produced, under laboratory conditions (i.e., not manufacturing conditions), highly-efficient solar cells that have been tested successfully under simulated space environments. These environments approximated the sunlight and temperature conditions at about 805 million kilometers (500 million miles) from the Sun, or about the same distance as Jupiter's orbit. These solar cells do not exhibit the typical low-intensity, low-temperature (LILT) degradation that considerably reduces efficiencies for currently-available commercial cells. However, it is important to note that the cells could be less efficient at Saturn, which is almost twice as far from the Sun as Jupiter. Figure 2-3 depicts the size of the theoretical arrays that would be required if a solar Cassini mission were possible.

Other limitations of the ESA solar cell technology include:

- The actual efficiencies of commercially-produced advanced solar cells have historically been somewhat lower than efficiencies reported for research and development (R&D) manufactured units.
- The ESA gallium arsenide (GaAs) devices are relatively thick and heavy compared to conventional solar cells.
- Considering theoretical analysis and published data, these advanced cells would be radiation sensitive. This would lower their efficiency if used on Cassini, due to the radiation environment through which the spacecraft will travel on its way to Saturn.
- If an array were to be made with the ESA cells (or any solar cells, for that matter), special diodes would have to be added to the array to compensate for cell fracturing that would be expected to occur from time to time. These diodes would add even more mass and complexity to the array.

Taking the previous data into consideration, the Jet Propulsion Laboratory (JPL) has estimated that solar arrays built for the Cassini mission would require a total area greater than 500 square meters (5,380 square feet) and that the spacecraft would require two arrays, each 9 meters (30 feet) wide and 32 meters (105 feet) long. There would also have to be supporting structures for the solar cells.

Attaching two such huge solar arrays to the Cassini spacecraft would severely impact the design, mass and operation of the spacecraft. One significant factor would be the array itself, which is a mechanical structure that ties the many solar cells together. This

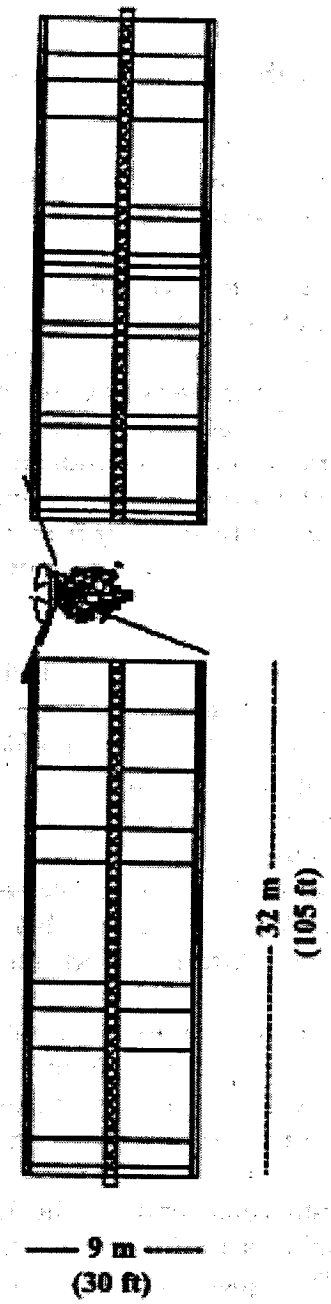

Figure 2-3 Theoretical Arrays (Using ESA GaAs Cells) for the Cassini Spacecraft

structure would have to be deployable, which means that it would have to be stowed for launch so that it could fit inside the Titan IV payload fairing and then unfold once the spacecraft was on its way to Saturn. This, in turn, would require mechanical components to fold and unfold the arrays and support the long array arms when extended. Such components and support structures would increase the size and mass of the spacecraft considerably. The long and unwieldy solar arrays would also severely complicate spacecraft maneuvering and turning for scientific observations and data transmission back to Earth. Therefore, special devices would have to be added to enable the spacecraft to turn, again adding significantly to the mass. Finally, to properly regulate electrical power on board the spacecraft, special regulators and batteries would be required. This, too, would increase the overall mass.

As with other solar power options studied for the Cassini spacecraft, the extremely large mass of even the lightest solar configuration is beyond the lift capability of the Titan IV (SRMU)/Centaur launch vehicle. Even if a heavy-lift booster and a suitable upper stage could be developed and certified for such a massive solar-powered spacecraft, the adjustments necessary to accommodate solar power would have substantial negative effects on the mission. First, they would make spacecraft maneuvering so slow and difficult that the mission would run out of time for scientific data collection, causing some crucial observations to be lost. Second, the addition of so many moving parts susceptible to mechanical failure would add considerably to the overall risk to mission success. As a final note, the researchers who developed the ESA solar cells evaluated the JPL solar study and concluded that "Low (insolation) intensity and low temperature (LILT) solar cells (including those developed by ESA) are not a viable power source alternative for the presently defined Cassini mission of NASA" (see Appendix C).

The present standard General Purpose Heat Source (GPHS) module is a product of years of extensive safety testing and analyses. Previous NASA spacecraft such as Galileo and Ulysses carried instruments powered by GPHS modules. Any future development of new GPHS modules would require extensive testing, evaluation, and space qualification before becoming potentially applicable to any space mission.

2.1.5 Spacecraft Propulsion Module Subsystem

The propulsive power for the Cassini spacecraft will be provided by two redundant bipropellant 445 N (105 lb of thrust) main engines for trajectory and orbit changes, and 16 monopropellant thrusters rated at 1.0 N (0.22 lb of thrust) for attitude control and very small orbit changes (JPL 1993c). The bipropellant engines use nitrogen tetroxide (NTO) and monomethyl hydrazine (MMH), and the monopropellant thrusters burn hydrazine. Pressures in both the bipropellant and monopropellant elements are maintained using helium gas.

2.1.6 Launch Vehicle (Titan IV [SRMU]/Centaur) Configuration

The Titan family of expendable launch vehicles has a launch history spanning more than 30 years of operations involving more than 320 Titan vehicles of all models. Titans have successfully carried astronauts into space ten times and have successfully launched RTG-powered spacecraft into space five times. The Titan IV/Centaur with the newly-developed SRMUs is proposed for this mission to Saturn. The SRMUs are now flight-certified and are the most capable strap-on U.S. boosters available.

The Titan IV/Centaur comprises four basic components: core vehicle, the solid rocket booster motors (upgrade) (SRMU), payload fairing (PLF) and Centaur (upper stage). The Titan IV (SRMU)/Centaur configuration is shown in Figure 2-4.

The core vehicle, which provides thrust, consists of two stages with their associated airframes, structures, avionics, mechanical systems and liquid propulsion system. Stage 1 contains two bipropellant liquid rocket engines. The oxidizer is 101,176 kg (223,051 lb) of NTO, and the fuel is 53,240 kg (117,372 lb) of Aerozine-50 (i.e., a 50-50 blend of unsymmetrical dimethylhydrazine and hydrazine). Stage 2 contains a single bipropellant engine virtually identical to the two used in Stage 1. The Stage 2 propellants comprise 22,239 kg (49,028 lb) of NTO and 12,436 kg (27,416 lb) of Aerozine-50 (Martin Marietta 1992).

Two SRMUs, located on opposites sides of the core vehicle, would provide the initial boost for the launch vehicle at liftoff. Each SRMU is composed of three solid rocket motor segments. The filament-wound motor segments consist of a graphite fiber/epoxy resin composite cased forward segment with an integral forward dome, two graphite/epoxy composite cylindrical sections and a steel aft dome. The SRMU has passed all of its qualification tests and is now flight-certified. The first mission using the SRMU was successfully launched by the USAF on February 23, 1997.

Each SRMU is 34.3 m (112.4 ft) long and has a 3.32 m (10.9 ft) outer diameter. The nominal weight for each SRMU is 352,271 kg (776,612 lb), of which 315,724 kg (696,040 lb) are propellant. The propellant is a U.S. Department of Defense (DOD) Hazards Class 1.3 (DOD 1992), solid propellant, consisting of 69 percent ammonium perchlorate (dizoxier) and 19 percent nonspherical aluminum (fuel), with 9.06 percent hydroxyl terminated polybutadiene (HTPB) binder. The remaining 2.94 percent includes bonding and curing agents (MMT 1992).

The PLF, mounted on top of the core vehicle, encases the Centaur (upper stage) and spacecraft, thereby providing aerodynamic and thermal protection for these elements during ascent. The payload fairing is an all-metal structure composed primarily of aluminum and has three segments. At approximately 206 seconds after liftoff, each of the

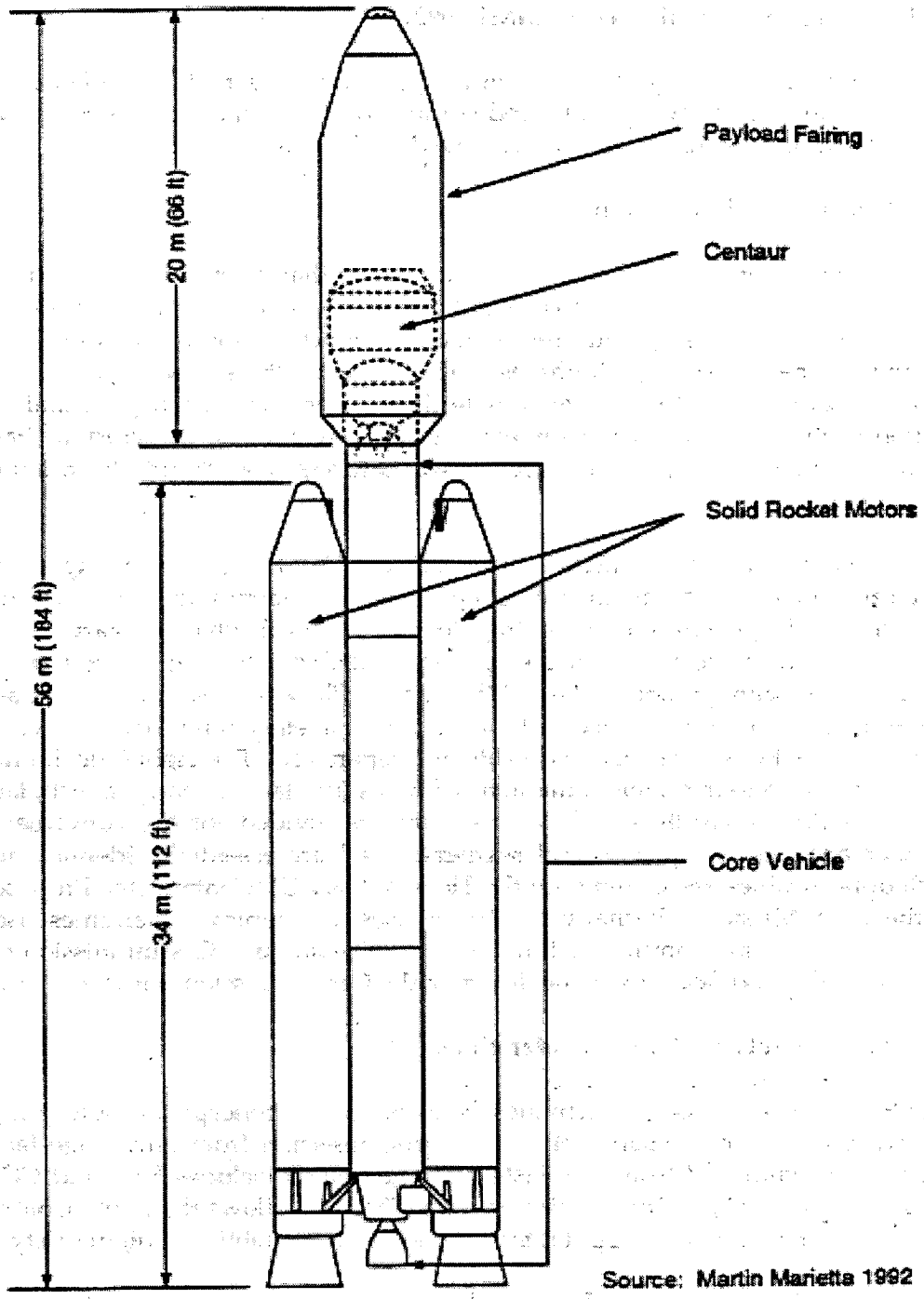

Figure 2-4 Diagram of the Titan IV (SRMU)/Centaur Launch Vehicle

three fairing segments would uncouple and be jettisoned from the rest of the launch vehicle, falling back into the ocean (MMT 1992).

The Centaur uses two liquid hydrogen (LH_2)/liquid oxygen (LO_2) rocket engines with multiple restart capability. The LH_2 and LO_2 are contained in two large tanks that account for the bulk of the Centaur's internal volume (MMT 1992).

2.1.7 Cassini Mission Timeline

The Cassini mission timeline is divided into phases that primarily serve as the basis for potential launch accident scenario definitions and environmental analyses. The 1995 Cassini EIS, in addressing four representative launch accident scenarios, divided the mission timeline into six launch phases, beginning with Phase 1, which commences at T-0 s, with ignition of the SRMUs to initiate liftoff from the launch pad, and ends with insertion of the spacecraft into its interplanetary gravity-assist trajectory in 1995 Cassini EIS Phase 6. The gravity-assist trajectory was addressed separately from launch of the spacecraft.

The updated safety analyses (MMT 1997, LMM&S 1997 a-j), in addressing a larger array of potential launch accidents (including a pre-launch accident with a release), divided the launch into eight phases, plus EGA trajectory. Pre-launch Phase 0, starts at T-48 hours with installation of the RTGs on the spacecraft, includes fueling of the Centaur upper stage, and ends with ignition of the SRMUs at T=0. Phase 8 (as with the 1995 Cassini EIS's Phase 6) is insertion of the spacecraft into its interplanetary trajectory. As with the 1995 Cassini EIS, the EGA trajectory was evaluated separately. The eight launch phases were also grouped into four principal mission segments (pre-launch, early launch, late launch, plus the EGA). Regardless of how the launch is divided for the convenience of the particular analysis, the phases and segments used are essentially identical for all the launch opportunities associated with the Titan IV (SRMU)/Centaur (the Proposed Action and the 2001 Mission Alternative). The phases and typical timeframes used in the ongoing analyses are summarized in Table 2-1. The nominal Cassini mission timeline is subject to slight modifications as the design of the Cassini mission is further refined.

2.1.8 Range Safety System Considerations

Range Safety encompasses all activities from the design concept through test, checkout, assembly and launch of space vehicles, to orbit insertion from any range facility. All space vehicles launched from the Eastern Range, which includes KSC and CCAS, must carry an approved Flight Termination System (FTS) that allows the Flight Control Officer (FCO) to terminate powered flight if the vehicle violates established flight safety criteria.

The FTS, which includes the Titan IV launch vehicle system and a Centaur system, provides ground personnel with the capability to shut down any thrusting liquid stage only, or to shut down any thrusting liquid stage and then destruct the SRMUs and all

Table 2-1. Cassini Mission Launch Segments and Phases and Key Events for the Updated Analyses

		Mission Elapsed Time, seconds		Phase Start and Finish Events
Mission Segment	**Phase**	**Phase Start**	**Phase Finish**	**Key Events in Phase**
Pre-Launch	0	-48 hours	0	**Complete RTG Installation (PLF Door Closure) to SRMU Ignition** Start Centaur Tanking; Complete Centaur Tanking; Arm Ordnance
Early Launch	1	0	143	**SRMU Ignition to SRMU Jettison** Clear Launch Complex; Clear Land; Reach 10 km Altitude; Safe SRMU and Centaur AutoDestruct Systems (ADSs); Stage 1 Ignition
	2	143	206	**SRMU Jettison to PLF Jettison** SRMU Separation System Fires
Late Launch	3	206	320	**PLF Jettison to Stage 1 Jettison** PLF Separation System Fires; Safe Stage 1 ADS; Stage 2 Ignition
	4	320	554	**Stage 1 Jettison to Stage 2 Jettison** Stage 1 Separation System Fires; Safe Stage 2 ADS
	5	554	707	**Stage 2 Jettison to Centaur Main Engine Cut-Off (MECO) 1** Stage 2 Separation System Fires; Centaur Main Engine Start (MES) 1; Attain Park Orbit
	6	707	1,889	**Centaur MECO 1 to Centaur MES 2** Safe Centaur Flight Termination System
	7	1,889	2,277	**Centaur MES 2 to Earth Escape**
	8	2,277	2,349	**Earth Escape to Centaur MECO 2**
EGA	Interplanetary trajectory/Earth swingby			

liquid stage tanks. This element of the FTS is called the command shutdown and destruct system (CSDS).

Additionally, the FTS will automatically destruct a stage that prematurely separates from the portion of the vehicle carrying the command receivers and antennas. This element is referred to as the automatic destruct system (ADS). Upon activation of an automatic destruct, Range Safety can, at their discretion, command destruct the Centaur and the remaining Titan IV elements.

The necessity for and design issues involved in a Space Vehicle Destruct System (SVDS) for the Cassini spacecraft were reviewed to determine if a SVDS would reduce the risk in the event of a launch phase accident. Analyses and testing involving the spacecraft's

hypergolic propellant indicated that the launch vehicle configuration for the Proposed Action would not require a SVDS. (A SVDS is, therefore, not on the Cassini spacecraft.)

Range Safety System Modifications Since the 1995 Cassini EIS: Since publication of the EIS, two additional Range Safety systems have been added to improve the FCO's ability to monitor vehicle off-nominal turns. These systems include a Laser Illumination System (LIS) and Range Safety Advisory System (RSAS).

The LIS provides vehicle attitude imaging during nighttime launches and is used in conjunction with the RSAS to detect off-nominal turns early in the launch. The LIS consists of three portable equipment setups to provide at least two operational systems for launch. Vehicle attitude imaging during nighttime launches and/or conditions of fog are provided by laser pulses that reflect off the vehicle back to cameras near the launch site. The image is displayed at the FCO console in the Range Operation Control Center (ROCC), providing the primary tool for determination of launch vehicle attitude during the first 30 seconds of flight.

The RSAS assures minimization of FCO reaction time early in the launch, when attitude control failures could result in an intact impact of the full vehicle with the surface of the Earth (ground or hard surface). The RSAS uses vehicle telemetry, from the Titan IV core vehicle and the Centaur upper stage, to supplement the full complement of data (including LIS) used to monitor launch vehicle attitude. This provides early detection of conditions that could lead to an intact impact of the launch vehicle by providing an auditory advisory signal to the FCO when abort telemetry criteria is reached. Primary information from the LIS for a command destruct decision is considered confirmed when the RSAS auditory signal is heard.

The effect of the above changes is to increase the reliability of the FCO response in the unlikely event that a command destruct action would be required during the early phases of the Titan IV launch. This, in turn, keeps the probability of an intact impact of a complete launch vehicle very low.

2.2 DESCRIPTION OF THE 2001 MISSION ALTERNATIVE

The 2001 Mission Alternative would be similar to the Proposed Action in that it would include the Cassini spacecraft with the Huygens Probe and the Titan IV (SRMU)/Centaur launch vehicle, as described in Sections 2.1.3 through 2.1.5 of this SEIS. The primary launch opportunity for this mission alternative, however, would insert the Cassini spacecraft into a non-EGA trajectory. The launch vehicle would be the Titan IV (SRMU)/Centaur and would have a similar mission timeline as described in Section 2.1.7 of this SEIS. The primary launch opportunity would occur during the first 2.5 weeks of March 2001 , and would use a 10.3-year VVVGA trajectory, as depicted in Figure 2-5. The first Venus swingby would occur in August 2001, the second in September 2002, and the

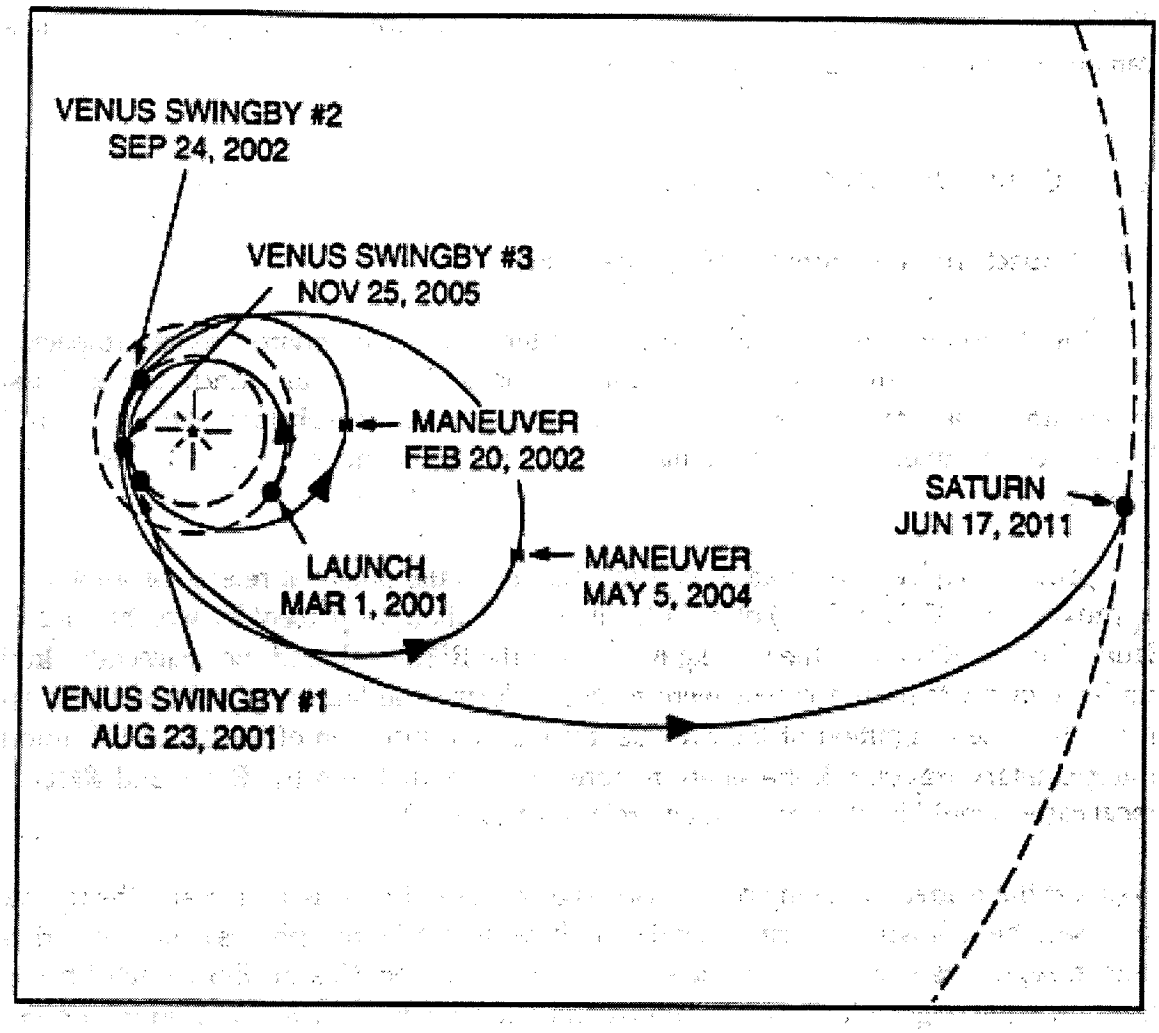

Figure 2-5 Cassini March 2001 VVVGA Interplanetary Trajectory

third in November 2005, with Cassini arriving at Saturn in June 2011 for the four-year tour of the Saturnian system (JPL 1994). A backup opportunity in May 2002 would use a VEEGA. This alternative was discussed in detail in Section 2.4 of the 1995 Cassini EIS.

2.3 DESCRIPTION OF THE NO-ACTION ALTERNATIVE

The No-Action Alternative would cancel the Cassini mission to Saturn. Additional details can be found in Section 2.5 of the 1995 Cassini EIS.

2.4 COMPARISON OF ALTERNATIVES

2.4.1 Impact Analysis from the 1995 Cassini EIS

For the Proposed Action and preferred alternative, the environmental impacts of completing preparations for the Cassini mission and a normal launch of the Cassini spacecraft on a Titan IV (SRMU)/Centaur would entail no substantial impacts on the human environment. For additional details, refer to Sections 2.7 and 4.1 of the 1995 Cassini EIS.

The principal concern associated with the mission is the potential release of some of the approximately 32.7 kg (72 lb) of PuO_2 (consisting of about 71 percent by weight Pu-238 at launch) in the RTGs and the 0.35 kg (0.77 lb) in the RHUs onboard the spacecraft. In the unlikely event that an accident were to occur during the launch of the spacecraft (i.e., from the time of ignition of the SRMUs, through the insertion of the spacecraft into its interplanetary trajectory), the safety features incorporated into the RTGs and RHUs, in most cases, would limit or prevent any release of the PuO_2.

To assist the reader in making comparisons between the 1995 Cassini EIS and the updated analyses, the following description indicates how the EIS launch phases compare with the launch segments used in the updated analyses. For 1995 Cassini EIS launch Phases 1 through 6 (analogous to the early launch and late launch segments used in the updated analyses), four accident scenarios were identified in the 1995 Cassini EIS as representative of the categories of failures that could release PuO_2 to the environment. Pre-launch accidents were not covered in the EIS because, at that time, none were postulated that would result in a release of PuO_2. In addition, two postulated low-probability (i.e., much lower than the probabilities for Phases 1 through 6) accident scenarios that could occur during the interplanetary portions of the VVEJGA and VEEGA trajectories were identified as the short-term (EGA) and long-term inadvertent reentry scenarios. The short-term scenario would involve the inadvertent reentry of the spacecraft into the Earth's atmosphere during a planned Earth swingby, and the long-term scenario would involve a

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spacecraft failure that leaves the spacecraft drifting in an Earth-crossing orbit and potentially reentering the Earth's atmosphere a decade to millennia later.

The 1995 Cassini EIS analyses indicated that, depending on the accident scenario, the CCAS/KSC regional area, limited portions of Africa for an 8-10 second period under the space vehicle flight path, or indeterminate locations within the global area could be impacted by PuO_2 releases. The CCAS/KSC regional area could be impacted if an early Phase 1 (early launch segment in the updated analyses) accident were to result in a release. Areas outside the region (i.e., a portion of the African continent; areas elsewhere around the world) could be impacted if an accident resulting in a release were to occur in Phase 5 or 6 (late launch segment in the updated analyses). No releases of plutonium from the RTGs or RHUs to the environment were postulated in the 1995 Cassini EIS if any of the representative accident scenarios occurred in Phases 2, 3, or 4.

During the interplanetary portions of the mission, postulated short-term (EGA segment of the updated analyses) and long-term inadvertent reentry accident scenarios could result in releases of PuO_2 to the environment. However, NASA is designing the mission to greatly reduce the potential for such accidents. Mission design criteria require that the mean probability of an inadvertent reentry during the VVEJGA trajectory be no greater than one in a million. If such an accident were to occur, PuO_2 could be released in the upper atmosphere and/or scattered on indeterminate locations on the Earth's surface, resulting in a slight increase in the background radiological exposure of a large number of people worldwide.

The principal measure used in the Galileo and Ulysses Tier 2 EISs, and in the 1995 Cassini EIS and supporting safety analyses, for characterizing the radiological impacts of each alternative evaluated, is health effects risk. Health effects are expressed as the number of excess latent cancer fatalities over a 50-year period (above the normally observed cancer fatalities). As used here, health effects mission risk is the probability of an accident resulting in a PuO_2 release (i.e., the probability of an initiating accident times the probability that the accident would result in a release of PuO_2), multiplied by the consequences of that accident (i.e., the 50-year health effects that could be caused by the exposure of individuals to the PuO_2), summed over all postulated accidents. Estimates of health effects mission risk, as discussed here, represent the expectation of latent cancer fatalities. The expectation health effects mission risk over all mission phases (i.e., the 50-year period health effects) does not include contributions to risk from the long-term EGA reentry scenario.

For the Proposed Action, the 1995 Cassini EIS mission risk estimate, considering all launch phases for the primary launch opportunity, was 8.4×10^{-7} (0.00000084) health effects. The mission risk from the short-term inadvertent reentry accident during the Earth swingby portion of the primary launch opportunity's VVEJGA trajectory was estimated as 1.7×10^{-3}, (0.0017) health effects, and for the secondary and backup opportunity VEEGA trajectories as 1.8×10^{-3} (0.0018) health effects. The overall mission risk (considering all

launch phases and the EGA trajectories), from the primary launch opportunity was 1.7×10^{-3} (0.0017) health effects, and from the backup launch opportunity, it was estimated at 1.8×10^{-3} (0.0018) health effects.

2.4.2 Changes in Estimated Impacts from Accidents Since the 1995 Cassini EIS

The refinements in the evaluation of accidents and estimates of their potential consequences since the early scoping analysis of the Cassini EIS have resulted in different estimates of impacts. The following highlights the changes in approach for estimating the accident probabilities, health effects and risks:

- The EIS used four representative accidents for the launch of the mission and estimated their probabilities of occurrence. Pre-launch accidents were not addressed in the 1995 Cassini EIS because, at that time, none were postulated that would result in a release of PuO_2.

  The updated analyses use more detailed accident descriptions, accident environments and probability distributions. In addition, the updated mission safety analyses have determined that a release could occur from some on-pad accidents during the two hour period prior to launch. Further, the probabilities of accidental reentries during the late launch segment are higher than in the 1995 Cassini EIS.

- Both the 1995 Cassini EIS and the updated analyses use the same accident definition and event trees for the inadvertent reentry during an Earth swingby accident. The 1995 Cassini EIS reported bounding estimates of potential releases because there was uncertainty in whether the General Purpose Heat Source (GPHS) modules or Graphite Impact Shells (GISs) would survive an inadvertent reentry during Earth swingby or release plutonium in the upper atmosphere.

  The updated analyses uses results of additional research and modeling to refine estimates of behavior of RTGs, GPHS modules and components on reentry. The analysis also uses probability distributions for some key variables on the reentry event trees used in the 1995 Cassini EIS rather than nominal estimates of the branch probabilities. The results are reported as probability distributions of source terms for the accident.

- The 1995 Cassini EIS used simpler techniques to estimate nominal and maximum source terms and the corresponding conditional probabilities that PuO_2 would be released.

The updated analyses use probabilistic techniques to evaluate the accident conditions. The resultant source terms are reported as a probability distribution for each accident case.

- The 1995 Cassini EIS modeled accident consequences using the same basic approaches, assumptions and model parameters that had been used for the Galileo and Ulysses missions.

  The updated analyses extends techniques used in the 1995 Cassini EIS and for the Galileo and Ulysses missions. The analysis makes wide-scale use of probability distributions. It uses best estimate values for certain key parameters, and more comprehensive modeling to determine PuO_2 particle dispersion, uptake by people and the potential for latent cancer fatalities. (Best estimates are defined in Appendix B.)

- The 1995 Cassini EIS stated that there were uncertainties in the estimated probabilities of an accident occurring, the conditional probabilities of material being released and the resultant source terms of the accidents.

  The updated analyses include the most extensive evaluation of the uncertainties of accident consequences ever attempted for a space mission. The analysis expands techniques reported for the Ulysses mission and provides an estimate of the consequences and risk with their associated uncertainties.

Launch phase consequence and risk estimates from the updated analyses are derived directly from a mathematical distribution as opposed to the 1995 Cassini EIS's point estimates that were based on a semi-quantitative assessment of previous mission safety analyses. A comparison of the two sets of estimates indicates that the 1995 Cassini EIS's overall assessment of risk was close to results of the updated analyses, even though the 1995 Cassini EIS's assessment of individual mission risk and variability were lower for launch phase accidents, but higher for the EGA swingby accident risk. Both the 1995 Cassini EIS and the updated analyses indicate that only a fraction of conceivable launch accidents could result in releases of PuO_2.

2.4.3 Overview of Updated Mission Safety Analyses of Radiological Impacts from Accidents

Since completion of the Final EIS for the Cassini Mission (dated June 1995) NASA and DOE have continued the safety analysis process for the mission. This process was described in Section 4.1.5.1 of the 1995 Cassini EIS. The "Cassini Titan IV/Centaur RTG Safety Databook, Revision B" dated March 1997 (MMT 1997), describes accident probabilities and environments for the mission. DOE contractors have incorporated the MMT 1997 information into their accident analyses and recently completed their preparation of the Safety Analysis Report (SAR) "GPHS-RTGs in Support of the Cassini

Mission" (LMM&S a-j). Results from those analyses, along with the companion SAR for the LWRHUs (EG&G 1997), are reported in this SEIS. While some of the individual results of the SARs differ from those reported in the April 1997 Draft SEIS and companion document HNUS 1997, the overall mission risk remains similar.

Concurrent with the recent completion of the SAR (LMM&S a-j), a supplement to the Cassini Earth Swingby Plan dated May 19, 1997 (JPL 1997) was issued. This supplement contains slightly lower estimates of EGA inadvertent reentry probabilities, and is part of the separate, (non-NEPA), ongoing nuclear launch safety analysis process and will be evaluated as a part of that process.

The process currently used by the updated mission safety analyses in determining the mission risk associated with the Cassini mission is similar to the process used for the earlier Galileo and Ulysses missions. The PuO_2 release potentially resulting from each accident (i.e., the source terms) are determined by evaluating the response of the RTGs and RHUs to the defined accident environments. For each combination of accident and environment, simulations are used to determine the probability of rupture or breach of the iridium clads of the RTGs or the platinum-rhodium clads of the RHUs, which contain the PuO_2. For simulations in which clad failure occurs, the mass of the PuO_2 escaping the clad is determined, along with information on particle size, particle density and release location. The safety analyses for both the RTGs and RHUs utilized empirical results of safety tests and analyses, and modeling studies conducted by DOE and NASA. The updated analyses, however, are more refined and comprehensive than those used for the 1995 Cassini EIS.

Table 2-2 presents the means of the best estimate results from the updated analyses, and compares them with the results in the 1995 Cassini EIS. (See Appendix B for a description of the best estimate.) The launch accidents and consequences addressed here apply to both the Proposed Action and 2001 Mission Alternative.

Pre-launch accidents were not addressed in the 1995 Cassini EIS because at that time none were postulated that would result in a release of PuO_2. Since that time, updated analysis has shown that PuO_2 releases could result at the launch pad if the Centaur upper stage experienced a major structural or mechanical failure during the two-hour pre-launch fueling and preparation period. The probability of a pre-launch accident that could result in a release of PuO_2 is 5.2×10^{-5}, or 1 in 19,200, and could result in 0.11 health effects and could contaminate 1.5 km^2 (0.58 mi^2) of land above 7.4×10^3 Bq/m^2 (0.2 $\mu Ci/m^2$) (the EPA's guideline level for considering the need for further action, EPA 1990). Based on the 99-percentile of the consequence distribution function, there would be a 1% probability that approximately 1.0 or more health effects could occur. The total probability of such an accident is 5.2×10^{-7}, approximately 1 in 1.92 million. Land area contaminated above the EPA guideline level could exceed 8.6 km^2 (3.3 mi^2). Note that doses and health impacts do not include implementation of accident contingency plans or any other mitigation actions by governmental authorities.

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Table 2-2. Comparison of Updated Mean Estimates of Accident Parameters with the 1995 Cassini EIS

Mission Segment	Document	Total Probability[a]	Maximum Individual Dose[b], rem	Land Area Contaminated[c], km^2	Health Effects[d] (w/o *de minimis*)	Mission Risks[e]
Pre-Launch	SEIS	$5.2x10^{-5}$	$1.4x10^{-2}$	$1.5x10^{0}$	$1.1x10^{-1}$	$5.5x10^{-6}$
	EIS	f	f	f	f	f
Early Launch	SEIS	$6.7x10^{-4}$	$2.1x10^{-2}$	$1.6x10^{0}$	$8.2x10^{-2}$	$5.5x10^{-5}$
	EIS	$1.1x10^{-3}$	$5.8x10^{-5}$	$8.8x10^{-2}$	$4.1x10^{-4}$	$4.6x10^{-7}$
Late Launch	SEIS	$2.1x10^{-3}$	$1.1x10^{0}$	$5.7x10^{-2}$	$4.4x10^{-2}$	$9.2x10^{-5}$
	EIS	$9.4x10^{-4}$	$3.2x10^{-2}$	$8.4x10^{-3}$	$3.9x10^{-4}$	$3.7x10^{-7}$
VVEJGA	SEIS	$8.0x10^{-7}$	$5.1x10^{2}$	$1.5x10^{1}$	$1.2x10^{2}$	$9.8x10^{-5}$
	EIS	$7.6x10^{-7}$	$3.1x10^{1}$	$2.0x10^{-3}$	$2.3x10^{3}$	$1.7x10^{-3}$
Overall Mission	SEIS	$2.8x10^{-3}$	$9.7x10^{-1}$	$4.5x10^{-1}$	$8.9x10^{-2}$	$2.5x10^{-4}$
	EIS	$2.1x10^{-3}$	$2.6x10^{-2}$	$7.8x10^{-1}$	$8.3x10^{-1}$	$1.7x10^{-3}$

a. Product of initating accident x conditional PuO_2 release probabilities.
b. Maximally exposed individual dose.
c. Land area potentially contaminated above $7.4x10^{3}$ Bq/m^2 (0.2 μCi/m^2).
d. Health effects are incremental latent cancer fatalities.
e. Risk calculated as the total probability times health effects.
f. No pre-launch accidents resulting in a release were postulated in the EIS.

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While the probability of an early launch accident that could threaten the RTGs is 6.2×10^{-3}, or 1 in 160, the probability of an early launch accident that could result in a release of PuO_2 is 6.7×10^{-4}, or 1 in 1,490, and could result in 0.082 health effects and could contaminate 1.6 km^2 (0.62 mi^2) of land above the EPA guideline level. Such an accident could occur in a number of ways, such as, if the RTGs impacted ground on or near the launch pad following an in-air explosion due to a malfunction, or by the activation of the CSDS or ADS. In comparison to the 1995 Cassini EIS, this mission segment's mean mission risk is 5.5×10^{-5} (0.000055) health effects, which exceeds the 1995 Cassini EIS estimate of 0.00000046. Based on the 99-percentile of the consequence distribution function, there would be a 1% probability that approximately 1.5 or more health effects could occur. The total probability of such an accident is 6.7×10^{-6}, less than 1 in 149,000. Land area contaminated above the EPA guideline level could exceed 20 km^2 (7.7 mi^2). Note that doses and health impacts do not include implementation of accident contingency plans or any other mitigation actions by governmental authorities.

While the probability of a late launch accident is 2.1×10^{-2}, or 1 in 48, the probability of an accident that results in a release of plutonium is 2.1×10^{-3}, or 1 in 476, and could result in 0.044 health effects and could contaminate 0.057 km^2 (0.02 mi^2) of land above the EPA guideline level. Such accidents could occur if a Centaur failure resulted in atmospheric reentry and hard surface impact of the RTG modules. For suborbital accidents, a hard surface impact on southern Africa and/or Madagascar is only possible during a ten-second window of the suborbital flight. Orbital failures leading to ground impact could occur after attaining park orbit and result in orbital decay reentries from minutes to years after the initial accident if implementation of the spacecraft's Sufficiently High Orbit (SHO) capability failed. (In the event of a late launch accident, such as a failure of the Centaur upper stage to initiate its second burn and send the spacecraft on its interplanetary trajectory, the spacecraft has a capability to be separated and boosted to a high [2000+ year] storage orbit.) For those late launch Centaur accidents, for which the spacecraft cannot be successfully separated and boosted, orbital decay reentries would occur from minutes to years after the accident. In comparison to the 1995 Cassini EIS, this mission segment's mean mission risk is 9.2×10^{-5} (0.000092) health effects, which exceeds the EIS estimate of 0.00000037. Based on the 99-percentile of the consequence distribution function, there would be a 1% probability that approximately 0.55 or more health effects could occur. The total probability of such an accident is 2.1×10^{-5}, or less than 1 in 47,600. Land area contaminated above the EPA guideline level could exceed 0.34 km^2 (0.13 mi^2). Note that doses and health impacts do not include implementation of accident contingency plans or any other mitigation actions by governmental authorities.

The probability of an EGA accident that results in a release of plutonium is 8.0×10^{-7} or less than 1 in 1 million, and could result in 120 health effects and could contaminate 15 km^2 (5.8 mi^2) of land above the EPA guideline level. Such an accident could occur if, during the EGA swingby, the Cassini spacecraft became non-commandable after experiencing a failure that placed it on an Earth impact trajectory and subsequently released PuO_2 at high altitude or as a result of ground impacts. In comparison to the 1995 Cassini EIS, this

mission segment's mean mission risk is 9.8×10^{-5} (0.000098) health effects, which is less than the 1995 Cassini EIS estimate of 0.0017. Based on the 99-percentile of the consequence distribution function, there would be a 1% probability that approximately 450 or more health effects could occur. The total probability of such an accident is 8.0×10^{-9}, approximately 1 in 125 million. Land area contaminated above the EPA guideline level could exceed 55 km^2 (21 mi^2). Note that doses and health impacts do not include implementation of accident contingency plans or any other mitigation actions by governmental authorities.

As noted earlier, if the spacecraft were to become non-commandable during its interplanetary trajectory, and control could not be restored, its orbit around the Sun could intersect that of the Earth resulting in a long-term inadvertent reentry. The probability of such an event is 2.0×10^{-7} or, 1 in 5 million. It is reasonable to assume that the consequences of such a reentry would be of a similar order of magnitude as that estimated for the short-term EGA.

In addition to the above best estimate analyses, DOE has conducted a study of the uncertainty in the underlying test data and models used to estimate accident risks and consequences. This information is presented in Chapter 4 of this SEIS; see also HNUS 1997 and Appendix D.

2.4.4 2001 Mission Alternative

With respect to the 2001 Mission Alternative, which would also be launched on a Titan IV (SRMU)/Centaur, the 1995 Cassini EIS concluded that potential launch accident consequences and risks would be essentially the same as those estimated for the Proposed Action. This also holds for the updated results from the ongoing mission safety analyses. Specifically, the pre-launch, early launch and late launch consequence and risk analyses results would also apply to those segments of the 2001 Mission.

The only difference postulated at this time is in the EGA results, which do not apply to this alternative. Without an Earth swingby as part of its primary opportunity 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. The backup opportunity for this alternative is a VEEGA, however, and therefore the potential exists for a short-term and a long-term inadvertent reentry as noted earlier for the Proposed Action. The potential consequences for the backup and the long-term accident are assumed similar to those postulated respectively for the secondary/backup and the short-term EGA accident described for the Proposed Action.

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2.4.5 No-Action Alternative

The No-Action Alternative would not result in any adverse health or environmental impacts. For other impacts associated with the Non-Action alternative see Section 4.4 of the 1995 Cassini EIS, and Section 4.3 of this SEIS.

2.4.6 Summary Comparison of Alternatives

Table 2-3 provides a summary comparison of the Proposed Action, including the secondary and backup launch opportunities, and the alternatives. The factors used are the key parameters discussed in more detail in Chapter 4 of this SEIS and the 1995 Cassini EIS. All launch opportunities involve the Titan IV(SRMU)/ Centaur and are expected to have similar environmental impacts with normal launches. The accident impacts and risks are expected to be similar for the pre-launch, early-launch, and late-launch segments of each mission alternative with any of the launch opportunities. The principal differences involve the short- and long-term risks of an inadvertent reentry during the EGA and interplanetary cruise portions of the mission. Updated analyses indicate that the EGA accident impacts and risks are now estimated to be less than those presented in the 1995 Cassini EIS. As a result the mission risk contributions of each inadvertent reentry would be nominally the same.

Although the primary opportunity for the the 2001 Alternative uses a VVVGA trajectory and therefore presents no short-term inadvertent reentry risk, a long-term risk of an inadvertent reentry similar to the other launch opportunities would remain. The risks associated with the backup opportunity (a VEEGA trajectory) would be the same as the secondary and backup VEEGA opportunities for the Proposed Action.

Table 2-3 Summary Comparison of the Potential Mean Radiological Impacts and Risks for Cassini Mission Alternatives

Mission Segment	Proposed Action		2001 Alternatives		No-Action
	Primary (VVEJGA)	Secondary/ Backup (VEEGA)	Primary VVVGA	Backup VEEGA	
Pre-Launch					
Total Probability[a]	1 in 19,200	Same	Same	Same	No Effect
Health Effects	0.11	Same	Same	Same	No Effect
Land Area Contaminated (km^2)	1.5	Same	Same	Same	No Effect
Health Effects Risk	$5.5x10^{-6}$	Same	Same	Same	No Effect
Early-Launch					
Total Probability[a]	1 in 1490	Same	Same	Same	No Effect
Health Effects	0.082	Same	Same	Same	No Effect
Land Area Contaminated (km^2)	1.6	Same	Same	Same	No Effect
Health Effects Risk	$5.5x10^{-5}$	Same	Same	Same	No Effect
Late-Launch					
Total Probability[a]	1 in 476	Same	Same	Same	No Effect
Health Effects	0.044	Same	Same	Same	No Effect
Land Area Contaminated (km^2)	0.057	Same	Same	Same	No Effect
Health Effects Risk	$9.2x10^{-5}$	Same	Same	Same	No Effect
EGA/Interplanetary Cruise • Short-Term Inadvertent Reenetry					
Total Probability[a]	1 in 1,250,000	1 in 2,900,000	No Short Term	Same as Sec.	No Effect
Health Effects	120	227	None	Same as Sec.	No Effect
Land Area Contaminated (km^2)	15	21	None	Same as Sec.	No Effect
Health Effects Risk	$9.8x10^{-5}$	$7.6x10^{-5}$	None	Same as Sec.	No Effect
• Long-Term Inadvertent Reenetry					
Total Probability[a]	1 in 5,000,000	1 in 1,700,000	Same	Same as Sec.	No Effect
Radiological Impacts	similar to short-term	similar to short-term	Same	Same as Sec.	No Effect
Overall Mission Risk	$2.5x10^{-4}$	$2.3x10^{-4}$	Same	Same as Sec.	No Effect

a. Total probability of an accident with a release of PuO_2

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Cassini Mission
Final Supplemental Environmental Impact Statement

Executive Summary

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3.0 AFFECTED ENVIRONMENT

The 1995 Cassini EIS addressed the affected environment in terms of the local/regional environment and the global environment that could potentially be affected by the Proposed Action and the alternatives. Given that potential accidents and the resulting radiological consequences are the focus of this SEIS, only the local/regional land use and population descriptions are summarized here. There has been no substantial change in the characteristics of the global environment since publication of the 1995 Cassini EIS.

The Cassini mission would be launched from CCAS, which is located on the east coast of Brevard County near the city of Cocoa Beach, approximately 24 km (15 mi) north of Patrick Air Force Base. CCAS is bounded by NASA/KSC on the north, the Atlantic Ocean on the east, the city of Cape Canaveral on the south and the Banana River and KSC/Merritt Island National Wildlife Refuge on the west.

The six-county region surrounding CCAS consists of Volusia, Seminole, Lake, Orange, Osceola and Brevard Counties. The region is about 1.7 million ha (4.1 million acres) in size, of which about 8 percent (132,742 ha; 328,000 acres) is urbanized. The most heavily populated urban areas in the region are Orlando in Orange County, about 85 km (53 mi), and Titusville, about 24 km (15 mi) to the west of the Titan IV launch complexes at CCAS, with the Daytona Beach/Ormond Beach area about 110 km (68 mi) and Port Orange and New Smyrna Beach 58 and 79 km (36 and 49 miles), respectively, to the north. To the east of CCAS is the Atlantic Ocean, with the city of Cape Canaveral immediately to the south. Cocoa Beach lies about 28 km (17 mi) to the south, with Melbourne and Palm Bay about 52 km (32 mi) also to the south.

About 35 percent of the land in the region is devoted to agriculture (about 566,580 ha; 1.4 million acres) and about 25 percent to conservation and recreation lands (about 404,700 ha; 1 million acres). Within the agricultural area, the three principal uses are crops, citrus and pasturage. About 29,900 ha (73,850 acres) is used for cropland, 50,200 ha (124,000 acres) is in citrus production, and about 309,100 ha (763,500 acres) is in pastureland. The region also contains about 2,185 ha (5,400 acres) of saltwater beaches and about 32 ha (80 acres) of historical and archaeological sites.

CCAS occupies about 6,394 ha (15,800 acres) of the barrier beach that also contains the city of Cape Canaveral. Approximately 1,880 ha (4,700 acres) of the facility, or 30 percent of the station, is developed, consisting of over 40 launch complexes and support facilities, many of which have been deactivated. The remaining 70 percent (about 4,440 ha; 11,100 acres) is unimproved land. The two Titan IV launch complexes (LC 40 and LC 41) are located in the northeastern most section of CCAS, about 450 m (1,500 ft) inland from the Atlantic Ocean.

About 85 percent of the regional population lives in urban areas, with the largest concentrations in three metropolitan areas: (1) Orlando in Orange County, with

expansions into the Lake Mary and Sanford areas of Seminole County to the north and into the Kissimmee and St. Cloud areas of Osceola County to the south; (2) the coastal area of Volusia County, including Daytona Beach, Ormond Beach and New Smyrna Beach; and (3) along the Indian River Lagoon and Coastal area of Brevard County, specifically the cities of Titusville, Melbourne and Palm Bay.

The 1990 population of the region numbered about 2 million people. About 86 percent of the regional population were white, 11 percent black, 2 percent Native American/Eskimo/Aleut/Pacific Islander/Asian and the remaining 1 percent not falling into any of the above categories. About 6 percent of the total population was of Hispanic origin. About 9 percent of the regional population (about 189,000 people) lived within 32 km (20 mi) of the Titan IV launch complexes at CCAS. The racial and ethnic composition of that group reflected the overall regional population, being predominantly white. Approximately 10 percent were black, with the remaining 10 percent falling into the other two categories. About 6 percent of this population were of Hispanic origin. The uncontrolled population nearest the launch complexes is about 16 km (10 mi) to the southeast and contains less than 2 percent of the regional population. Racial composition was about 97.5 percent white, 1 percent black and the remaining 1.5 percent divided amongst the remaining two racial categories. About 2 percent of the uncontrolled population were of Hispanic origin.

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

Cassini Mission
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4.0 ENVIRONMENTAL IMPACTS

The environmental impacts of the Cassini mission were addressed in Chapter 4 of the 1995 Cassini EIS. Completing preparations for and implementing a normal, incident-free mission were determined to have no substantial impacts to the human environment for either the Proposed Action or any of the other mission alternatives, including the 2001 Mission. It is unlikely, given the present composition of the population in the region, that any given racial, ethnic, or socioeconomic group in the population would bear a disproportionate share of any environmental impacts. The ongoing mission safety analyses have yielded no information that changes those analyses, nor is there any change in the impacts associated with the No Action Alternative. The cumulative impacts of a normal Cassini mission which center around the SRMU exhaust emissions are unaffected by the results of the updated analyses. Details of the impact evaluations of a normal launch can be found in Sections 4.1, 4.2, 4.3 and 4.4 of the 1995 Cassini EIS.

4.1 RADIOLOGICAL IMPACT ASSESSMENT OF THE PROPOSED ACTION

Since completion of the Final EIS for the Cassini Mission (dated June 1995; issued in July 1995), NASA and DOE have continued the safety analysis process for the mission. This process was described in Section 4.1.5.1 of the 1995 Cassini EIS. The "Cassini Titan IV/Centaur RTG Safety Databook, Revision B" dated March 1997, (MMT 1997), describes accident probabilities and environments for the mission. DOE contractors have incorporated the MMT 1997 information into their accident analyses and recently completed their preparation of the Safety Analysis Report (SAR) "GPHS-RTGs in Support of the Cassini Mission" (LMM&S a-j). Results from these recent analyses, along with the companion SAR for the LWRHUs (EG&G 1997), are reported in this SEIS. While some of the individual results of the SARs differ from those reported in the April 1997 Draft SEIS and companion document HNUS 1997, the overall mission risk remains similar.

The Draft SEIS was issued in April 1997 with the best available information available at that time. A separate report (HNUS 1997) was prepared that summarized the methodology and interim results available from the NASA/DOE safety analysis process for the Cassini mission. Since that time, definition of the probabilities and accident environments for launch area accidents that might involve fallback of the SRMU propellant and the "full stack intact impact" accident have been completed (MMT 1997). The DOE contractor has incorporated that information into the accident analyses and completed their RTG SAR (LMM&S g, LMM&S h, LMM&S j). This final SEIS incorporates the results of these recently completed analyses.

As with the Draft SEIS (DSEIS), the analytical results reported in this Final SEIS (FSEIS) do not include consideration of *de minimis*. To review analytical results both with and without *de minimis*, please refer to Appendix D.

4.1.1 Radiological Accident Impact Analysis

4.1.1.1 Safety Analysis Process

The process used in the safety analyses to determine the risk associated with the Cassini mission is fundamentally similar to the process used for the earlier Galileo and Ulysses missions and is illustrated in Figure 4-1. NASA has defined those accidents which might occur during the pre-launch, early launch, late launch, and EGA segments of the mission in the Cassini Titan IV/Centaur RTG Safety Databook (MMT 1997). The JPL swingby plan (JPL 1993b), and supplement (JPL 1997), address those accidents which may occur during the interplanetary trajectory. Together, MMT 1997 and JPL 1993b/JPL 1997 define the accidents, associated probabilities of occurrence, and accident environments that might threaten the RTGs and RHUs.

The source terms are determined by evaluating the response of the RTGs and RHUs to the defined accident environments (LMM&S a-j, EG&G 1997). For each combination of accident and environment, techniques such as computer simulations (again, similar to those performed for the Galileo and Ulysses missions), and analyses based upon empirical data from safety tests and evaluations are used to determine the probability of rupture or breach of the iridium RTG clads and the platinum-rhodium RHU clads which contain the PuO_2. For simulations in which clad failure occurs, the mass of the PuO_2 released from the clad is determined, along with information on particle size, particle density and release location. For clad failures in the vicinity of burning propellant, the source term also includes the amount of PuO_2 vaporized and the fireball buoyancy effects.

The source terms for each case are then evaluated to determine the consequences of the release to the environment and to people. The approach used is again quite similar to that used for the Galileo and Ulysses missions, as well as the 1995 Cassini EIS. Each source term is evaluated to determine how it transports and disperses from the point of release, including the effects of weather, deposition and resuspension. Long-term (50-year) passive exposure from inhalation of resuspended material and ingestion of foodstuffs is considered, as well as the more immediate airborne and ground-based external exposures. The consequence reported consists of the overall radiological effect of the source term via all of these pathways over a period of 50 years (immediate or short-term exposure, plus subsequent exposures over a 50-year period) and is expressed in terms of radiological dose (rem), potential health effects (latent cancer fatalities) and area of land potentially contaminated above the EPA recommended guideline level (7.4×10^3 Bq/m^2 [0.2 μCi/m^2]) at which the need for further action needs to be considered.

The final element of the analysis is the combination of the first three steps in Figure 4-1 into an overall estimate of risk. This is accomplished by weighting the consequences determined for each accident case by the respective probability of occurrence and conditional probability of release. The measure of risk is then the probability-weighted sum of consequences.

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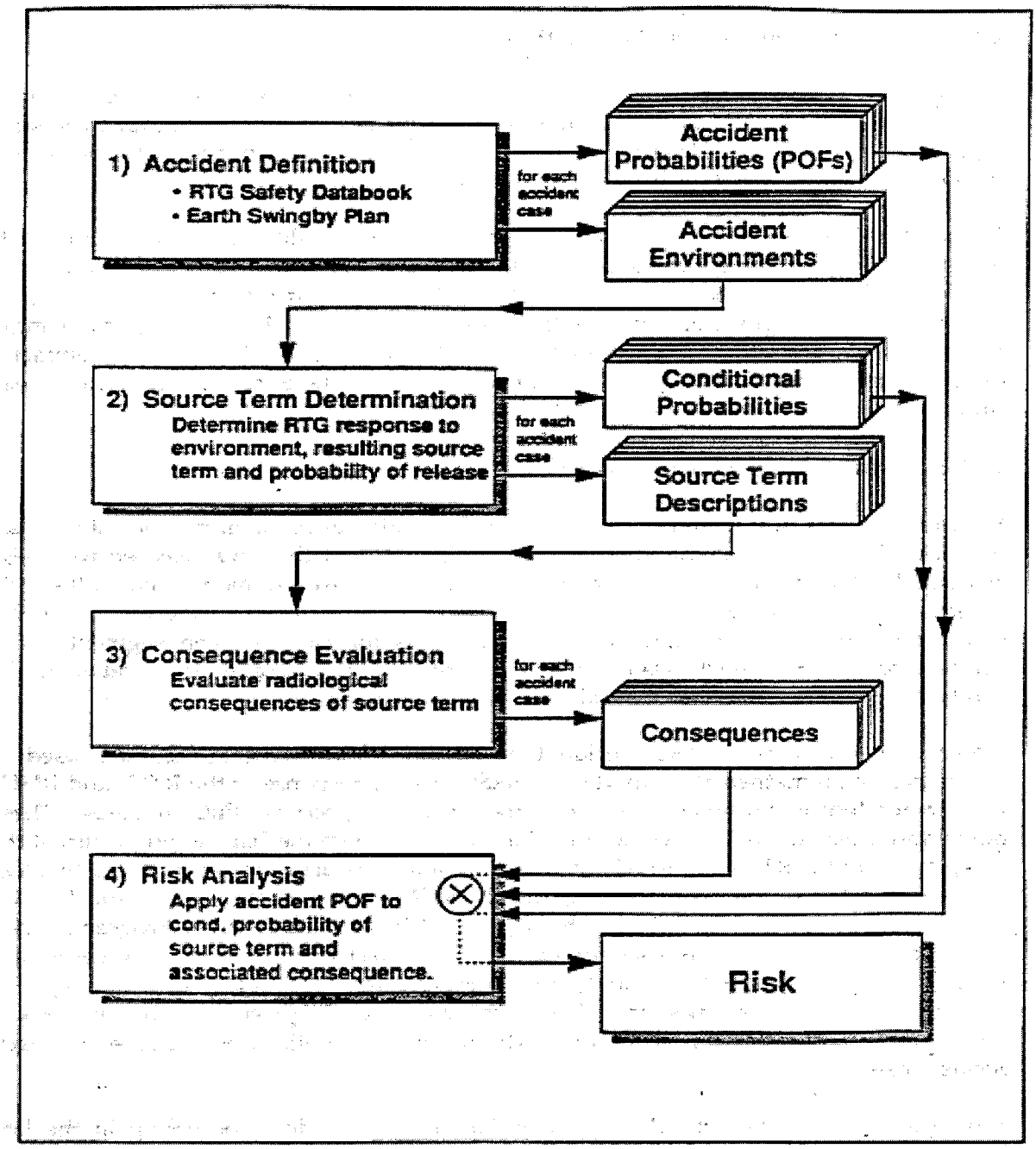

Figure 4-1 Overview: Basic Elements in the Nuclear Launch Safety Risk Analysis Process

4.1.1.2 Accident Scenarios and Probabilities

The updated mission safety analyses include detailed evaluations of 14 accident cases for the pre-launch and early launch segments, and four cases for the late launch mission segment, plus the EGA. These 19 accident cases and their contribution to the overall mission segment accident probabilities are listed in Table 4-1.

During the Earth gravity assist swingby, malfunctions could cause the spacecraft to reenter the Earth's atmosphere, subjecting the RTG and RHUs to high aerodynamic loads and thermal stresses. The mean probability of short-term Earth impact (i.e., during the VVEJGA Earth swingby maneuver) by the spacecraft is 8.0×10^{-7}. Loss of spacecraft control during the interplanetary cruise could potentially result in long-term Earth impact a decade to millennia later as the spacecraft orbits around the Sun. The estimated mean probability of long-term Earth impact is 2.0×10^{-7}.

4.1.1.3 Potential Accident Source Terms

For each accident case identified, the associated conditional probability that PuO_2 would be released and the resultant amount and characteristics of the PuO_2 released were also evaluated. Rather than the expectation and maximum case estimates used in the 1995 Cassini EIS, the updated mission safety analyses use more elaborate computer simulations for the probabilities and source terms for each mission segment. The simulations for the launch-related mission segment accident cases are fundamentally similar to those performed for the Galileo and Ulysses missions.

Information on launch vehicle accident probabilities and environments was used in conjunction with mathematical models to determine the response of the RTGs and RHUs to each accident environment and the characteristics of potential PuO_2 releases. These models are based upon (1) physical principles, (2) the known mechanical properties of the components of the RTGs and RHUs and (3) the results of series of tests conducted by DOE on the GPHS-RTGs, their components, and the RHUs. As with the Galileo and Ulysses EIS's, a computer code, the Launch Accident Scenario Evaluation Program, Titan IV/Centaur (LASEP-T), was used to simulate the effect of explosions, fragments and ground impacts on the RTGs and their components. The result of repeating the simulation thousands of times for each accident case produces probability distributions of the amount, location and particle size distribution of potential PuO_2 releases for each accident case.

Source terms from the sub-orbital and orbital reentry accidents occurring in the late launch mission segment were estimated using techniques similar to the early launch mission segment. Probabilistic sampling techniques were employed to account for the variations in location of the event, the source term if hard rock surfaces are hit, the number of modules that might hit rock, meteorological conditions, and population densities.

Table 4-1. Accident Case Descriptions [a b]

Mission Segment	Accident Case Number	Case Description	Mean Initiating Probability
Pre-Launch	0.0	On-Pad Explosion, Configuration 1	6.7×10^{-5}
Pre-launch Total [b]			6.7×10^{-5}
Early Launch	1.1	Total Boost Vehicle Destruct (TBVD)	4.2×10^{-3}
	1.2	Command Shutdown and Destruct (CSDS)	6.6×10^{-4}
	1.3	TBVD with SRMU Aft Segment Impact	8.1×10^{-4}
	1.4	SRMU Explosion	1.2×10^{-4}
	1.5	Space Vehicle (SV) Explosion	7.6×10^{-14}
	1.6	TBVD without Payload Fairing (PLF)	9.1×10^{-6}
	1.7	CSDS without PLF	1.5×10^{-6}
	1.8	SV Explosion without PLF	1.4×10^{-6}
	1.9	Centaur Explosion	1.4×10^{-4}
	1.10	Space Vehicle/RTG Impact	2.3×10^{-4}
	1.11	Payload Fairing/RTG Impact	1.9×10^{-6}
	1.12	Payload Fairing/RTG Impact, RTG Falls Free	1.9×10^{-6}
	1.13	Full Stack Intact Impact	1.6×10^{-6}
Early Launch Total [b]			6.2×10^{-3}
Late Launch	3.1	Sub-Orbital Reentry	1.4×10^{-3}
	5.1	Sub-Orbital Reentry from CSDS Configuration 5	1.2×10^{-2}
	5.2	Orbital Reentry, Nominal	8.0×10^{-3}
	5.3	Orbital Reentry, Off-Nominal Elliptic Decayed	3.0×10^{-7}
Late Launch Total [b]			2.1×10^{-2}
VVEJGA		Short Term Reentry	8.0×10^{-7}
Overall Mission Total [b]			2.8×10^{-2}

a. See HNUS 1997, Section 4.1 and LMM&S 1997 a for more information on the accident case descriptions.
b. Only accidents which threaten the RTGs or RHUs with a potential for release of PuO_2 are included.

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Since the 1995 Cassini EIS, more detailed reentry analyses have been completed that provide additional insights into various branch-point probabilities in the source term event trees for the EGA (LMM&S b&c). This has allowed refinements to many of the values in the event trees that result in different probabilities for each of the potential end states for the PuO_2. As with the earlier mission phase accidents, probabilistic sampling techniques were employed to account for the variations in parameters that could affect the source term, such as reentry angle, latitude band of reentry, altitude of fuel releases, location of the event, the source term if rock or soil surfaces are hit, and the number of modules that might fail.

For additional detail about source terms see Appendix D and LMM&S b, c, g & h and EG&G 1997.

4.1.2 Environmental Consequences and Impacts

4.1.2.1 Radiological Consequences and Risk Methodology

The Cassini nuclear launch safety risk analysis performed for each of the accident cases identified for the RTGs and RHU's is fundamentally similar to that performed for the Galileo and Ulysses missions and for the 1995 Cassini EIS. The updated analysis, however, extends the techniques developed in the earlier analyses and applies probabilistic techniques to each of the source term probability distributions. Calculations include (1) collective radiation dose (50-year), (2) latent cancer fatalities (health effects) over a 50-year period induced by exposure to released PuO_2, (3) maximum individual dose and average individual risk, (4) land area contaminated above the EPA guideline level for considering the need for further evaluation, and (5) radiological risk.

For further information on radiological consequences and risk methodology see LMM&S d-h and EG&G 1997. It should be noted that although the Cassini spacecraft will carry 129 RHUs, the updated analyses presented in this SEIS are based on an inventory of 157 RHUs.

4.1.2.2 Radiological Consequences and Risks

The summary of radiological consequences and mission risks is presented in Table 4-2. The mean, 5-, 50-, 95- and 99-percentiles values of health effects are presented.

It should be noted that the radiological consequences and risks are reported in Table 4-2 for the GPHS-RTGs, the LWRHU's, and as "Combined." The results reported for the GPHS-RTGs can be found in the Safety Analysis Report for the RTGs (LMM&S a-j). Those reported for the LWRHUs can be found in the Safety Analysis Report for the RHUs (EG&G 1997). The "Combined" consequences and risks reported in Table 4-2 are probability-weighted to account for the results of both the above referenced safety analyses. See Appendix D, page D-2 for a sample calculation.

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Table 4-2 Summary of Radiological Consequences and Missions Risks

Mission Segment	Source	Total Probability[a]	Maximum Individual Dose[b], rem	Land Area Contaminated[c], km^2 (mean)	Health Effects Over 50 Years [d] (w/o *de minimis*)					Mission Risks[e] (mean)
					5%	50%	Mean	95%	99%	
Pre-Launch	GPHS-RTG	$5.2x10^{-5}$	$1.3x10^{-2}$	$1.5x10^{0}$	$3.3x10^{-3}$	$2.8x10^{-3}$	$6.6x10^{-2}$	$5.7x10^{-2}$	$1.8x10^{-1}$	$3.4x10^{-6}$
	LWRHU	$1.1x10^{-5}$	$2.5x10^{-3}$	g	$1.6x10^{-2}$	$1.7x10^{-2}$	$1.9x10^{-1}$	$2.2x10^{-1}$	$4.1x10^{0}$	$2.1x10^{-6}$
	Combined[f]	$5.2x10^{-5}$	$1.4x10^{-2}$	$1.5x10^{0}$	$3.4x10^{-3}$	$6.4x10^{-3}$	$1.1x10^{-1}$	$1.0x10^{-1}$	$1.0x10^{0}$	$5.5x10^{-6}$
Early Launch	GPHS-RTG	$6.7x10^{-4}$	$2.1x10^{-2}$	$1.6x10^{0}$	$4.2x10^{-5}$	$6.3x10^{-3}$	$7.1x10^{-2}$	$1.7x10^{-1}$	$1.2x10^{0}$	$4.7x10^{-5}$
	LWRHU	$1.8x10^{-4}$	$5.6x10^{-4}$	g	$8.1x10^{-4}$	$5.8x10^{-3}$	$4.2x10^{-2}$	$4.4x10^{-2}$	$1.3x10^{0}$	$7.6x10^{-6}$
	Combined[f]	$6.7x10^{-4}$	$2.1x10^{-2}$	$1.6x10^{0}$	$2.6x10^{-4}$	$7.8x10^{-3}$	$8.2x10^{-2}$	$1.8x10^{-1}$	$1.5x10^{0}$	$5.5x10^{-5}$
Late Launch	GPHS-RTG	$2.1x10^{-3}$	$1.1x10^{0}$	$5.7x10^{-2}$	$3.1x10^{-4}$	$8.2x10^{-3}$	$4.4x10^{-2}$	$2.3x10^{-1}$	$5.5x10^{-1}$	$9.2x10^{-5}$
	LWRHU	$3.9x10^{-9}$	$7.7x10^{-6}$	g	h	h	$2.4x10^{-6}$	h	h	$8.9x10^{-15}$
	Combined[f]	$2.1x10^{-3}$	$1.1x10^{0}$	$5.7x10^{-2}$	$3.1x10^{-4}$	$8.2x10^{-3}$	$4.4x10^{-2}$	$2.3x10^{-1}$	$5.5x10^{-1}$	$9.2x10^{-5}$
VVEJGA	GPHS-RTG	$6.3x10^{-7}$	$6.5x10^{2}$	$1.9x10^{1}$	$4.0x10^{0}$	$1.1x10^{2}$	$1.4x10^{2}$	$3.6x10^{2}$	$4.8x10^{2}$	$8.8x10^{-5}$
	LWRHU	$8.0x10^{-7}$	$2.1x10^{-2}$	$1.7x10^{-1}$	$4.3x10^{0}$	$7.4x10^{0}$	$1.3x10^{1}$	$3.9x10^{1}$	$7.0x10^{1}$	$1.0x10^{-5}$
	Combined[f]	$8.0x10^{-7}$	$5.1x10^{2}$	$1.5x10^{1}$	$7.4x10^{0}$	$9.4x10^{1}$	$1.2x10^{2}$	$3.2x10^{2}$	$4.5x10^{2}$	$9.8x10^{-5}$
Overall Mission	GPHS-RTG	$2.8x10^{-3}$	$9.7x10^{-1}$	$4.5x10^{-1}$	$1.1x10^{-3}$	$3.2x10^{-2}$	$8.2x10^{-2}$	$2.9x10^{-1}$	$8.0x10^{-1}$	$2.3x10^{-4}$
	LWRHU	$1.9x10^{-4}$	$7.6x10^{-4}$	$7.1x10^{-4}$	$2.0x10^{-2}$	$3.7x10^{-2}$	$1.0x10^{-1}$	$2.2x10^{-1}$	$1.7x10^{0}$	$2.0x10^{-5}$
	Combined[f]	$2.8x10^{-3}$	$9.7x10^{-1}$	$4.5x10^{-1}$	$2.5x10^{-3}$	$3.5x10^{-2}$	$8.9x10^{-2}$	$3.0x10^{-1}$	$9.2x10^{-1}$	$2.5x10^{-4}$

a. Product of initating accident and conditional PuO_2 release probabilities.
b. Maximally exposed individual dose, mean estimate.
c. Land area potentially contaminated above $7.4x10^3$ Bq/m^2 (0.2 µCi/m^2).
d. Health effects are incremental latent cancer fatalities.
e. Risk calculated as the total probability times health effects.
f. The combined impacts of the GPHS-RTG and LWRHU analyses are probability weighted.
g. Estimated impacts are extremely small.
h. No statistics generated due to low probability of release and small source terms.

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For 5-, 50-, 95-, and 99- percentile values of maximum individual dose, land area contaminated, and collective 50-year radiation dose, refer to Appendix D. The dose and health effects consequences presented assume no implementation of accident contingency plans or any other mitigation actions by governmental authorities. A value less than or equal to the 5-percentile level of consequences would be expected to occur 5 percent of the time (i.e., 1 in 20). Similarly, a value greater than or equal to the 95-percentile consequence level would be expected to occur 5 percent of the time.

The combined total probability that a pre-launch mission segment accident would result in a PuO_2 release is 5.2×10^{-5}, or 1 in 19,200. The mean 50-year health effect consequence is 1.1×10^{-1} or 0.11 health effects. The mean area of land contaminated above the EPA guideline level predicted for this mission segment is 1.5×10^{0} or 1.5 km^2 (0.58 mi^2). The mean maximum individual dose associated with the pre-launch mission segment is 1.4×10^{-2} or 0.014 rem over 50 years--a dose that represents about 0.093% of the average individual's 50-year exposure to natural background radiation. The risk contribution attributed to the pre-launch mission segment is 2.2% of the overall mean mission risk. At the 95-percentile level, the predicted health effects and land contamination for this segment is equal to or less than 1.0×10^{-1} or 0.10 health effects and (from Section 4.1.2.5 of this SEIS), 5.5 km^2 (2.1 mi^2). At the 99-percentile level, the predicted health effects and land contamination for this segment will be equal to or less than 1.0×10^{0} or 1.0 health effects and (from Section 4.1.2.5 of this SEIS), 8.6 km^2 (3.3 mi^2).

The combined total probability that an early launch mission segment accident would result in a PuO_2 release is 6.7×10^{-4}, or 1 in 1,490. The mean health effect consequence is 8.2×10^{-2} or 0.082. The mean area of land contaminated above the EPA guideline level predicted for this mission segment is 1.6×10^{0} or 1.6 km^2 (0.62 mi^2). The mean maximum individual dose associated with the early launch mission segment is 2.1×10^{-2} or 0.021 rem over 50 years--a dose that represents about 0.14% of the average individual's 50-year exposure to natural background radiation. The risk contribution attributed to the early launch mission segment is 22% of the overall mean mission risk. At the 95-percentile level, the predicted health effects and land contamination for this segment will be equal to or less than 1.8×10^{-1} or 0.18 health effects and (from Section 4.1.2.5 of this SEIS), 6.1 km^2 (2.4 mi^2). At the 99-percentile level, the predicted health effects and land contamination for this segment will be equal to or less than 1.5×10^{0} or 1.5 health effects and (from Section 4.1.2.5 of this SEIS), 20 km^2 (7.7 mi^2).

The combined total probability that a late launch mission segment accident would result in a PuO_2 release is 2.1×10^{-3}, or 1 in 476. The mean health effect consequence is 4.4×10^{-2} or 0.044. The mean maximum individual dose associated with the late launch mission segment is 1.1×10^{0} or 1.1 rem over 50 years--a dose that represents 7.3% of the average individual's 50-year exposure to natural background radiation. The risk contribution attributed to the late launch mission segment is 37% of the overall mean mission risk. The area of land contaminated above the EPA guideline level predicted for this mission segment is 5.7×10^{-2} or 0.057 km^2 (0.022 mi^2). At the 95-percentile level, the predicted

health effects and land contamination for this segment will be equal to or less than $2.3x10^{-1}$ or 0.23 health effects and (from Section 4.1.2.5 of this SEIS), 0.24 km^2 (0.093 mi^2). At the 99-percentile level, the predicted health effects and land contamination for this segment will be equal to or less than $5.5x10^{-1}$ or 0.55 health effects and (from Section 4.1.2.5 of this SEIS), 0.34 km^2 (0.13 mi^2).

The combined total probability that an EGA mission segment accident would result in a PuO_2 release is $8.0x10^{-7}$, or less than 1 in 1 million. The mean health effect consequence is $1.2x10^2$ or 120. The mean area of land contaminated above the EPA guideline level predicted for this mission segment is $1.5x10^1$ or 15 km^2 (5.8 mi^2). The mean maximum individual dose associated with the EGA mission segment is $5.1x10^2$ or 510 rem over 50 years, about 34 times the average individual's 50 year exposure to natural radiation. This mean maximum individual dose is accounted for in the 120 estimated health effects noted above. It should be noted that this estimate is at a probability of less than 1 in 1 million. At the 95-percentile level, the predicted health effects and land contamination for this segment will be equal to or less than $3.2x10^2$ or 320 health effects and (from LMM&S), 37 km^2 (14 mi^2). At the 99-percentile level, the predicted health effects and land contamination for this segment will be equal to or less than $4.5x10^2$ or 450 health effects and (from LMM&S), 55 km^2 (21 mi^2). The risk contribution attributed to the EGA mission segment is 39% of the overall mean mission risk.

In the unlikely event that the spacecraft becomes non-commandable anytime after injection into its interplanetary trajectory, and control could not be reestablished, the spacecraft's orbit around the Sun could eventually cross that of the Earth, and the spacecraft could impact the Earth a decade to millenia later. The combined total probability of such an impact is $2x10^{-7}$, or 1 in 5 million, and the amount of PuO_2 released could be similar to that released in a short-term EGA accident. However, there are uncertainties related to the amount of PuO_2 released. The uncertainties include the timing of the reentry which has a bearing on the composition of the PuO_2, given the 87.75-year half-life of Pu - 238. The radiological consequences of a long-term reentry are therefore assumed to be similar (same order of magnitude) to those estimated for the short-term EGA.

Overall, the consequences predicted for the Cassini mission are low when compared with other risks. Using a typical natural (background) radiation dose of 0.3 rem/yr and a health effects estimator of $5x10^{-4}$ latent cancer fatalities/rem, the risk to an individual of developing fatal cancer from a 50-year exposure to background radiation is estimated at $7.5x10^{-3}$, or 1 in 133. This estimated lifetime risk from background radiation is over five orders of magnitude (i.e., 100,000 times) higher than the Cassini mission segment with the highest average individual risk (late launch; see Appendix D, Table D-8), estimated at $1.8x10^{-8}$ or less, or a probability of less than 1 in 55 million of any given individual in the potentially exposed population incurring a fatal cancer due to exposure from an accidental PuO_2 release.

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4.1.2.3 Uncertainty Analysis

In addition to the best estimate analysis, a study of the underlying test data and model input parameters used to estimate accident consequences and risks has been conducted (LMM&S f, h). Because of uncertainty, the mean consequence of the overall mission or a given mission segment has a distribution of possible values where the best estimate for this analysis lies near the median of that distribution. Table 4-3 summarizes the risks for various mission segments and the total mission from accidental PuO_2 release. The 95 percent confidence level risk is two orders of magnitude higher than the best estimate, and the 5 percent confidence level is about two orders of magnitude lower than the best estimate.

Table 4-3 Summary of Uncertainty Analyses: GPHS-RTG Mission Risks

Mission Segment	Mean Risk	5% Confidence Level	50% Confidence Level	95% Confidence Level
Pre-Launch	3.4×10^{-6}	7.6×10^{-8}	6.0×10^{-6}	4.2×10^{-4}
Early Launch	4.7×10^{-5}	5.1×10^{-6}	6.2×10^{-5}	7.9×10^{-4}
Late Launch	9.2×10^{-5}	4.1×10^{-7}	7.3×10^{-5}	1.3×10^{-2}
EGA Reentry (Short Term)	8.8×10^{-5}	1.2×10^{-6}	7.5×10^{-5}	4.6×10^{-3}
Total Mission	2.3×10^{-4}	8.3×10^{-6}	2.2×10^{-4}	1.9×10^{-2}

4.1.2.4 Emergency Response Planning

In accordance with the Federal Radiological Emergency Response Plan (FRERP), prior to the launch of the Cassini spacecraft with RTGs and RHUs onboard, comprehensive radiological contingency plans will be in place. These contingency plans, similar to the ones developed for the Galileo and Ulysses missions, would ensure that any accident, whether it involves a radiological release or not, will be met with a well-developed and tested response. The plans will reflect the combined efforts of Federal agencies, including NASA, DOE, DOD, EPA and the Federal Emergency Management Agency, and the State of Florida and local organizations involved in emergency response. (For additional details, see response to comment no. 8-1 in Appendix E.)

4.1.2.5 Potential Clean Up Costs Associated with Land Contamination

While the need for mitigation, and the cost involved, would be based upon actual conditions, and the amount of land area contaminated by an accident, the 1995 Cassini EIS developed an estimated range of cleanup costs for a postulated early launch accident

near the launch site. Potential costs were estimated by taking the land area potentially contaminated at greater than the EPA guideline level ($7.4x10^3$ Bq/m^2; 0.2 μCi/m^2), and multiplying by a range of costs (escalated to 1994 dollars) developed by the EPA for mitigation both with ($50 million/km^2) and without ($5 million/km^2) removal and disposal of contaminated soil at a near-surface facility. Using the land area potentially contaminated by a near-launch site accident (1.5 km^2 [0.58 mi^2]), the EIS estimated the potential costs to range from about $7.5 million (without removal and disposal), to about $75 million (with removal and disposal). Table 4-4 of this SEIS uses the same methodology and unit costs as the 1995 Cassini EIS in developing cost estimates for the mean, 95- and 99-percentile land area contamination estimates provided by the updated analyses.

Table 4-4 Summary of Potential Cleanup Costs Associated with Land Contamination

Mission Segment	Consequence Level [a]	Land Area Contaminated [b] (km^2)	Cleanup Cost without Removal and Disposal [c] ($ millions)	Cleanup Cost with Removal and Disposal [c] ($ millions)
Pre-launch	mean	1.5	7.5	75
	95%	5.5	27.5	275
	99%	8.6	43	430
Early Launch	mean	1.6	8.0	80
	95%	6.1	30.5	305
	99%	20	100	1000

a. Estimated land areas are presented for the mean and 95- and 99-percentile levels of the consequence distribution functions.

b. Land area estimated contaminated above $7.4x10^3$ Bq/m^2 (0.2 μCi/m^2).

c. Assumes $5 million dollars/km^2 for cleanup without removal and disposal of contaminated materials; and $50 million dollars/km^2 for cleanup with removal and disposal of contaminated materials

4.1.3 Radiological Impacts of the Secondary and Backup Launch Opportunities

Impacts of pre-launch, early-launch, and late-launch accidents associated with the secondary and backup launch opportunities for the proposed action are expected to be approximately the same as for the primary Titan IV/SRMU launch opportunity presented in Table 4-2. The analysis was prepared for the secondary launch opportunity, and is applicable to the backup opportunity.

Updated analyses of the potential impacts of a short-term reentry accident associated with each Earth swingby of the VEEGA trajectory are reported in HNUS 1997. Those analyses were performed using the same techniques and models used for the primary launch opportunity. Like the reentry accident with the VVEJGA trajectory, the updated analyses for the VEEGA reentries indicate that more of the RTG components are likely to survive the reentry conditions, resulting in less vaporization of the PuO_2 in the upper atmosphere and lower world-wide impacts. As with the VVEJGA reentry, the updated analyses indicate that high-altitude vaporization of a large fraction of the PuO_2 is less likely than

indicated in the EIS. This results in lower estimates of mean source terms and mean radiological impacts than reported earlier in the 1995 Cassini EIS.

The accident risks and impacts of a short-term inadvertent reentry for both the secondary and backup launch opportunities using VEEGA trajectories are predicted to be similar. The updated analyses indicate that the total probability of a PuO_2 release from the RTGs and RHUs with the two Earth swingby portions of the VEEGA trajectory is 3.4×10^{-7} (1 in 2.9 million). The updated analyses also indicate that the mean impacts from an inadvertent reentry could be 227 health effects with 21 km^2 (8.1 mi^2) of land contaminated above the EPA guideline level. As with the VVEJGA accident impact estimates, larger impacts would be predicted at lower probabilities. The estimated health effects risk for the Earth swingby portions of the secondary and backup mission is 7.6×10^{-5}.

The probability of a long-term inadvertent reentry from the interplanetary cruise portion of the VEEGA trajectory prior to the final gravity assist is 5.9×10^{-7}. No additional analyses are available of the estimated impacts of such an accident. The reader is referred to Section 4.1.6.2 of the 1995 Cassini EIS for discussion of the potential impacts of an inadvertent long-term reentry accident.

4.2 RADIOLOGICAL IMPACT ASSESSMENT OF THE 2001 MISSION ALTERNATIVE

The 2001 Mission Alternative would be similar to the Proposed Action in that it would include the Cassini spacecraft with the Huygens Probe and the Titan IV (SRMU)/Centaur launch vehicle, as described in Sections 2.1.3 through 2.1.5 of this SEIS. The primary opportunity of this mission alternative, however, would insert the Cassini spacecraft into a non-EGA trajectory. The launch would have a similar mission timeline as described in Section 2.1.7 of this SEIS. This mission alternative would have a primary launch opportunity during the first 2.5 weeks of March 2001 from CCAS, and would use a 10.3-year VVVGA trajectory, as depicted in Figure 2-5. The first Venus swingby would occur in August 2001, the second in September 2002, and the third in November 2005, with Cassini arriving at Saturn in June 2011 for the four-year tour of the Saturnian system (JPL 1994). A backup opportunity in May 2002 would use a VEEGA. This alternative was discussed in detail in Section 2.4 of the 1995 Cassini EIS.

Radiological impacts of pre-launch, early-launch, and late-launch accidents associated with either the primary VVVGA or backup VEEGA launch opportunities are expected to be approximately the same as for the primary Titan IV/SRMU launch opportunity presented in Table 4-2.

With the primary VVVGA trajectory, there would be no opportunity for a short-term inadvertent reentry but a long-term inadvertent reentry risk would remain. However, with the backup VEEGA trajectory, both short- and long-term inadvertent risks would be

present and be approximately the same as indicated for the secondary and backup (VEEGA) primary launch opportunities presented in Section 4.1.4 of this SEIS.

Prior to launch of either the primary or backup opportunity, comprehensive radiological emergency plans would be in place and implemented as discussed for the Proposed Action in Section 4.1.2.4 of this SEIS.

4.3 THE NO-ACTION ALTERNATIVE

There would be no adverse environmental impacts associated with the No-Action alternative; however, there would be major adverse programmatic and potentially adverse international relations impacts from a cancellation of the Cassini mission. In addition, cancellation of the mission would result in the loss of existing United States engineering and scientific expertise and capabilities. For further discussion of the impacts of the No-Action alternative, see Section 4.4 of the 1995 Cassini EIS.

4.4 ADVERSE ENVIRONMENTAL IMPACTS THAT CANNOT BE AVOIDED

The unavoidable adverse environmental impacts associated with both the Proposed Action and the remaining 2001 Mission alternative are related primarily to the effects of solid rocket motor emission during the first few seconds of the launch. These impacts remain unchanged by the ongoing mission safety analyses. For details, refer to Section 4.5 of the 1995 Cassini EIS.

4.5 INCOMPLETE OR UNAVAILABLE INFORMATION

The recently available analyses referenced in this SEIS constitute the full analytical documentation relied upon in this NEPA process. Risk estimates may subsequently become available and could potentially vary from the risk estimates reported in this SEIS. Such subsequent information may occur as a result of statistical variance from the ongoing separate and independent nuclear launch safety analysis and evaluation for Presidential decision-making.

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 a millennia) in a space environment are highly uncertain. Therefore, the response of the GPHS modules and GISs in the long-term inadvertent reentry were therefore assumed to be similar (same order of magnitude) to those estimated for the short-term VVEJGA inadvertent reentry.

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

Neither the short-term uses of the environment nor the enhancements to long-term productivity addressed in the 1995 Cassini EIS are affected by the updated mission safety analyses. Should an accident occur causing a release, short-term uses of contaminated land could be curtailed, pending mitigation. Refer to Section 4.7 of the 1995 Cassini EIS for additional details.

4.7 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

For both the Proposed Action and the 2001 Mission alternative, quantities of various non-renewable resources, such as energy and fuels, iridium metal, plutonium and other materials, would be irreversibly and irretrievably committed. These remain unchanged by the updated mission safety analyses. Additional details can be found in Section 4.8 of the 1995 Cassini EIS.

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5.0 CONTRIBUTORS TO THE SEIS

This Supplemental Environmental Impact Statement (SEIS) was prepared by the Office of Space Science, National Aeronautics and Space Administration (NASA). The U.S. Department of Energy (DOE) has participated as a cooperating agency in the preparation of this SEIS due to its special expertise (see 40CFR1501.6). The organizations and individuals listed below contributed to the overall effort in the preparation of this document.

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6.0 AGENCIES AND INDIVIDUALS CONSULTED

This Final Supplemental Environmental Impact Statement (FSEIS) was preceded by a Draft SEIS (DSEIS) and supporting documentation (HNUS 1997), which were made available on April 9, 1997, to Federal, State and local agencies, organizations and to the public for review and comment. The public review and comment period closed on May 27, 1997. Comments received were considered during the preparation of this FSEIS (see Appendix E).

In preparing this SEIS, NASA has actively solicited input from a broad range of interested parties. In addition to the publication in the Federal Register (F.R.) of a Notice of Intent (NOI) (62 F.R. 10879) and a Notice of Availability (62 F.R. 17216) for the DSEIS, NASA distributed copies of the DSEIS and the supporting documentation (HNUS 1997), directly to agencies, organizations, and individuals who may have an interest in the environmental impacts and alternatives associated with the Cassini mission.

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

Federal Agencies

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

State Agencies

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

State of New Mexico - Office of the Governor
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APPENDIX A, CASSINI RECORD OF DECISION

RECORD OF DECISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Cassini Mission
Environmental Impact Statement (EIS)

A. The Cassini Mission

The Cassini mission is an international cooperative effort undertaken by NASA, the European Space Agency (ESA), and the Italian Space Agency (ASI) to explore the planet Saturn and its environment. Cassini is part of NASA's continuing program for exploration of the solar system, the goal of which is to understand its birth and evolution. The Cassini mission is planned to be launched from Cape Canaveral Air Station (CCAS) and will involve a 4-year tour of Saturn, its atmosphere, moons, rings, and magnetosphere by the Cassini spacecraft, which consists of the Orbiter and the detachable Huygens Probe. The Huygens Probe will be released from the Cassini Orbiter to descend by parachute through the atmosphere of Saturn's largest moon, Titan. During the descent, instruments on the Probe will directly sample the atmosphere and determine its composition. The Probe will also gather data on Titan's landscape. Upon completion of the Probe mission, the Orbiter will continue to make remote and in-situ measurements of Saturn and its environment. This information could provide significant insights into the formation of the solar system and the conditions that led to life on Earth.

NASA will provide the Orbiter, the Earth-based communications and operations network, and two scientific instruments on the Huygens Probe. ESA will provide the Huygens Probe, and ASI will provide major elements of the Orbiter's communications equipment and elements of several science instruments.

The scientific and technological benefits expected from the Cassini mission are demonstrated by the long record of support not only by our Nation's scientific community, the Congress, and Executive Branch agencies, but also by the international science community and many European nations.

B. Introduction to the EIS

This EIS was developed to address all major elements of the Cassini mission. Formal scoping began in February 1991 and continued into April 1991. This scoping period was for the Outer Solar System Exploration Program, which included both the Comet Rendezvous Asteroid Flyby (CRAF) and Cassini missions. Thirty-three scoping comment letters were received. They dealt with: alternative power sources; risks and impacts from plutonium-238 (PU-238) in the Radioisotope Thermoelectric Generators (RTGs) ; accident probabilities and risk factors; mission alternatives; and NASA policy. In January 1992 the CRAF mission was canceled and by May 1992 Cassini was

restructured; an information update to this effect was published in October 1992. The scoping comments were then used in developing a cassini-specific Draft EIS (DEIS).

The DEIS was made available to the public in October 1994. Fifty-one comment letters were received. These comments dealt with a range of issues, including: the use of plutonium in space; the status of solar technology for deep space missions; the properties of plutonium; the radiological consequence and risk analyses; effects on ground water near the launch site; and cumulative environmental impacts on stratospheric ozone.

The Final EIS was made available on July 21, 1995, and the waiting period expired on August 21, 1995. Ten comment letters were received. These letters raised no new issues, nor did they provide new information; six of the commentors reiterated issues they raised earlier for the DEIS.

Alternatives Considered

The alternatives addressed in the EIS were:

1. Completion of preparation for and implementation of the Cassini mission to Saturn, including its launch onboard a Titan IV (with either the Solid Rocket Motor Upgrade [SRMU] or the Solid Rocket Motor [SRM][1], and a Centaur upper stage) during the primary launch opportunity in October 1997, using a Venus-Venus-Earth-Jupiter Gravity Assist (VVEJGA) trajectory; a secondary opportunity in December 1997, using a Venus-Earth-Earth Gravity Assist (VEEGA) trajectory; or a backup opportunity in March 1999, using a VEEGA trajectory. The primary opportunity will enable gathering the full science return (i.e., data) desired to accomplish the mission science objectives. Achievement of the science objectives for the secondary and backup opportunities would essentially be the same as for the primary, but with reduced science return.

2. Completion of preparation for and implementation of the Cassini mission to Saturn involving dual Space Shuttle launches in early 1999, with on-orbit assembly of the spacecraft with its upper stage(s), followed by injection in March 1999 on a VEEGA trajectory. A backup opportunity, also a VEEGA, occurs in August 2000. This alternative, including both the primary and backup opportunities, would
obtain less science return than the Titan IV (SRMU)/Centaur 1997 primary opportunity.

3. Completion of preparation for and implementation of the Cassini mission to Saturn onboard a Titan IV (SRMU)/Centaur using a Venus-Venus-Venus Gravity Assist (VVVGA) trajectory in March 2001 or a VEEGA backup opportunity in May 2002. This alternative would require both increasing the propellant capacity of the Cassini spacecraft and completing development of a new, high-performance rocket engine. This alternative, including both the

[1] At the time of this Record of Decision, the SRM has become unavailable as an option.

primary and backup opportunities, would obtain less science return than the Titan IV (SRMU)/Centaur 1997 primary opportunity.

4. Adoption of the no-action alternative, resulting in termination of preparations for implementing the Cassini mission. This alternative would impede our Nation's Solar System Exploration Program, deprive the world of invaluable scientific discoveries, and disrupt internationally cooperative space activities for the benefit of all humankind.

Mission Components Evaluated

In addition to the basic engineering design of the spacecraft, the other key components associated with the Cassini mission are the launch vehicle, the interplanetary trajectory, and the power system for the spacecraft's electrical requirements. These must function together to satisfy the requirements of the mission.

Key components were evaluated in the EIS in terms of technical feasibility, ability to satisfy the science objectives of the mission, and potential for reducing the postulated environmental impacts associated with the October 1997 baseline mission design. To be considered technically feasible, a component must have been tested for space-flight applications or must be in the development stages on a timetable consistent with satisfying Cassini's science objectives. The requirement for components to satisfy the science objectives is essential because the mission must provide useful information in a timely manner.

The evaluation of mission components led to the following determinations: (1) the Titan IV (SRMU)/Centaur is the most capable U.S. launch system available and most closely matches this requirements of the Cassini mission; (2) the Cassini mission to Saturn requires planetary gravity-assist trajectories; and (3) the spacecraft requires the use of three mainly plutonium-238 dioxide-fueled ($^{238}PuO_2$) RTGs and up to 157 Radioisotope Heater Units (RHUs) to satisfy the mission electrical and thermal requirements. The total $^{238}PuO_2$ inventory will be around 400,000 curies at time of launch. NASA's Jet Propulsion Laboratory conducted an in-depth analysis of the available electrical power systems, including many different solar, battery, and long-life fuel cell power sources and hybrid systems to identify the most appropriate power source for the Cassini mission. None of-these were found to be technically feasible for Cassini. For example, a Cassini spacecraft equipped with the highest efficiency solar cells available would make the spacecraft too massive for launching to Saturn. The spectrum of available launch vehicles was also analyzed, and it was determined that there is no available launch vehicle which could avoid planetary gravity assist trajectories.

Environmental Consequences of the Alternatives

In considering the consequences of the alternatives, it was recognized that ordinarily the only direct or immediate environmental impacts would be associated with the normal launch of Cassini. The environmental impacts of normal Titan IV or Space Shuttle launches have been addressed in other National Environmental Policy Act (NEPA) documentation (e.g., the Titan IV Environmental Assessments [EAs]; Space

Shuttle, Kennedy Space Center, Galileo [Tier-2] and Ulysses [Tier-2] EISs), and have been updated in the Cassini EIS. These impacts have been deemed insufficient to preclude either Titan IV or Space Shuttle operations.

Consideration of launch and inadvertent reentry accidents involving radiological consequences was a principal focus of the Cassini EIS. The U.S. Department of Energy (DOE), a cooperating agency, provides the RTGs and RHUs. For the Cassini mission, DOE has prepared a preliminary risk analysis for accidents which are postulated as causing a release of plutonium dioxide fuel from the RTGs or RHUs. The EIS incorporates the results of DOE's preliminary risk analysis.

The analysis proceeded as follows:

a) NASA defined the launch vehicle representative (postulated) accident scenarios[2], and the environments (e.g. propellant fires and explosions, high speed fragments, reentry conditions, etc.) to which the RTGs and RHUs might be exposed in the event of an accident. NASA also provided the probabilities of occurrence of the accident scenarios.

b) Based on the similarity of the representative accident scenario environments to those arising from the accident scenarios analyzed for the 1990 Ulysses Final Safety Analysis Report (FSAR) supplemented with additional analyses, DOE estimated the response of the RTGs and RHUs to those environments. In this manner, DOE was able to determine if a given representative scenario could lead to a release of plutonium dioxide fuel and the potential amount of a release (i.e., a "source term").

C) For those cases where a release could possibly occur, DOE then estimated the dispersion, deposition, and health and environmental consequences along with the probability of occurrence given that the postulated release occurred.

The radiological consequence results are reported in the EIS in terms of "expectation" and "maximum" cases. The expectation case for a given representative accident scenario represents a probability-weighted average over conditions associated with the accident scenario under consideration, and uses the average source terms developed in the analysis. The maximum case for a given representative accident scenario represents a nominal upper limit without consideration of uncertainties[3] , based on the use of the maximum source terms. The maximum case corresponds to either the upper limit deemed credible for a given representative scenario based on consideration

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[2] The Cassini EIS deals with a set of four credible launch phase accident scenarios (i.e., Command Shutdown and Destruct, Titan IV (SRMU) Fail-to-Ignite, Centaur Tank Failure/Collapse, and Inadvertent Reentry from Earth Orbit) that are deemed representative of those which could potentially result in a release of plutonium dioxide from the RTGs or RHUs. The planned Cassini Final Safety Analysis Report (FSAR) for the nuclear launch safety analysis and evaluation processes will provide more detailed evaluations of the full set of accidents and environments that could occur during the Cassini mission.

[3] Due to the preliminary nature of the analyses presented in the EIS, no uncertainty analysis was performed and uncertainties are addressed in only general terms. Uncertainty analysis will be performed as part of the ongoing studies in support of the Cassini FSAR.

of currently available supporting analyses, or that corresponding to a total release probability greater than or equal to a probability cutoff of 10^{-7}.

C. Assessment of the Analysis

Through over three decades of research, development, test, and evaluation, DOE has reduced the hazards associated with the use of the RTG space power system by the design of the RTG. Materials have been chosen (e.g., plutonium dioxide in ceramic form) and designs selected which, in the event of an accident, contain or immobilize the fuel to the maximum extent practical.

The results of the analysis show that in most launch phase accidents[4] there would be no release of nuclear material. In the event of a release, the analysis indicates that for neither the expectation case nor the maximum case would there be any health effects (i.e., excess latent cancer fatalities).

During the interplanetary portion of the mission, postulated inadvertent reentry accident scenarios could result in release of plutonium dioxide. However, the mission's design ensures that the expected probability of such reentry is less than one in one million. If such an accident were to occur, the expectation case predicts that there could be approximately 2300 health effects worldwide over a 50-year period. The EIS presents a mission risk summary (Table 4-18, page 4-78 of the EIS) in which the risks of health effects are divided by the potentially affected populations to estimate the average risk per individual. In this regard, there would be a chance of about one in three trillion for the average potentially exposed individual, in the global population, incurring a fatal cancer as a result of a fuel release from an inadvertent reentry during Earth swingby.

Finally, the risks are compared with tabulated, published risk data. The risks associated with the Cassini mission are thereby seen to be several orders of magnitude less than risks encountered and accepted elsewhere in our daily lives.

Choice of Alternatives

In view of the small risks associated with the Cassini mission, it is my intention to choose the proposed action, Alternative 1 (above, page 2), based on programmatic grounds as follows.

Alternative 1, completion of preparations for and implementation of the Cassini mission, including its launch on a Titan IV (SRMU or SRM)/Centaur in October 1997, the secondary opportunity in December 1997, or the backup opportunity in March 1999, would enable the earliest and best return of scientific information, make most effective use of fiscal, human and material resources, and avoid disruption of the Nation's program for solar system exploration.

[4] See footnote 2 on p. 4

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It is important that the Cassini mission is accomplished while the Voyager exploration results are recent and much of the associated scientific expertise is still available. There would be more than 23 years between the Voyager flybys of Saturn and the 2004 arrival of Cassini (for the primary launch opportunity). The exploration of the Saturn system by Cassini is essential to answering some fundamental questions about the origins of life and of our solar system. The international scientific and technological community anxiously awaits its results.

The no-action alternative, while presenting the minimum environmental risk, would, however, jeopardize our Country's unique Outer Solar System Exploration Program, deprive society of the invaluable scientific knowledge which will result from this mission, and could seriously disrupt and strain the international partnerships the U.S. has formed to undertake space activities for peaceful purposes, such as the Cassini mission. The choice to complete preparations for and to implement the mission is fully consistent with the mandate of the National Aeronautics and Space Act to contribute materially, among other things, to the expansion of human knowledge of phenomena in space.

D. Additional Information

In addition to requirements under the NEPA and NASA policy and procedures, there is a separate and distinct Executive Branch interagency process for evaluating the nuclear launch safety of the mission. Pursuant to paragraph 9 of Presidential Directive/National Security Council Memorandum #25 (PD/NSC-25), a Safety Evaluation Report (SER) will be prepared by an ad hoc Interagency Nuclear Safety Review Panel (INSRP). I will be fully briefed on the outcome of the safety analyses and the Cassini INSRP evaluation prior to the launch of the Cassini mission.

Extensive safety and technical reviews are continuing for the Cassini mission. In the event there are significant differences between the analysis for the EIS and the results of the final safety analyses and evaluations, those differences will be considered and a determination made as to the need for any additional NEPA documentation.

E. Mitigation

The only expected or immediate environmental impacts of the Cassini mission are the same as those for every Titan IV launch, and mitigation will accordingly be the same. This EIS primarily addressed possible radiological consequences of mission accidents. Regarding such possible radiological impacts, NASA, with expert technical assistance from DOE, the Department of Defense, the U.S. Environmental Protection Agency, and other federal agencies, and in cooperation with state and local authorities, will develop a federal radiological emergency response plan. Key elements of monitoring and data analysis equipment will be predeployed to enable rapid response in the event of a launch contingency. The plan, to be documented elsewhere, will address both monitoring and mitigation activities associated with the launch. In particular, post-accident mitigation activities, if required, will be based on detailed monitoring and

assessment at that time. The plan will carefully detail the roles of the agencies involved. NASA will 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.

Decision

Based upon all of the foregoing, I am confident that reasonable means to avoid or minimize environmental harm from the Cassini mission have been adopted; or, if not already adopted, will be adopted, as appropriate, upon conclusion of the safety analyses. Accordingly, it is my decision to complete preparation of the Cassini mission for launch in the October 1997 opportunity, or either the secondary or backup opportunities, and to implement the mission.

Wesley T. Huntress, Jr.
Associate Administrator for
Space Science

10/20/95
Date

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APPENDIX B, GLOSSARY OF TERMS

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accident environment--Resulting conditions from an accident scenario, such as blast overpressure, fragments and fire.

accident scenario--Launch vehicle and/or spacecraft condition resulting from failure model(s) at the component and/or subsystem level(s). Different failure modes can result in the same accident scenario.

astronomical unit (AU)--The distance from the Earth to the Sun. It is equal to 149,599,000 km (92,960,818 mi).

background radiation--Ionizing radiation present in the environment from cosmic rays and natural sources in the Earth; background radiation varies considerably with location.

Becquerel (Bq)--Unit of radioactivity equal to 1 disintegration per second.

Best estimate--The best estimate reflects what is considered to be the most representative mathematical models, parameter values used in the models, and probability distributions to describe inherent variability as inputs to the analysis. As such, the best estimate reflects the anticipated outcome of the radiological consequences and risk without consideration of uncertainty in either the models or parameter values.

cancer--A group of diseases characterized by uncontrolled cellular growth.

clad--Thin-walled metal enclosure that encases the outer shell of nuclear fuel and prevents the release of plutonium dioxide and alpha particles into the environment.

conditional probability--The probability that a release of radioactive material could occur given an initiating accident (i.e., the accident has occurred).

cumulative impacts--Additive environmental, health, safety and significant socioeconomic impacts that result from a number of similar activities in an area.

Curie (Ci)--A measure of the radioactivity level of a substance (i.e., the number of unstable nuclei that are undergoing transformation in the process of radioactivity decay); one curie equals the disintegration of 3.7×10^{10} (37 billion) nuclei per second and is equal to the radioactivity of one gram of radium-226.

decay heat--The heat produced by the energy of decay of radionuclides.

decay, radioactive--The decrease in the amount of any radioactive material with the passage of time due to the transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The decay process results in the emission of nuclear radiation (alpha, beta, or gamma and neutrons) and heat.

decontamination (radioactive)--The reduction or removal of radioactive contaminants from surfaces of equipment by cleaning or washing with chemicals, by wet abrasive blasting, or by chemical processing.

de minimis--This is a concept to indicate a collective dose level at which the risks to human health are considered negligible.

deposition--In atmospheric transport terms, the settling out on ground and building surfaces of atmospheric aerosols and particles (dry deposition) or their removal from the air to the ground by precipitation (wet deposition or rainout).

dose--The amount of energy deposited in the body by ionizing radiation per unit body mass.

dose commitment--The dose that an organ or tissue would receive during a specified period of time (e.g., usually 50 years) as a result of intake (as by ingestion or inhalation), frequently over one year, of one or more radionuclides from a defined release.

dose equivalent--The product of the absorbed dose from ionizing radiation and such factors that account for the difference in biological effectiveness due to the type of radiation and its distribution in the body (measured in Sieverts [rem]). The weighting factor for beta and gamma radiation is 1, and, for alpha radiation, it is approximately 20; thus, 1 Gy (100 rad) gamma radiation is equivalent to 1 Sv (100 rem), and 1 Gy (100 rad) alpha radiation is equivalent to 20 Sv (2,000 rem).

exposure to radiation--The incidence of radiation from either external or internal sources on living or inanimate material by accident or intent:

- Background--exposure to natural background ionizing radiation
- Occupational--exposure to ionizing radiation that takes place during a person's working hours
- Population (or collective)--sum of the exposures to a number of persons who inhabit an area

gravity-assist--Using the planetary gravitational field to increase the velocity or decrease the injection energy of a spacecraft.

half-life (radiological)--The period required for the disintegration of half the atoms in a given amount of a specific radioactive substance. The half-life varies for specific radioisotopes from millionths of a second to billions of years.

health effect (for this EIS)--The impact to human health due to radiation doses. The number of excess latent cancer fatalities over and above the normal occurrence rate that

could occur in the exposed population as a result of radiation from a launch accident or swingby accident.

initiating event (failure)--An event that can begin an accident sequence if followed by systems failures.

initiating probability--The probability that an identified accident scenario and associated adverse conditions (accident environment) will occur.

ionizing radiation--Any radiation capable of displacing electrons from atoms for molecules, thereby producing ions.

isotope--One of perhaps several different species of a given chemical element with the same number of protons, which are distinguishable by variations in the number of neutrons in the atomic nucleus, but indistinguishable by chemical means.

maximum individual dose--The maximum individual dose that an individual could receive over a 50-year commitment period.

offsite--The area outside the property boundary of the CCAS/KSC site.

onsite--The area within the property boundary of the CCAS/KSC site.

onsite population--NASA, DOD and contractor personnel who are on duty at CCAS or KSC and badged onsite visitors.

Orbiter--For purposes of this EIS, a spacecraft, such as Cassini, designed to orbit a planet (i.e., a celestial body) without landing on its surface.

plutonium--A heavy artificially produced radioactive metal (atomic number 94) with 15 isotopes. The Pu-238 isotope forms the basis for the fuel in the RTG. With a decay half-life of 87.7 years, Pu-238 is produced from the neutron bombardment of neptunium-237.

proposed action--For this SEIS, the proposed action consists of completing the preparation for and implementing the Cassini mission, including launching the spacecraft for its four-year science tour of Saturn.

radiation--The emitted particles (alpha, beta, neutrons) or photons (gamma) from the nuclei of unstable (radioactive) atoms as a result of radioactive decay. Some elements are naturally radioactive; others are induced to become radioactive by bombardment in a nuclear reactor or other particle accelerator. The characteristics of naturally occurring radiation are indistinguishable from those of induced radiation.

radioactivity--The spontaneous decay or disintegration of unstable atomic nuclei, usually accompanied by the emission of ionizing radiation.

radioisotope heater unit (RHU)--An RHU is a radioisotope-fueled system consisting of a one-watt pellet of plutonium-238 dioxide, a platinum-30 rhodium (Pt-30Rh) clad, an insulation system of pyrolitic graphite (PG) and an aeroshell/impact body of fine-weave pierced fabric (FWPF). RHUs help to regulate temperatures onboard the spacecraft and the Huygens Probe.

radioisotopes--Unstable isotopes of an element that decay or disintegrate and spontaneously emit particles or electromagnetic radiation.

rem--The unit dose representing the amount of ionizing radiation needed to produce the same biological effects as one roentgen of high-penetration X-rays (about 200 kv).

risk--The accident probability coupled with the associated consequences. Risk is defined quantitatively as the product of the frequency and the consequence. Risk, for the purpose of the Cassini EIS and for this supplement, is defined as the total probability of an accident times the consequence, and summed over all accidents in a given mission phase, segment, or the overall mission.

risk assessment--A process comprising the identification of the hazards, such as patterns and level of exposure, and the evaluation of the risk (i.e., accident frequency and consequences) to affected individuals or populations from a known event.

Sievert (Sv)--The SI unit of dose equivalent. One Sv is equivalent to 100 rem.

solar energy--Energy from the Sun or heat from the Sun converted into an energy source.

source term--The quantities of materials released during an accident to air or water pathways and the characteristics of the releases (e.g., particle size distribution, release height and duration); used for determining accident consequences.

swingby--Part of the trajectory when, during an interplanetary mission, a space vehicle passes by a planet to use the planetary gravitation to change course and to obtain additional velocity/momentum.

trajectory--The flight path that a spacecraft will take during a mission.

upper stage--The portion of the launch system that injects the spacecraft (payload) from a parking orbit into the desired orbit or interplanetary trajectory.

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APPENDIX C, ESA TECHNICAL EVALUATION OF JPL CASSINI SOLAR CONCEPT (Hassan 1996)

esa

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OUR REF.:	PY/1.0/IIII/6339/sp		
SUBJECT:	LILT Solar Cells		

Attached please find a memo from the Head of Power Conversion Division (XP) on the above subject .

I thrust that this closes the related action item satisfactorily.

Best regards,

H. Hassan

European Space Agency
Agence spatiale europeene

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esa

memorandum

Ref: XP- **1612-dos** **Date:** 31st August 1996 Reg. 40

Your Ref.:

To: H. Hassan (PY)

From: D. M. O'Sullivan (XP)

CC: K. Bogus (XPG), C. Signorini (XPG), J. Haines (XPM

Subject: Assessment of the JPL system study related to the possible use of photovoltaic arrays for the CASSINI mission

Following evaluations of recently provided JPL documentation in the ESTEC Power and Energy Conversion Division, please find attached two relevant assessments.

It is evident from the attached assessments that although ESA is currently proposing to use photovoltaic solar arrays supporting Low Intensity, Low Illumination (LILI) solar cells for the ROSETTA cometary encounter (3.25 AU) spacecraft, such an approach for the more power demanding, much deeper space (9.3 AU) and poorly known Saturn radiation environment of the CASSINI mission, is impractical in respect of its launcher capability and the scientific requirement for a rapid body orientation ability.

As a result we concur with the reviewed JPL system level study which shows a mass and configuration impact for the currently defined 837 watt CASSINI mission, which would be prohibitive for the programme.

Although a new generation of ultrathin LILT soar cells could potentially offer a solution and produce a lower mass impact than the 1396 kg addressed by JPL in the study such solar cells have not yet been developed.

As a result of the attached deliberations it can be concluded that as of this point in time, LILT solar cells (including those developed by ESA) are not a viable power source alternative for the presently defined CASSINI mission of NASA.

D. M. O'Sullivan

Head of Power and Energy Conversion Division (XP)

European Space Agency
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memorandum

Ref: XP- **1611-jh** **Date:** 31st August 1996

Your Ref.:

To: H. Hassan (PY) via D. O'Sullivan (XP

From: J.E. Haines (XPM)

CC: K. Bogus (XPG), C. Signorini (XPG)

Subject: Assessment of the JPL system study related to the possible use of photovoltaic arrays supporting Low Intensity, Low Illumination GaAs and Si solar cells for the CASSINI mission. (Appendix D of the Cassini EIS Supporting Studies Vol.2)

Following your request to assess the overall system/power system aspects of the JPL study on the possibility of using GaAs and LILT solar cells for satisfying the CASSINI mission, please find the result of my own evaluation:

1) General

It is evident that the work presented in Appendix D demonstrates a comprehensive study on the part of JPL into the potential of applying new solar cell technologies to the CASSINI mission. In particular the study addresses the possibility of applying:

i) High efficiency silicon (Si) solar cells with defined Low Intensity, Low Temperature (LILT) performance.

and

ii) Gallium Arsenide (GaAs) solar cells with defined Low Intensity, Low Illumination (LILT) performance

to the CASSINI mission.

It must of course be noted that although the ESA ROSETTA spacecraft programme is intended to be operated with LILT solar cells up to a maximum sun distance of 5.2 AU (with full science operations only needed up to a sun distance of 3.25 AU), CASSINI has the distinct disadvantage of having to operate in Saturn orbit, this resulting in a full spacecraft performance requirement at a sun distance ranging between 9 AU and 9.3 AU.

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In terms of solar intensity this results in CASSINI receiving only:

$[(1/9.3)^2/1]$ - 0.0115 (1.15 %) of the solar insulation as compared to an earth orbit

2) Solar Cell Technologies and Performances

An assessment regarding the solar cell performances evaluated during the course of the JPL study contained in memorandum K. Bogus to H. Hassan (XPG/KB/4796-1/mac) dated 4th July 1996.

The conclusions of this memorandum however were that JPL had presented a balanced and realistic picture with regard to the predicted performances of both the LILT Si and LILT GaAs solar cells evaluated during the course of this study.

3) System Level Aspects

In reviewing Appendix D it is apparent that an extensive assessment of the system level impacts of incorporating a suitable photovoltaic array onto the CASSINI spacecraft has been conducted with the mass and cost implications being addressed in detail. The specific performances assumed for the solar array area and consequent mass, its incorporation onto the spacecraft and integration with the on-board electrical power system appear to be realistic figures.

The only two technical points where it is considered the assessment has been excessively optimistic is ;

i) In regard to the fact that the introduction of the peak power tracker for main power bus regulation (in lieu of an RTG shunt regulator), will result in an additional 5% - 10% throughput power loss within this 'serial' type regulator.

This will be reflected as a 5% to 10% increase in the power required from the photovoltaic array.

ii) In regard to the implications for spacecraft attitude control where for the LILT GaAs solar cell case the predicted increase in the CASSINI launch (wet) mass is from its current level of 5.630 tonnes to 7.026 tonnes (6023 kg of core spacecraft and 1003 kg of deployed, and highly flexible solar arrays).

Although the JPL study addressed the implication of a much reduced maneuver rate capability for a solar powered CASSINI, it can be foreseen that the resultant configuration where the deployed, flexible, solar array is a significant proportion of the overall spacecraft mass, will result in the definition of highly complex attitude control laws and an extensive supporting verification test programme.

This mass ratio between the core spacecraft and the deployed solar array panels will of course get worse at end of mission life when the 3130 kg of on-board liquid propellant is depleted, the core spacecraft mass then reducing to only 2893 kg.

4) Conclusions

The detailed assessment conducted by JPL into the possibility of powering the CASSINI mission with photovoltaic array and energy storage batteries has resulted in the identification of a projected mass increase of 1.396 tonnes for a LILT GaAs solution to 1.977 tonnes for a LILT Si solution. Both of these deltas result in a total spacecraft mass which is outside of the capability of the current best launcher option (Titan IV/Centaur) for the CASSINI mission.

As a result of reviewing the system level evaluation conducted by JPL on can only support their present conclusion, that replacement of the three currently baselined Radio-isotope Thermal Electric Generators (RTGs) by a photovoltaic power source utilizing 'start of the art' technology is impractical for the currently defined CASSINI/HUYGENS mission to Saturn and its moon Titan.

J. E. Haines

MEMO: XPG/KB/4796-1/mac 4-7-1996

FROM: K. Bogus (XPG)

TO: H. Hassan (PY)

cc.: XP, C. Signorini (XPC)

Subj.: LILT Solar Cells and JPL's CASSINI Study

Attached please find a draft of the XPG-assessment of the JPL-memo on "European LILT solar cells and Cassini" for your perusal. Following the incorporation of changes which you might propose, this could be send to JPL as planned.

It is essential to take note of the following comments and remarks in order to read the assessment in the proper perspective:

[1] The JPL-memo is a revision of on earlier JPL note by the same author, P. Stella who is a well-known solar cell expert at JPL. This previous note is not accessible in XPG.

[2] The JPL-memo mentions a Cassini solar array (system) analysi s performed previously at JPL which apparently studied the mission-impact of replacing RTG's by a solar array using US-solar cells. This report is also not available and outside the scope of our comments.

[3] The comments made on European LILT cells developed under ESA contract are limited to the component level. No solar array has been designed yet with these cells and statements on array subsystem level are therefore of somewhat hypothetical nature. Further comments on system level aspects could possibly be generated by systems engineers of the ROSETTA team.

ESTEC, 4-07-1996

ESTEC-Solar Generator Technology Section Comments to the JPL-MEMO on "European LILT Solar Cells and Cassini" (P. Stella/Ref. nr. 342-PSRE-95-119 Rev. A/date: 26-06-96)

[1] General Remarks:

Data available at ESTEC on European LILT-solar cells are limited to ROSETTA-type applications, i.e. up to about 6 A.U. and down to temperatures of -150 °C. Therefore, data for the CASSINI mission have to be based on extrapolations with their associated uncertainties. This also applies to the particle radiation damage which for CASSINI is much more severe that for ROSETTA.

The approach chose for these extrapolations in the JPL-memo appears generally sound and the general results obtained are considered as balanced and without over-pessimistic bias.

[2] Detailed Comments:

[2.1] The LILT-silicon cell efficiency reported by ESTEC at 5.8 A.U. and -150 degrees C is 24%-26% whereas the JPL-memo quotes 22%-24%. These lower values are considered as realistic in the context of the memo considering the fact that the ESTEC reported data are peak values of laboratory-made devices and not mass-production devices on the one hand and also the possibly detrimental effects of temperature and lower sun intensity at 9.2 A.U..

[2.2] Similar comments apply for the efficiency of the GaAs-on-GaAs cells.

[2.3] The assumptions on cell mass and thickness for CASSINI-type solar arrays are considered as non-pessimistic for the silicon and GaAs-Ge-LILT-cells developed so far. It is noted that a reduction of cell mass might be feasible by developing LILT-GaAs cells in ultrathin substrate-free configurations as demonstrated by recent developments for 1 A.U. applications. Admittedly, the mass reduction on array level would be limited since the solar cell mass is only one of several array-mass determining factors. Moreover, ultrathin LILT cells have not yet been developed.

JPL's assumptions on array mass can not be verified at ESTEC since they are based on a specific JPL-subsystem design. However, there is no reason to assume that the JPL data as used in the previous CASSINI solar array study, are over-pessimistic.

[2.4] The statements made in the JPL-memo on radiation damage of LILT cells in the CASSINI radiation environment indicate correctly the general trends but are fairly vague. From the data available at ESTEC the general trends as stated are confirmed and no data with higher accuracy can be provided since (a) the available measured data of low-temperature radiation damage in LILT cells are not giving a complete picture yet and (b) the CASSINI radiation environment is not known in detail and has not been analyzed at ESTEC.

[3] Conclusion:

The statements made in the JPL-memo referring to European LILT-solar cells result in an overall balanced and realistic picture of the LILT development results. The numerous uncertainties appearing in the memo are unavoidable since the LILT-development in Europe is oriented towards the ROSETTA-application which is very different from the CASSINI case. It is doubtful whether more accurate CASSINI-specific LILT solar cell data would lead to a radically different assessment regarding array mass and area.

MEMO

342-PSRE-95-119 **REV.A**

To: Sandra Dawson
From: Paul Stella
Subject: European LILT silicon cells and Cassini
Date: June 26, 1996

Revision Items: This memo has been revised to include recent data on the European LILT solar cells and on integral bypass diodes for solar cells. The diodes that are now undergoing development would fit beneath the solar cells and not utilize additional array area. Although it is not clear that these would be compatible with ultra-thin solar cells, it will be assumed that they will be suitable. This most recent data indicates that the initial Cassini array study results are still valid, i.e., that any such array will be prohibitively massive.

References:
1. "Low Temperature Irradiation Damages in Silicon Solar-Cells" by Isamu Nashiyama, 11th International Symposium on Space Technology and Science, Tokyo, Japan, July, 1975,
2. "Development of Advanced Si and Ga As Solar Cells for Interplanetary Missions", by G. Strobl et al, Proceedings of the 14th Space Photovoltaic Research and Technology Conference, October, 1995, NASA Conference Publication 10180

The Cassini solar array analysis was reviewed and updated to account for improved silicon cell LILT performance using published data on the European research cells. This was done using data from the December, 1994, World Photovoltaic Conference in Hawaii. The analysis that we performed attempted to determine a cell efficiency for operation at 9.2 AU. Data presented above extends their measurements to 5.8 AU and requires an extrapolation for use at 9.2 AU. It is noted from their data that their is a small fall off in efficiency when moving from 3 AU to 5.8 AU. This would suggest that 9.2 AU efficiencies would be even lower. However, it was decided to use the 5.8 AU values, as measured, as an optimistic estimate. Their measured cell efficiencies have been in the 22-24+% range at 5.8 AU, depending on the type of cell measured. They now are working with three (3) cell types, silicon, GaAs/GaAs, and GaAs/Ge (for the latter two cells the second entry is the base substrate material. The GaAs/Ge cell has been added since this memo was originally prepared. This was done to reduce costs and also to increase cell strength since pure GaAs is extremely fragile. Ge (germanium) provides an improvement although it is still much more fragile than silicon. For this reason, the GaAs type cells must be limited to minimum thicknesses twice the thickness of the thinnest usable silicon cell. Since GaAs and Ge have more than twice the density of silicon, the thinnest GaAs cell is approximately four times the mass of the thinnest silicon cell. We assumed that actual production cell performances would average approximately 22% for use on Cassini. This reduction from the research results is

observed for both existing silicon cells and GaAs/Ge cells and reflects the cell variations that exist in large production lots. At present, the existing process is more complex than for conventional space cell manufacture and a drop of an efficiency point is not unusual for reasonable production yields. Since a Cassini array would utilize a very large quantity of cells it would not be practical to "handpick" just the "highest" cells. This is especially true since a cell optimized for 9.2 AU, reduced grid line density, for example, would not be suitable for typical Earth orbiting missions.

The existing European LILT silicon cell is approximately 200 microns thick, appreciably greater than the 62 microns assumed in our existing Cassini analyses. Due to the complexity of their process and the need for accurate cell surface etching, it is expected that cell thickness reduction to this level would incur substantial handling and breakage problems. In fact, manufacturers of conventional cells have discouraged use of cells of this thin size due to extreme breakage. (It turns out that the use of a 200 micron silicon cell will have approximately the same array blanket areal mass density ($Kg/meter^2$) as the 85 micron thick GaAs/Ge cell used in the initial Cassini analysis). The approach undertaken in our "quick look" reassessment was to recalculate the GaAs/Ge array performance using the higher value of 22% efficiency obtained by the Europeans rather than the 18.3% value originally assumed for GaAs/Ge. (This basically simulated replacing the GaAs/Ge cell with the thicker European LILT silicon cell maintaining the array blanket areal mass density value.) The projected savings in array area would then be 20%, corresponding to the difference in cell efficiencies. It was assumed that the mass savings would be somewhat less, in the 10-15% range. There are two reasons for this. First, a large fraction of the lightweight deployable array mass is contained in area independent components such as deployment motors and latches/containment structures. Consequently, these masses would not change. Second, as in the case of silicon, it has proven difficult to manufacture ultra light solar cells without extreme breakage. For GaAs/ Ge, the minimum practical thickness is most likely 100-125 microns. For GaAs/As it would be even thicker, especially in view of the use of an ultra-low mass flexible substrate and ultra-thin coverglasses (50 microns). This is considered an optimistic evaluation.

At a first look it would seem that a cell mass savings could be achieved by using the LILT silicon cell which exhibits efficiencies at 5.8 AU comparable or better than the GaAs based cells. However, reasons why this is not expected to be the case are focussed primarily on cell radiation behavior. However, it is well known that silicon cells degrade more severely than GaAs cells. Data presented in reference two shows a substantial power loss for the silicon cells at radiation levels that are lower than presently anticipated for the Jupiter fly-bye. From the data it is estimated that the silicon cells will lose between 30 and 40% of their unirradiated efficiency during the severe fly-bye. Consequently it is likely that the a silicon array consisting of the LILT silicon cells would end up heavier than the GaAs array in order to compensate for the radiation induced power loss. As a final note, information (ref 1.) discovered in our literature search (B. Nesmith and P. Stella) indicates that cells irradiated at low temperature conditions, such as would be encountered at Jupiter, may suffer more severe degradation than cells subjected to the

same irradiation at room temperature conditions. Inasmuch as the Cassini analysis has been conducted to date using room temperature laboratory radiation data it is likely that all solar array analyses have been using overly optimistic cell radiation assumptions. This can only be quantified by performing low temperature irradiations on the U. S. and European cells of interest.

Consequently, it is concluded that the use of European LILT cells on a Cassini array may provide some improvement in mass and area factors. However, due to the extreme requirements of this mission, the impact of these improvements is minimal and does not substantially change the basic conclusion regarding excessive array mass and area.

cc: C. Lewis
B. Nesmith
R. Wilcox

Cassini Mission
Final Supplemental Environmental Impact Statement

Executive Summary

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APPENDIX D, SUMMARY TABLES OF SAFETY ANALYSIS RESULTS

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APPENDIX D

Summary Tables of Safety Analysis Results

This appendix presents tables summarizing results from the most recent Cassini mission safety analyses for the GPHS-RTG Final Safety Analysis Report (FSAR) (LMM&S 1997a-h) and the LWRHU FSAR (EG&G 1997) for use in the Final SEIS. The primary reference for the GPHS-RTG results was the FSAR Supplemental Analysis volume (LMM&S 1997h). The results presented by mission segment (Pre-Launch, Early Launch, Late Launch, VVEJGA, and Overall) include accident source terms, release probabilities, radiological consequences, mission risks, and average individual risks. These results are presented in the following tables:

Table D-1 Summary of Accident Source Terms

Table D-2 Summary of Mean Radiological Consequences

Table D-3 Summary of 5-th Percentile Radiological Consequences

Table D-4 Summary of 50-th Percentile Radiological Consequences

Table D-5 Summary of 95-th Percentile Radiological Consequences

Table D-6 Summary of 99-th Percentile Radiological Consequences

Table D-7 Summary of Mission Risks

Table D-8 Summary of Average Individual Risks

Table D-9 Summary of GPHS-RTG Uncertainty Analysis Results

Table D-10 summarizes the information sources for the results presented in Tables D-1 through D-9, along with notes related to values extracted from the information sources and any calculations performed in summarizing the results. In summarizing the results from the safety analyses in Tables D-1 through D-9, slight differences occur when compared to the source documents due primarily to roundoff.

For a given mission segment result type reported in Tables D-1 through D-9, results for the GPHS-RTG and LWRHU are first reported separately and then combined. The combined result represents a probability weighting of the separate results for the GPHS-RTG and the LWRHU. As an example of this procedure, consider the results for the mean health effects (without de minimis) for a VVEJGA inadvertent reentry, presented in Table D-2 as 13 health effects for the LWRHU at a total probability of release of 8.0×10^{-7} and 140 health effects for the GPHS-RTG

at a total probability of 6.3×10^{-7}. The combined result is calculated as follows:

$$\text{Combined (rounded): } 120 = [\, 13(8.0 \times 10^{-7}) + 140(6.3 \times 10^{-7}) \,] / 8.0 \times 10^{-7}$$

The results of 140 health effects for the GPHS-RTG and 13 health effects for the LWRHU cannot be simply added. The difference in the total probabilities of 8.0×10^{-7} for the LWRHU and 6.3×10^{-7} GPH-RTG reflects the situation that given a VVEJGA inadvertent reentry with a probability of 8.0×10^{-7}, there is a conditional probability of 1.0 that there would be a radiological consequence from the LWRHU and a conditional probability of $(6.3 \times 10^{-7} / 8.0 \times 10^{-7}) = 0.79$ that there would be a consequence from the GPHS-RTG. This difference in conditional probabilities is associated with the larger number of LWRHUs (157 considered in the analysis) compared to the number of GPHS modules (54) that reenter.

This probability weighting procedure has been followed in Tables D-1 through D-6, always normalizing to the higher of the two (GPHS-RTG or LWRHU) total release probabilities in each case. One exception to this approach to combining results occurs when the risk values in Tables D-7 and D-8 are combined. In this case, the risk is additive. Thus, the GPHS-RTG risk is added to the LWRHU risk to determine the combined risk, because the probabilities are already imbedded in the risk values.

Table D-1 Summary of Accident Source Terms (Page 1 of 2)

Mission Segment	Mission Phase	Source Term Contribution	Initiating Accident Probability[a]	Conditional Probability[b]	Total Probability[c]	Mean Source Term, Ci
Pre-Launch	0	GPHS-RTG	6.7×10^{-5}	7.8×10^{-1}	5.2×10^{-5}	4.68×10^{1}
		LWRHU[(d)]	6.7×10^{-5}	1.6×10^{-1}	1.1×10^{-5}	9.6×10^{-1}
		Combined	6.7×10^{-5}	7.6×10^{-1}	5.1×10^{-5}	4.7×10^{1}
Early Launch	1	GPHS-RTG	6.2×10^{-3}	1.1×10^{-1}	6.7×10^{-4}	1.76×10^{2}
		LWRHU[(d)]	6.2×10^{-3}	2.9×10^{-2}	1.8×10^{-4}	2.12×10^{-1}
		Combined	6.2×10^{-3}	1.1×10^{-1}	6.7×10^{-4}	1.76×10^{2}
Late Launch	3-8	GPHS-RTG	2.1×10^{-2}	1.0×10^{-1}	2.1×10^{-3}	2.61×10^{0}
		LWRHU[(d)]	2.1×10^{-2}	1.9×10^{-7}	3.9×10^{-9}	1.54×10^{-4}
		Combined	2.1×10^{-2}	1.0×10^{-1}	2.1×10^{-3}	2.61×10^{0}
VVEJGA	-	GPHS-RTG	8.0×10^{-7}	$7.9x\ 10^{-1}$	6.3×10^{-7}	3.20×10^{4}
		LWRHU[(d)]	8.0×10^{-7}	1.0×10^{0}	8.0×10^{-7}	6.22×10^{2}
		Combined	8.0×10^{-7}	1.0×10^{0}	8.0×10^{-7}	2.58×10^{4}

a. Initiating accident probability associated with launch-vehicle or space-vehicle related failures.
b. Conditional probability associated with accident environment sequence and fuel release conditions.
c. Product of initiating accident probability and conditional probability.
d. The LWRHU analysis used an earlier estimate of the initiating probability of Phase 0 accidents.

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Table D-1 Summary of Accident Source Terms (Page 2 of 2)

Mission Segment	Mission Phase	Source Term Contribution	Total Probability[a]	Source Term, Ci				
				Mean	Percentile Level			
					5-th	50-th	95-th	99-th
Pre-Launch	0	GPHS-RTG	5.2×10^{-5}	4.68×10^{1}	3.20×10^{-1}	5.29×10^{0}	2.59×10^{1}	2.83×10^{2}
		LWRHU	1.1×10^{-5}	9.57×10^{-1}	b	b	b	b
		Combined	5.2×10^{-5}	4.70×10^{1}	3.20×10^{-1}	5.29×10^{0}	2.59×10^{1}	2.83×10^{2}
Early Launch	1	GPHS-RTG	6.7×10^{-4}	1.76×10^{2}	3.47×10^{-1}	4.86×10^{0}	6.34×10^{2}	4.32×10^{3}
		LWRHU	1.8×10^{-4}	2.12×10^{-1}	1.63×10^{-1}	2.45×10^{-2}	1.60×10^{-1}	5.29×10^{0}
		Combined	6.7×10^{-4}	1.76×10^{2}	3.91×10^{-1}	4.87×10^{0}	6.34×10^{2}	4.32×10^{3}
Late Launch	3-8	GPHS-RTG	2.1×10^{-3}	2.61×10^{0}	2.31×10^{-1}	1.58×10^{0}	8.30×10^{0}	1.54×10^{1}
		LWRHU	3.9×10^{-9}	1.54×10^{-4}	c	c	c	c
		Combined	2.1×10^{-3}	2.61×10^{0}	2.31×10^{-1}	1.58×10^{0}	8.30×10^{0}	1.54×10^{1}
VVEJGA	-	GPHS-RTG	6.3×10^{-7}	3.20×10^{4}	6.16×10^{-1}	1.48×10^{4}	1.19×10^{5}	1.48×10^{5}
		LWRHU	8.0×10^{-7}	6.22×10^{2}	2.34×10^{2}	3.96×10^{2}	2.60×10^{3}	2.88×10^{3}
		Combined	8.0×10^{-7}	2.58×10^{4}	2.34×10^{2}	1.21×10^{4}	9.63×10^{4}	1.19×10^{5}

a. Product of initiating accident and conditional probabilities.

b. No statistics generated because only four source terms were identified.

c. No statistics generated because the source term is either zero or 1.54×10^{-4} Ci.

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Table D-2 Summary of Mean Radiological Consequences

Mission Segment	Mission Phase	Consequence Contribution	Collective Dose, person-rem[a]		Health Effects[a]		Maximum Individual Dose, rem[b]	Land Area Contaminated, km^2
			w/o De Minimis	w De Minimis	w/o De Minimis	w De Minimis		
Pre-Launch	0	GPHS-RTG	1.3×10^{1}	9.6×10^{1}	6.6×10^{-2}	5.3×10^{-2}	1.3×10^{-2}	1.5×10^{0}
		LWRHU	3.8×10^{2}	-	1.9×10^{-1}	-	2.5×10^{-3}	-
		Combined	2.1×10^{2}	9.6×10^{1}	1.1×10^{-1}	5.3×10^{-2}	1.4×10^{-2}	1.5×10^{0}
Early Launch	1	GPHS-RTG	1.4×10^{2}	9.6×10^{1}	7.1×10^{-2}	4.8×10^{-2}	2.1×10^{-2}	1.6×10^{0}
		LWRHU	8.4×10^{1}	-	4.2×10^{-2}	-	5.6×10^{-4}	-
		Combined	1.6×10^{2}	9.6×10^{1}	8.2×10^{-2}	4.8×10^{-2}	2.1×10^{-2}	1.6×10^{0}
Late Launch	3-8	GPHS-RTG	8.8×10^{1}	7.9×10^{1}	4.4×10^{-2}	3.9×10^{-2}	1.1×10^{0}	5.7×10^{-2}
		LWRHU	4.8×10^{-3}	-	2.4×10^{-6}	-	7.7×10^{-6}	-
		Combined	8.8×10^{1}	7.9×10^{1}	4.4×10^{-2}	3.9×10^{-2}	1.1×10^{0}	5.7×10^{-2}
VVEJGA	-	GPHS-RTG	2.6×10^{5}	3.7×10^{4}	1.4×10^{2}	2.6×10^{1}	6.5×10^{2}	1.9×10^{1}
		LWRHU	2.6×10^{4}	5.0×10^{1}	1.3×10^{1}	2.5×10^{-2}	2.1×10^{-2}	1.7×10^{-1}
		Combined	2.3×10^{5}	2.9×10^{4}	1.2×10^{2}	2.0×10^{1}	5.1×10^{2}	1.5×10^{1}
Overall Mission	-	GPHS-RTG	1.6×10^{2}	9.2×10^{1}	8.2×10^{-2}	4.7×10^{-1}	9.7×10^{-1}	4.5×10^{-1}
		LWRHU	2.1×10^{2}	2.1×10^{-1}	1.0×10^{-1}	1.0×10^{-4}	7.6×10^{-4}	7.1×10^{-4}
		Combined	1.7×10^{2}	9.2×10^{1}	8.9×10^{-2}	4.7×10^{-1}	9.7×10^{-1}	4.5×10^{-1}

a. Collective dose and health effects reported with and without a de minimis dose level of 0.001 rem per year applied.

b. Maximally exposed individual dose.

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Table D-3 Summary of 5-th Percentile Radiological Consequences

Mission Segment	Mission Phase	Consequence Contribution	Collective Dose, person-rem[a]		Health Effects[a]		Maximum Individual Dose, rem[b]	Land Area Contaminated, km^2
			w/o De Minimis	w De Minimis	w/o De Minimis	w De Minimis		
Pre-Launch	0	GPHS-RTG	6.6×10^{-2}	-	3.3×10^{-5}	-	2.5×10^{-5}	5.1×10^{-3}
		LWRHU	3.3×10^{1}	-	1.6×10^{-2}	-	1.0×10^{-5}	-
		Combined	7.0×10^{0}	-	3.4×10^{-3}	-	2.7×10^{-5}	5.1×10^{-3}
Early Launch	1	GPHS-RTG	8.4×10^{-2}	-	4.2×10^{-5}	-	4.3×10^{-5}	8.9×10^{-4}
		LWRHU	1.6×10^{0}	-	8.1×10^{-4}	-	1.0×10^{-5}	-
		Combined	5.1×10^{-1}	-	2.6×10^{-4}	-	4.6×10^{-5}	8.9×10^{-4}
Late Launch	3-8	GPHS-RTG	6.2×10^{-1}	4.9×10^{-1}	3.1×10^{-4}	2.4×10^{-4}	2.6×10^{-2}	-
		LWRHU	c	-	c	-	c	c
		Combined	6.2×10^{-1}	4.9×10^{-1}	3.1×10^{-4}	2.4×10^{-4}	2.6×10^{-2}	-
VVEJGA	-	GPHS-RTG	6.7×10^{3}	-	4.0×10^{0}	-	4.4×10^{-5}	-
		LWRHU	8.5×10^{3}	d	4.3×10^{0}	d	1.8×10^{-6}	1.3×10^{-1}
		Combined	1.4×10^{4}	-	7.4×10^{0}	-	3.6×10^{-5}	1.3×10^{-1}
Overall Mission	-	GPHS-RTG	2.0×10^{0}	3.9×10^{-1}	1.1×10^{-3}	1.8×10^{-4}	1.9×10^{-2}	3.1×10^{-4}
		LWRHU	3.9×10^{1}	-	2.0×10^{-2}	-	1.0×10^{-5}	5.4×10^{-4}
		Combined	4.6×10^{0}	3.9×10^{-1}	2.5×10^{-3}	1.8×10^{-4}	1.9×10^{-2}	3.5×10^{-4}

a. Collective dose and health effects reported with and without a de minimis dose level of 0.001 rem per year applied.
b. Maximally exposed individual dose.
c. No statistics generated due to low probability of release and small source term.
d. No statistics generated due to few cases above de minimis.

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Table D-4 Summary of 50-th Percentile Radiological Consequences

Mission Segment	Mission Phase	Consequence Contribution	Collective Dose, person-rem[a]		Health Effects[a]		Maximum Individual Dose, rem[b]	Land Area Contaminated, km^2
			w/o De Minimis	w De Minimis	w/o De Minimis	w De Minimis		
Pre-Launch	0	GPHS-RTG	5.6×10^{0}	-	2.8×10^{-3}	-	5.0×10^{-4}	6.6×10^{-1}
		LWRHU	3.4×10^{2}	-	1.7×10^{-2}	-	1.2×10^{-4}	-
		Combined	7.8×10^{1}	-	6.4×10^{-3}	-	5.3×10^{-4}	6.6×10^{-1}
Early Launch	1	GPHS-RTG	1.2×10^{1}	5.3×10^{-4}	6.2×10^{-3}	2.6×10^{-7}	1.5×10^{-3}	5.0×10^{-1}
		LWRHU	1.2×10^{1}	-	5.8×10^{-3}	-	1.8×10^{-5}	-
		Combined	1.5×10^{1}	5.3×10^{-4}	7.8×10^{-3}	2.6×10^{-7}	1.5×10^{-3}	5.0×10^{-1}
Late Launch	3-8	GPHS-RTG	1.6×10^{1}	1.4×10^{1}	8.2×10^{-3}	7.3×10^{-3}	4.8×10^{-1}	3.0×10^{-2}
		LWRHU	c	-	c	-	c	-
		Combined	1.6×10^{1}	1.4×10^{1}	8.2×10^{-3}	7.3×10^{-3}	4.8×10^{-1}	3.0×10^{-2}
VVEJGA	-	GPHS-RTG	1.9×10^{5}	-	1.1×10^{2}	-	3.0×10^{-4}	-
		LWRHU	1.5×10^{4}	d	7.4×10^{0}	d	4.0×10^{-6}	1.7×10^{-1}
		Combined	1.6×10^{5}	-	9.4×10^{1}	-	2.4×10^{-4}	1.7×10^{-1}
Overall Mission	-	GPHS-RTG	5.7×10^{1}	1.0×10^{1}	3.2×10^{-2}	5.6×10^{-3}	3.6×10^{-1}	1.5×10^{-1}
		LWRHU	9.3×10^{1}	-	3.7×10^{-2}	-	2.4×10^{-5}	7.1×10^{-4}
		Combined	6.3×10^{1}	1.0×10^{1}	3.5×10^{-3}	5.6×10^{-3}	3.6×10^{-1}	1.5×10^{-1}

a. Collective dose and health effects reported with and without a de minimis dose level of 0.001 rem per year applied.
b. Maximally exposed individual dose.
c. No statistics generated due to low probability of release and small source term.
d. No statistics generated due to few cases above de minimis.

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Table D-5 Summary of 95-th Percentile Radiological Consequences

Mission Segment	Mission Phase	Consequence Contribution	Collective Dose, person-rem[a]		Health Effects[a]		Maximum Individual Dose, rem[b]	Land Area Contaminated, km^2
			w/o De Minimis	w De Minimis	w/o De Minimis	w De Minimis		
Pre-Launch	0	GPHS-RTG	1.1×10^{2}	6.1×10^{0}	5.7×10^{-2}	3.0×10^{-3}	5.0×10^{-3}	5.5×10^{0}
		LWRHU	4.4×10^{2}	-	2.2×10^{-1}	-	5.8×10^{-3}	-
		Combined	2.0×10^{2}	6.1×10^{0}	1.0×10^{-1}	3.0×10^{-3}	6.2×10^{-3}	5.5×10^{0}
Early Launch	1	GPHS-RTG	3.4×10^{2}	1.2×10^{2}	1.7×10^{-1}	6.0×10^{-2}	5.7×10^{-2}	6.1×10^{0}
		LWRHU	8.8×10^{1}	-	4.4×10^{-2}	-	8.3×10^{-4}	-
		Combined	3.6×10^{2}	1.2×10^{2}	1.8×10^{-1}	6.0×10^{-2}	5.7×10^{-2}	6.1×10^{0}
Late Launch	3-8	GPHS-RTG	4.6×10^{2}	3.9×10^{2}	2.3×10^{-1}	2.0×10^{-1}	4.1×10^{0}	2.4×10^{-1}
		LWRHU	c	-	c	-	c	c
		Combined	4.6×10^{2}	3.9×10^{2}	2.3×10^{-1}	2.0×10^{-1}	4.1×10^{0}	2.4×10^{-1}
VVEJGA	-	GPHS-RTG	6.6×10^{5}	1.8×10^{5}	3.6×10^{2}	1.3×10^{2}	3.3×10^{3}	4.6×10^{1}
		LWRHU	7.9×10^{4}	d	3.9×10^{1}	d	6.3×10^{-5}	2.9×10^{-1}
		Combined	6.0×10^{5}	1.8×10^{5}	3.2×10^{2}	1.3×10^{2}	2.5×10^{3}	3.7×10^{1}
Overall Mission	-	GPHS-RTG	5.7×10^{2}	3.6×10^{2}	2.9×10^{-1}	1.9×10^{-1}	3.8×10^{0}	1.7×10^{0}
		LWRHU	4.4×10^{2}	-	2.2×10^{-1}	-	1.1×10^{-3}	1.2×10^{-3}
		Combined	6.0×10^{2}	3.6×10^{2}	3.0×10^{-1}	1.9×10^{-1}	3.8×10^{0}	1.7×10^{0}

a. Collective dose and health effects reported with and without a de minimis dose level of 0.001 rem per year applied.
b. Maximally exposed individual dose.
c. No statistics generated due to low probability of release and small source term.
d. No statistics generated due to few cases above de minimis.

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Table D-6 Summary of 99-th Percentile Radiological Consequences

Mission Segment	Mission Phase	Consequence Contribution	Collective Dose, person-rem[a]		Health Effects[a]		Maximum Individual Dose, rem[b]	Land Area Contaminated, km^2
			w/o De Minimis	w De Minimis	w/o De Minimis	w De Minimis		
Pre-Launch	0	GPHS-RTG	3.6×10^{2}	4.1×10^{1}	1.8×10^{-1}	2.1×10^{-2}	1.6×10^{-2}	8.6×10^{0}
		LWRHU	8.2×10^{3}	-	4.1×10^{0}	-	2.7×10^{-2}	-
		Combined	2.1×10^{3}	4.1×10^{1}	1.0×10^{0}	2.1×10^{-2}	2.2×10^{-2}	8.6×10^{0}
Early Launch	1	GPHS-RTG	2.3×10^{3}	1.7×10^{3}	1.2×10^{0}	8.3×10^{-1}	3.1×10^{-1}	2.0×10^{1}
		LWRHU	2.5×10^{3}	-	1.3×10^{0}	-	9.7×10^{-2}	-
		Combined	3.0×10^{3}	1.7×10^{3}	1.5×10^{0}	8.3×10^{-1}	3.4×10^{-1}	2.0×10^{1}
Late Launch	3-8	GPHS-RTG	1.1×10^{3}	9.6×10^{2}	5.5×10^{-1}	9.3×10^{-1}	7.1×10^{0}	3.4×10^{-1}
		LWRHU	c	-	c	-	c	c
		Combined	1.1×10^{3}	9.6×10^{2}	5.5×10^{-1}	9.3×10^{-1}	7.1×10^{0}	3.4×10^{-1}
VVEJGA	-	GPHS-RTG	8.9×10^{5}	3.9×10^{5}	4.8×10^{2}	2.7×10^{2}	4.9×10^{3}	7.0×10^{1}
		LWRHU	1.4×10^{5}	d	7.0×10^{1}	d	2.0×10^{-1}	2.9×10^{-1}
		Combined	8.4×10^{5}	3.9×10^{5}	4.5×10^{2}	2.7×10^{2}	3.9×10^{3}	5.5×10^{1}
Overall Mission	-	GPHS-RTG	1.6×10^{3}	1.2×10^{3}	8.0×10^{-1}	9.5×10^{-1}	6.4×10^{0}	5.2×10^{0}
		LWRHU	3.4×10^{3}	-	1.7×10^{0}	-	9.3×10^{-2}	1.2×10^{-3}
		Combined	1.8×10^{3}	1.2×10^{3}	9.2×10^{-1}	9.5×10^{-1}	6.4×10^{0}	5.2×10^{0}

a. Collective dose and health effects reported with and without a de minimis dose level of 0.001 rem per year applied.
b. Maximally exposed individual dose.
c. No statistics generated due to low probability of release and small source term.
d. No statistics generated due to few cases above de minimis.

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Table D-7 Summary of Mission Risks

Mission Segment	Mission Phase	Mission Risk Contribution	Total Probability[a]	Health Effects[b]		Mission Risks[c]	
				w/o De Minimis	w De Minimis	w/o De Minimis	w De Minimis
Pre-Launch	0	GPHS-RTG	5.2×10^{-5}	6.6×10^{-2}	5.3×10^{-2}	3.4×10^{-6}	2.8×10^{-6}
		LWRHU	1.1×10^{-5}	1.9×10^{-1}	-	2.1×10^{-6}	-
		Combined	5.2×10^{-5}	1.1×10^{-1}	5.3×10^{-2}	5.5×10^{-6}	2.8×10^{-6}
Early Launch	1	GPHS-RTG	6.7×10^{-4}	7.0×10^{-2}	4.8×10^{-2}	4.7×10^{-5}	3.2×10^{-5}
		LWRHU	1.8×10^{-4}	4.2×10^{-2}	-	7.6×10^{-6}	-
		Combined	6.7×10^{-4}	8.1×10^{-2}	4.8×10^{-2}	5.5×10^{-5}	3.2×10^{-5}
Late Launch	3-8	GPHS-RTG	2.1×10^{-3}	4.4×10^{-2}	3.9×10^{-2}	9.2×10^{-5}	8.2×10^{-5}
		LWRHU	3.9×10^{-9}	2.4×10^{-6}	-	8.9×10^{-15}	-
		Combined	2.1×10^{-3}	4.4×10^{-2}	3.9×10^{-2}	9.2×10^{-5}	8.2×10^{-5}
VVEJGA	-	GPHS-RTG	6.3×10^{-7}	1.4×10^{2}	2.6×10^{1}	8.8×10^{-5}	1.6×10^{-5}
		LWRHU	8.0×10^{-7}	1.3×10^{1}	2.5×10^{-2}	1.0×10^{-5}	2.0×10^{-8}
		Combined	8.0×10^{-7}	1.2×10^{2}	2.0×10^{1}	9.8×10^{-5}	1.6×10^{-5}
Overall Mission	-	GPHS-RTG	2.8×10^{-3}	8.2×10^{-2}	4.7×10^{-2}	2.3×10^{-4}	1.3×10^{-4}
		LWRHU	1.9×10^{-4}	1.0×10^{-1}	1.1×10^{-4}	2.0×10^{-5}	2.0×10^{-8}
		Combined	2.8×10^{-3}	8.9×10^{-2}	4.7×10^{-2}	2.5×10^{-4}	1.3×10^{-4}

a. Total source term probability.
b. Health effects reported as excess cancer fatalities with and without a de minimis dose level of 0.001 rem per year applied.
c. Risk calculated as the total probability times health effects.

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Table D-8 Summary of Average Individual Risks

Mission Segment	Mission Phase	Mission Risk Contribution	Average Individual Risks[a]	
			w/o De Minimis	w De Minimis
Pre-Launch	0	GPHS-RTG	3.4×10^{-11}	2.8×10^{-11}
		LWRHU	2.1×10^{-11}	-
		Combined	5.5×10^{-11}	2.8×10^{-11}
Early Launch	1	GPHS-RTG	4.7×10^{-10}	3.2×10^{-10}
		LWRHU	7.6×10^{-11}	-
		Combined	5.5×10^{-10}	3.2×10^{-10}
Late Launch	3-8	GPHS-RTG	1.8×10^{-8}	1.6×10^{-8}
		LWRHU	1.6×10^{-18}	-
		Combined	1.8×10^{-8}	1.6×10^{-8}
VVEJGA	-	GPHS-RTG	4.6×10^{-14}	2.6×10^{-14}
		LWRHU	4.0×10^{-15}	4.0×10^{-18}
		Combined	5.0×10^{-14}	2.6×10^{-14}

a. Average individual risk equals mission risk contribution from Table D-7 divided by an order of magnitude estimate of the population receiving most of the collective dose, (Pre-Launch, Early-launch = 10^5 persons; Late Launch = 5×10^3 persons; VVEJGA = $5X10^9$ persons).

Table D-9 Summary of GPHS-RTG Uncertainty Analysis Results

Mission Segment	Mean Risk	5% Confidence Level	50% Confidence Level	95% Confidence Level
Pre-Launch	3.4×10^{-6}	7.6×10^{-8}	6.0×10^{-6}	4.2×10^{-4}
Early Launch	4.7×10^{-5}	5.1×10^{-6}	6.2×10^{-5}	7.9×10^{-4}
Late Launch	9.2×10^{-5}	4.1×10^{-7}	7.3×10^{-5}	1.3×10^{-2}
VVEJGA	8.8×10^{-5}	1.2×10^{-6}	7.5×10^{-5}	4.6×10^{-3}
Overall	2.3×10^{-4}	8.3×10^{-6}	2.2×10^{-4}	1.9×10^{-2}

Table D-10 Summary of Information Source and Notes (Page 1 of 3)

1.	**Table D-1**	**Summary of Accident Source Terms**	
	GPHS-RTG	a.	Pre-Launch, Early Launch (accident scenarios 1.1, 1.3, 1.10 and 1.13), Late Launch, and VEEJGA: LMM&S 1997j, Table 4, p. 19. Early launch (accident scenarios 1.2, 1.4, 1.5, 1.6, 1.7, 1.8, and 1.9): LMM&S 1997g, Table D.3-1, p. D-16. The referenced RTG FSAR tables reported source terms in grams, which were converted to curies (Ci) in Table D-1 using a specific activity of 12.31 Ci/g. The probability of release (POR) for Early Launch accident scenario 1.10 was changed from 2.1×10^{-7} to $2.1\ 10^{-5}$ to be consistent with all other relevant information in LMM&S 1997h.
		b.	Results for Early and Late Launch were probability weighted using the total probability of release (POR) for each accident scenario form LMM&S 1997h, Table 4.2-3, p. 4-13. In the latter table, the POR for accident scenario 1.1 was changed from 4.4×10^{-4} to 4.5×10^{-4} (to be consistent with all other related information in LMM&S 1997h), resulting in a change in the POR for Early Launch from 6.6×10^{-4} to 6.7×10^{-4}.
	LWRHU	c.	EG&G 1997, Table VII-3, p. VII-4. The referenced LWRHU FSAR table reported source terms in becquerel (Bq), which were converted to Ci in Table D-1 by dividing the Bq by 3.7×10^{10} Bq/Ci.
		d.	Results for Early and Late Launch were probability weighted using the POR for each accident scenario from EGG&G, Table 9-3, p. 9-5.
2.	**Table D-2**	**Summary of Mean Radiological Consequences**	
	GPHS-RTG	a.	LMM&S 1997h, Table 3.3-4, p. 3-15
		b.	Note 1.b applies.
	LWRHU	c.	EGG&G 1997h: Collective dose (w de minimis): Table VII-9, p. VII-11 Health effect (w/o de mininis): Table VII-10, p. VII-12 Maximum individual dose: Table VII-11, p. VII-13 Land contamination: Table VII-12, p. VII-14
		d.	Note 1.d applies.

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Table D-10 Summary of Information Source and Notes (Page 2 of 3)

3.	**Table D-3**	**Summary of 5-th Percentile Radiological Consequences**	
	GPHS-RTG	a.	LMM&S 1997h, Table 3.3-5, p. 3-16.
		b.	Note 1.b above applies.
	LWRHU	c.	Note 1.d and 2.c above apply.
4.	**Table D-4**	**Summary of 50-th Percentile Radiological Consequences**	
	GPHS-RTG	a.	LMM&S 1997h, Table 3.3-6, p. 3-17.
		b.	Note 1.b above applies.
	LWRHU	c.	Note 1.d and 2.c above apply.
5.	**Table D-5**	**Summary of 95-th Percentile Radiological Consequences**	
	GPHS-RTG	a.	LMM&S 1997h, Table 3.3-7, p. 3-18.
		b.	Note 1.b above applies.
	LWRHU	c.	Note 1.d and 2.c above apply.
5.	**Table D-5**	**Summary of 99-th Percentile Radiological Consequences**	
	GPHS-RTG	a.	LMM&S 1997h, Table 3.3-8, p. 3-19.
		b.	Note 1.b above applies.
	LWRHU	c.	Note 1,d and 2.c above apply.

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Table D-10 Summary of Information Source and Notes (Page 3 of 3)

7.	**Table D-7**	**Summary of Mission Risks**
	a.	Total probabilities: Table D-1 of this appendix
	b.	Health effects (w and w/o de minimis): Table D-2 of this appendix
GPHS-RTG	c.	The mission risk values (w/o de minimis) for Late Launch (9.2×10^{-5}) and VVEJGA (8.8×10^{-5}) are calculated in Table D-7 as the porduct of the total probability times mean health effects. LMM&S 1997 h and j report these values as 9.4×10^{-5} and 8.6×10^{-5} for the same total probabilities and mean health effects as presented in Table D-7.
8.	**Table D-8**	**Summary of Average Individual Risks**
	a.	Mission risks from Table D-7 of this appendix
	b.	Note 7.c above applies.
9.	**Table D-9**	**Summary of Uncertainty analysis Results for GPHS-RTG**
	a.	Note 7.c above applies.
	b.	5%confidence level: LMM&S 1997h, Table 2.5-4, p. 2-35 50%confidence level: LMM&S 1997h, Table 2.5-5, p. 2-36 95%confidence level: LMM&S 1997h, Table 2.5-6, p. 2-37

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Cassini Mission
Final Supplemental Environmental Impact Statement

Executive Summary

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Chapter 2

Chapter 3

Chapter 4

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Chapter 6

Chapter 7

Chapter 8

Appendix A

Appendix B

Appendix C

Appendix D

Appendix E

APPENDIX E, COMMENTS ON THE DRAFT SEIS AND RESPONSES

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APPENDIX E

RESPONSES TO PUBLIC REVIEW COMMENTS

The U.S. Environmental Protection Agency (EPA) published a Notice of Availability (NOA) for the Draft Supplemental Environmental Impact Statement (DSEIS) for the Cassini mission in the Federal Register on April 11, 1997 (62 F.R. 17810). The DSEIS was distributed by NASA, along with supporting documentation (HNUS 1997), to over 150 potentially interested Federal, State and local agencies, organizations, and individuals. The public review and comment period closed on May 27, 1997. A total of 16 comment letters were received: 3 from Federal agencies, 1 from an organization, and 12 from individuals.

This appendix provides specific responses to the comments received from the agencies, the organization, and the individuals listed in Table E-1. Copies of the comment letters are presented in the following pages. The relevant issues in each comment letter are marked and numbered for identification along with the National Aeronautics and Space Administration's (NASA) response to each issue. Where a comment resulted in a change in the text of the SEIS, it is so noted in the response.

The comments received address a number of issues, including, but not necessarily limited to:

- the use of solar technology for the Cassini mission
- the properties of plutonium (e.g. , toxicity)
- the ability of the RTGs to survive reentry
- emergency response plans
- availability of baseline assumptions and analyses

In addition, for those commentors requesting more in-depth background information on the analyses, NASA has forwarded a copy of the Final SEIS and a copy of the recently available Safety Analysis Reports (SARs). The SARs provide an in-depth discussion of the assumptions and methodologies used to develop the consequences reported in this SEIS.

Table E-1 Agencies and Individuals Providing Comments

Commentor Number	Date of Comment	Organization	Individual Presenting Comment
A	5/8/97	Department of the Air Force	Olin C. Miller
B	5/20/97	Department of the Interior	James H. Lee
C	5/27/97	Environmental Protection Agency	Richard E. Sanderson
1	4/14/97	Private Citizen	Dr. MaryAnn Lawrence
2	5/23/97	Private Citizen	Russell D. Hoffman
3	5/21/97	Private Citizen	Gary L. Bennett
4	5/21/97	Private Citizens	Anthony Ehrlich and Harvey Baker
5	5/24/97	Private Citizen	John Robert Lehman
6	5/21/97	Private Citizen	Marc M. Cohen
7	5/23/97	Private Citizen	Thomas W. Chao
8	5/22/97	Private Citizen	Victoria Nichols
9	5/3/97	Private Citizen	Dorothy Scott Smith
10	5/19/97	Private Citizen	Jeanna D. Vicini
11	5/23/97	Private Citizen	Margaret N. Spallone
12	4/11/97	Private Citizen	Edward D. Ramsberger
13	4/29/97	Florida Southwest Peace Education Coalition	Malcolm Chubb

DEPARTMENT OF THE AIR FORCE
45TH SPACE WING (AFSPC)

U.S. AIR FORCE 1947 - 1997

MEMORANDUM FOR CODE SD
ATTN: Mr. MARK R. DAHL
NASA HEADQUARTERS
WASHINGTON DC 20546 -0001

FROM: 45 CES/CEV
1224 Jupiter Street MS 9125
Patrick AFB FL 32925-3343

SUBJECT: Review Comments for the Draft Supplemental Environmental Impact Statement (EIS) Baseline for NASA's Proposed CASSINI Mission to be Launched from Canaveral Air Station

1. The attached review comments (Atch 1) for the subject Draft Supplemental EIS are provided for your action. We have requested additional copies of the subject document from HQ NASA (Mr. Ken Kumor) for review by the 45th Space Wing (45 SW) Safety Office and Radiation Office. Therefore, you may receive additional comments at a later date. Please incorporate these comments and provide a minimum of four copies of the future documents to 45 CES/CEV at the above address. Please return a copy of all comment sheets showing the action taken on each comment received.

2. In addition we are providing a copy the 45 SW updated Environmental Impact Analysis Process (Atch 2) and our NEPA requirements regarding payloads (Atch 3). The point of contact for the National Environmental Police Act at the 45 SW is Ms. Ginger Crawford at 407-494-5286.

OLIN C. MILLER
Chief, Environmental Flight

Attachments:
1. Review Comments
2. 45 CES/C Ltr, 28 Jan 97
3. 45 CES/CEV Ltr, 12 Jul 96

cc:
NASA/MD-MED-P94-142 wo atch
NASA/DE-EMO wo atch
45 SW/XP wo atch
LBSC 5055 wo atch

Golden Legacy, Boundless Future...Your Nation's Air Force

Commentor A: Department of the Air Force

DATE 8 May 97	PROJECT REVIEW COMMENTS	PAGE 1 OF 1
X 35% __ 65% __ FINAL	PROJECT NO DRAFT SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT PROJECT NAME FOR THE CASSINI MISSION	
	REVIEWER Ginger Crawford SIGNATURE OFF SYM 45CES/CEV PHONE 408/494-5280 1224 Jupiter St., Patrick AFB, FL 32925-3343	

DWG NO OR PAGE NO	ITEM NO	COMMENTS	ACTION CODE	
na	1	This document shoud be reviewed and approved by 45th Space Wing (SW) Safety and Radiation as they have launch approval control.		A-1
a	2	Information from the recent Delta failure should be included in your evaluation.		A-2
na	3	The cleanup costs do not include cost impacts due to the non-availability of the area.		A-3

ACTION CODE	A-Approved D-Disapproved C-Check	

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Commentor A: Department of the Air Force

Johnson Controls World Services Inc.
Launch Base Support Project
Cape Canaveral Air Station
Post Office Box 1228
Cape Canaveral, FL 32920-1228

JOHNSON CONTROLS

MAY 12 1997

MAY 14 1997

45 CES/CEV
1224 Jupiter Street
Patrick AFB, FL 32925-3343

SUBJECT: CONTRACT F08650-92-C-0062; Review of the Draft Supplemental Environmental Impact Statement (DSEIS) for the Proposed Cassini Mission From Cape Canaveral Air Station (CCAS), Florida (CDRL 063A2)

REFERENCE: Written Request From Ms. Ginger Crawford 45 CES/CEV Dated 8April 1997, Review of the Draft Supplemental Environmental Impact Statement (DSEIS) for the Proposed Cassini Mission from Cape Canaveral Air Station (CCAS), Florida (CDRL 063A2)

The LBS Environmental office has reviewed the Draft Supplemental Environmental Impact Statement (DSEIS) for the proposed Cassini Mission to be launched from Cape Canaveral Air Station (CCAS), as requested by reference. Our reviewers find the DSEIS to be complete and adequate with regards to addressing the potential for radiological contamination caused by a catastrophic mission accident that results in the release of plutonium dioxide (PuO_2). This office would like to offer the following suggestions for consideration by the proponent.

1) The last sentence in section 4.1.2.2 states a probability of less than 1 in 53 million of incurring cancer due to exposure from an accidental PuO_2 release. Some other cancer probabilities, such as exposure to second-hand cigarette smoke, listed for comparison, may further interpreting the low probability/insignificance of this potential impact, and A-4

2) based upon the new information recently made available from updated mission safety analysis, the proponent might consider revising the Record of Decision (ROD) included as Appendix A of the DSEIS. A-5

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Questions or requests for additional information regarding the review of the subject DSEIS should be directed to Mr. Don George, 853-6578.

Mark P. Chatelain
Manager, Environmental Compliance

DG/lb/853-6578/FAX 853-6543

Attachments: a/s

cc: Environmental Superintendent
Director, Technical Assurance
LBS 5055 (D. George)

Comment Number A-1

Additional copies of the Draft Supplemental EIS were provided to the 45th Space Wing for use by its Safety Office and Radiation Office.

Comment Number A-2

The safety analysis conducted for the Cassini mission encompasses all the accident environments that were present during the Delta failure. Scenarios related to launch pad accidents took into consideration the observed dispersal plumes associated with the Delta solid rocket motor propellant fires.

Comment Number A-3

A Phase 0 and Phase 1 accident could potentially affect CCAS and its ability to launch Department of Defense (DOD) missions. This eventuality is addressed in the contingency planning process for the Cassini mission and in CCAS—specific radiological protection plans. In the unlikely event of such an accident, the contamination levels would be assessed and the appropriate cleanup response measures initiated to restore the affected portions of CCAS to mission-capable status in a timely fashion.

Comment Number A-4

The June 1995 Cassini EIS provided a table (Table 4-20) which is useful in comparing Cassini mission risks with various fatality risks in the U.S.

Comment Number A-5

A Record of Decision will be issued at the completion of the NEPA process with the Final SEIS serving as a primary input document.

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United States Department of the Interior

OFFICE OF THE SECRETARY
OFFICE OF ENVIRONMENTAL POLICY AND COMPLIANCE
Richard B. Russell Federal Building
75 Spring Street, S.W.
Atlanta, Georgia 30303

May 20, 1997

ER-97/229

Mark R. Dahl
Program Executive, Cassini
Mission and Payload Development Div.
Office of Space Science
Code SD, NASA Headquarters
Washington, DC 3330546-0001

Dear Mr. Dahl:

The Department of the Interior has reviewed the Draft Supplemental Environmental Impact Statement (EIS) for the NASA's Cassini Mission, as requested. We have no comments to offer.

Thank you for the opportunity to review this environmental impact statement.

Sincerely,

James H. Lee
Regional Environmental Officer

Thank you for your letter.

Commentor C: United States Environmental Protection Agency

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MAY 27 1997

OFFICE OF
ENFORCEMENT AND
COMPLIANCE ASSURANCE

Mr. Mark Dahl
Office of Space Science (Code SD)
NASA Headquarters
Washington, DC 20546-0001

Dear Mr. Dahl:

The Environmental Protection Agency (EPA) has reviewed the National Aeronautics and Space Administration (NASA) draft supplemental environmental impact statement (EIS) for the **Cassini Mission**. This review was conducted in accordance with our responsibilities under section 309 of the Clean Air Act and the National Environmental Policy Act (NEPA). We have classified this draft EIS as EC-2 (environmental concerns, insufficient information).

EPA is concerned that the radiological dose estimates were presented in the document without sufficient information regarding the key underlying assumptions used to make those estimates. The documentation should have provided population distribution information used to develop the radiological collective dose and health effect information. Additional information regarding the methods used to verify, validate or benchmark the computer models used to perform these calculations should be provided to the decision-maker and the public as well. C-1 C-2 C-3

Additionally, EPA does not believe that the information presented in the EIS sufficiently addresses the needs of emergency response planning and activities. The consequences from a full range of scenarios, including the worst case source terms for both launch and reentry scenarios, should be calculated and included in the final supplemental EIS. The use of statistically derived worst case scenarios downplays the level of risk which could occur in the worst case. C-4

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To illustrate our concern for this issue, a set of calculations for releases of radioactivity from accidents during the early launch phase of the Cassini Mission have been performed by EPA's Center for Risk Modeling and Emergency Response. While EPA recognizes that such an event has a very low likelihood of occurring, EPA thinks it is important to consider such occurrences for emergency response planning purposes. In general, these equations estimate that higher doses may exist miles downwind if the full inventory of radioactivity were released near the ground. In contrast, the worst case scenario in the supplemental EIS results in lower offsite doses than EPA's calculations because it is weighted *by the probability of such an occurrence*. The equations and assumptions used to make these calculations are enclosed. C-5

Thank you for the opportunity to comment on this supplemental EIS. If you have any questions regarding these comments or the ratings, please contact Patricia Haman of my staff at 202-564-7152.

Sincerely,

Richard E. Sanderson
Director
Office of Federal Activities

Enclosure

Radiological Dose In Turbulent Shear Environment, T. Margulies, EPA

$$\chi = Q \frac{\sqrt{a}}{\sqrt{4\Pi(X - X_s)}} Exp[-\frac{a(y - y_s)^2}{4(X - X_s)}] \frac{(z z_s)^{(1-\beta)/2}}{b(2 + \alpha - \beta)(x - x_s)}$$

$$Exp\left[-\frac{a(z^{2+\alpha-\beta} + z_s^{2+\alpha-\beta})}{b(2 + \alpha - \beta)^2 (x - x_s)}\right]$$

$$I_{-\nu}\left[\frac{2a(z z_s)^{(2+\alpha-\beta)/2}}{b(2 + \alpha - \beta)^2 (x - x_s)}\right]$$

$$X = \int_0^x B(t)\,dt$$

$$u = a z^{\alpha} \qquad K_z = b z^{\beta} \qquad K_y = B(x) z^{\gamma}$$

$$\beta = 1 - \alpha \qquad \nu = \frac{(1 - \beta)}{(2 + \alpha - \beta)}$$

Concentration calculations in a turbulent wind shear environment have been solved for the case of constant conditions when the vertical wind profile, the horizontal diffusivity, and vertical diffusivity can be represented by power law functions of the vertical axis z. This relationship provides the concentration versus location (x,y,z) available to hypothethetical individuals outdoors.This information has been combined with a source of radioactivity, adult weighted breathing rate (2.66 10^{-4} m^3/s), and dose factor information (1.04 10^{-4} Sv/Bq) to estimate the inhalation pathway contribution to dose. Formulas for the concentration χ are shown above to obtain the concentration field from a source at (x_s, y_s, z_s). I-ν is a modified Bessel function of the first kind of order -ν. This was calculated in a program for accidental releases of plutonium-238 with a decay rate of 87.75 years to estimate doses versus distance . The release term assumed was 4360 curies at 10 meters, during neutral weather conditions. The 50-year dose commitments are shown below.

Distance (mi.)	Dose (Rem)
1	24028
5	1556
10	474
15	236
20	144
25	98

a = 61; b=11.3; α=.145; β=.855; z=1; B=1.65 x^(0.667); z_s=10; z=1; Q=4360

Comment Number C-1

The recently available Cassini Mission Safety Analysis Reports (SARs) (LMM&S a-j; EG&G 1997) have been forwarded to the commentor. The SARs provide detailed descriptions of the suite of atmospheric transport and diffusion models, the modeling assumptions, and the methodology implemented for the nuclear safety analysis. This information can be found in the Nuclear Risk Analysis Document Appendices, Volume III, Book 2 (LMM&S e):

Appendix F: SATRAP Model Description
Appendix G: GEOTRAP Model Description
Appendix H: HIAD Model Description
Appendix I: PARDOS Model Description
Appendix J: PUFF Plume Rise Model

The population data for the KSC/CCAS region, defined by a 200 kmx200 km grid centered between LC-40 and LC-41 at CCAS, includes information for on-site and off-site spectator, on-site worker, and off-site residential population groups as well as surface type data (dry land, water, swamp, and ocean) at a 1 kmx1 km resolution. Other launch area data bases used in the risk analysis include pasture land, crop land, citrus farms, ground cover, and land usage information. Beyond the launch area grid, population distribution information is provided in a worldwide data base, which provides surface type and population density distributions by surface type in 720 equal area cells. See the RTG SAR, Volume III, Book 2, Appendices D and E (LMM&S e) for additional information.

Comment Number C-2

The KSC/CCAS regional and worldwide population and land use data bases used for these analyses are also presented in the document cited in C-1 above:

Appendix D: Site-Specific Demographic/Land Usage Data Description
Appendix E: Worldwide Demographic, Surface Type, and Meteorological Data

Comment Number C-3

Available verification of the modeling is contained in the SAR Volume III, Book 2, Appendices F, G, H and J, (LMM&S e).

Comment Number C-4

It should be noted, at the outset, that the EPA's Office of Radiation and Indoor Air is a participant in emergency planning for the Cassini mission. Radiological contingency plans are being developed by NASA/KSC and USAF/CCAS in accordance with the Federal Radiological Emergency Response Plan (FRERP) to address specifically

the initial response that would be required in the unlikely event of an accident affecting the launch site. Similar plans already exist at the State and county (Brevard) levels in Florida, and are in the process of being updated for the Cassini mission. The NASA/USAF and State of Florida plans are also being closely coordinated with the USDOE, which maintains its own set of emergency response instructions for radiological accidents of many kinds, to ensure a coordinated initial response to any accident.

In addition NASA/KSC and the DOE are coordinating closely with the State of Florida on development of recommended protective actions that could be implemented in the unlikely event of a release of radioactive material, both for the launch site and for public areas. Because there is a large range of variables influencing the outcome of potential accident situations, the range of protective actions can be similarly large. Protective actions for the general public would be announced by the State of Florida in consideration of the specific circumstances accompanying any accident.

Further, in coordination with other Federal agencies, all contingency plans will be in place prior to launch of the mission. In those plans the concept of operations for longer-term actions such as recovery of the radioactive material and facilities are also considered. Long-term actions will depend on all the circumstances surrounding an accident, and cannot be fully developed until all such circumstances have been taken into account. The details of the emergency response plans are independent of the NEPA documentation for the mission.

The objective of a probabilistic risk assessment is to determine the likelihood of potential radiological consequences for the full range of possible pre-launch, launch, and inadvertent EGA reentry release accidents, and to communicate the associated risks to the decision makers and the public. The information presented in the draft SEIS and the accompanying HNUS technical support document (HNUS-97-0010) provides radiological consequence results for the mean and 5-th, 50-th, 95-th, and 99-th percentile levels. These calculated source terms and radiological consequences are conditional on the occurrence of a plutonium dioxide release accident, and the information summarized by mission segment were developed from individual accident case simulation results given in Appendix A of HNUS-97-0010. These source term and radiological consequence results represent credible accident outcomes determined by the detailed modeling, and any credible worst case scenario is implicit in these results.

Comment Number C-5

The difference between the SEIS and EPA early launch accident calculations is unrelated to a probability weighting of the results, but rather arises from the fact that the EPA calculations do not properly account for the particle size characteristics or vertical distribution of the plutonium dioxide release. The hypothetical accident scenario used in the EPA calculations involved the 99-th percentile GPHS-RTG source term (4360 Ci) for the early launch mission segment as presented in HNUS-97-0010, and the assumption that the total plutonium dioxide release was entirely in the form of submicron, respirable plutonium dioxide in a puff at 10 meters. These are not credible

early launch accident plutonium dioxide release conditions. The relevant information on the early launch accident particle size distributions and the vertical plume configurations are now presented in the SAR Addendum (LMM&S g).

As noted in the response to Comment C-4, the 99-th percentile radiological consequences presented in Table 6-5 of HNUS-97-0010 apply given the occurrence of the accident release. The calculated collective dose value at the 99-th percentile level was 7500 person-rem for early launch accidents, while the corresponding maximum individual dose for this mission segment showed that the dose received by any individual in the exposed population was no more than 2.2 rem. The probability of exceeding this radiological consequence outcome was and is 0.01 given an early launch plutonium dioxide release accident, and the total probability was 6.3×10^{-6} to observe this radiological consequence outcome during the early launch mission segment. The SAR Addendum provides updated and additional information, in the form of complementary cumulative distribution functions, to estimate the possible radiological consequence outcomes of early launch accidents at lower probabilities of occurrence, but there are no credible accident outcomes that resemble the conditions of the hypothetical scenario used in the EPA calculations. Additional information is provided in Table D-6 of Appendix D.

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Commentor 1: MaryAnn Lawrence

pg. 1 of 2 pgs.

5951 S.W. 45th Way
Ft. Lauderdale, Fl. 33314
April 14, 1997

Mr. Mark R. Dahl
Program Executive, Cassini
Mission and Payload Development Division
Office of Space Science
National Aeronautics and Space Administration
Headquarters
Washington, D.C. 20546-0001

re: Cassini Mission - EIS dated 2/92, FEIS dated 6/95, Nuclear Safety Analysis dated 4/97 and DSEIS dated 4/97

Dear Mr. Dahl,

Thank you for the opportunity to review and comment.

The people have spoken with overwhelming comments in FEIS, reiterating that that the public doesn't want NASA to put deadly plutonium in space. The creator gave man a natural life system, which holds the earth together. When the air is destroyed, man will be destroyed and there will be no future except death for mankind. No government or industry owns the air and has the right to send deadly plutonium into the air, with a potential capability to fall to earth and kill millions of people. It is likely that much smaller amounts of plutonium releases have already occurred at different times in the past, resulting in increased rates of lung cancer worldwide.

An important question to ask is: Why is NASA taking such a big risk when there is evidence that Cassini could be performed safely with solar power? 1-1

It has been common practice in the past for the government to collaborate with big industry on environmental issues, using a 'good old boy' policy, often allowing industry to set up government procedures and rules for mutual perks and benefits. One cannot help but wonder 'who is benefiting' by NASA insistence on going ahead with a program which could have such damaging results. Never before, in the history of mankind, has such a large amount of plutonium (73 lbs), been sent up in space.

And all this is costing the taxpayers over three(3) billion dollars.

Could it just be that this so-called peaceful mission of NASA, in combined cooperation with the European and Italian Space Agencies, to explore Saturn and its environment, is, in reality, a frantic race by the industrial/military complex to develop technology for control of nuclear militarization of space? 1-2

I close with a short prayer I made:

Oh great creator of the Universe
Maker of the natural systems of life
Giver of the sweet air we breathe and fresh water we drink
Let not the little men of greed, power and money destroy our mother earth
Turning it from heaven into a living hell
Don't the little men know that, just as in the past, sooner or later, a nuclear accident will occur, and their manipulated statistical charts will become meaningless
Don't the little men know that they will perish right along with millions of others - whose rights they have trampled upon

Sincerely,
Dr. MaryAnn Lawrence
DR. MARYANN LAWRENCE

ML:ml

Comment No. 1-1

It is not correct, as the commentor asserts, that the Cassini mission involves a "big" risk. The recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997) indicate that the risks are low.

The Jet Propulsion Laboratory conducted for NASA an in-depth analysis of the available electrical power systems, including many different solar, battery, and long life fuel cell power sources and hybrid systems to identify the most appropriate power source for the Cassini mission (see JPL 1994, Supporting Studies Volume 2). This study concluded that RTGs are the only technically feasible and available power source for the mission. Subsequent to this study, JPL conducted a further assessment of the new high-efficiency cells under development by the European Space Agency, which reaffirmed JPL's previous finding that solar power is not a viable option for the Cassini mission to Saturn. For more details please refer to Section 2.1.4 of this Final Supplemental Environmental Impact Statement (FSEIS).

Comment No. 1-2

Cassini is an international scientific mission for peaceful purposes to benefit all humankind. It is not "nuclear militarization of space" as the commentor contends.

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From: Russell D. Hoffman
P.O. Box 188006
Carlsbad CA 92009-0801

To: Mark R. Dahl
Program Executive
Cassini Mission and Payload Development Division
Office of Space Science, Code SD
NASA Headquarters
Washington DC 20546-0001

Cc: Earle K. Huckins III
Deputy Associate Administrator for Space Science
NASA Headquarters
Washington DC 20546-0001

Cc: The White House, various other interested parties

Date: May 23rd, 1997

Re: Final submission of 36-point commentary on NASA DSEIS for the Cassini Mission.

Dear Sir:

Enclosed please find one copy of my comments to NASA regarding the DRAFT SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT FOR THE CASSINI MISSION. As stated in a letter from Mr. Huckins dated May 14th, 1997, I understand that NASA will be publicly addressing the items in this commentary in the upcoming 1997 "Final" EIS on the Cassini mission.

This document replaces the version of my answer marked "draft" and sent to you approximately one month ago and sent to NASA Administrator Daniel Goldin and President Clinton and others somewhat more recently. I am sending this final version via overnight courier service to ensure it's receipt at your office prior to the May 27th (4:30 pm EDT) submission deadline.

The most significant change is an additional paragraph (#3) in item #8. There is also some additional commentary in the beginning, and a few minor corrections throughout the rest of the document.

I look forward to reading how NASA intends to answer this commentary. However, I must make clear my feeling that the correct action on NASA's part would be to throw out the entire EIS procedures and redo the document based on better science.

In any event, thank you again for sending me the DSEIS and for your assistance in the matter of getting this submission into the system. If I can be of any service please do not hesitate to contact me.

Sincerely,
Russell D. Hoffman

Headquarters

S

Mr. Russell D. Hoffman
P.O. Box 188006
Carlsbad, CA 92009-0801

Dear Mr. Hoffman:

Thank you for your letter and printed version of your web site dated April 26, 1997, to NASA Administrator Daniel S. Goldin concerning the Cassini mission to Saturn. Your materials were forwarded to me for a response.

We appreciate your concern in taking the time to read and comment on all our informational material. However, I would like to emphasize that the information contained and referenced in our Environmental Impact Statements, fact sheets, and web site are the best available, factual information relating to risks associated with the Cassini mission. Your 36 points commenting on the Cassini Supplemental Environmental Impact Statement will be addressed in the Cassini Final Supplemental Environmental Impact Statement and made available to the public.

Additionally, before launching NASA spacecraft with RTGs, thorough and detailed safety tests and analyses of the consequences of potential accidents are conducted. The nuclear safety analyses for a mission undergo independent evaluations by nationally or internationally recognized experts. Knowledgeable representatives from other Federal agencies who have special expertise in nuclear materials also evaluate these analyses. These evaluations are presented to and considered by the NASA Administrator prior to a decision to launch.

Sincerely,

Earle K. Huckins III
Deputy Associate Administrator
for Space Science

Laugh, Cry, Be Angry, Do Something...

Draft Supplemental Environmental Impact Statement for the Cassini Mission

Analysis of NASA Procedures (*Final Version*)

by Russell D. Hoffman Copyright (c) 1997

First published online Saturday, April 12th, 1997

On Monday, April 6th, 1997, NASA sent me, via Certified Mail, Return Receipt Requested, a copy of the DRAFT SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT FOR THE CASSINI MISSION (DSEIS) and an accompanying document called NUCLEAR SAFETY ANALYSES FOR CASSINI MISSION ENVIRONMENTAL IMPACT STATEMENT PROCESS.

These two NASA documents are not good science. They are not even science. They are nothing more than a biased review of selected data, and very little real data is actually presented.

I found my name on the back pages of the DSEIS, along with about 80 other individuals, 30 environmental, peace, and other groups, and about 30 Federal, state, and local government organizations. A quick look where my name appears might lead you to think (as it did some of my friends) that I **endorse** this DSEIS, or that I have at least been **consulted**. I **have not** been consulted and I **do not** endorse these documents!

A US EPA Notice of Availability (NOA) regarding the DSEIS was published in the Federal Register on April 11, 1997.

On May 17th, 1997 I received a letter from Mr. Earle K. Huckins III, NASA Deputy Associate Administrator for Space Science, stating that this 36-point commentary "will be addressed in the Cassini Final Supplemental Environmental Impact Statement and made available to the public". Fat lot of good that's going to do! NASA should be THROWING OUT the EIS and redoing it with good science based on the work of people such as Dr. Sternglass, Dr. Gofman, Dr. Morgan, Dr. Gould, Dr. Caldicott, and many many others. Merely answering my questions can only go so far...

After receiving the documents, I called a **former director of the Health Physics Division of Oak Ridge National Laboratories, Dr. Karl Z. Morgan**. Dr. Morgan is referred to as "the father of Health Physics" and stands in staunch opposition to NASA's nuclear space policies.

I started to ask him about some of the claims NASA makes in the document, but he stopped me and said it all **doesn't really matter**, because "it's a serious mistake to carry out such 'research'" and that all such calculations "are a bit absurd".

What plutonium particles can do:

Dr. Morgan explained to me that the way plutonium works is basically like this: when a particle of plutonium lodges in the body, the localized radiation dose to the nearby living cells from one of the "fine particles" can be 1000's of REM per year if the plutonium stays fixed in one place. If it moves around in the body, the dose will be spread out among the cells it is in close proximity to.

At that high level of radiation, nearby cells will die, but ones a little further away will survive -- and be irradiated, and possibly mutate into a cancerous form. 2-a

Dr. Morgan also explained that the incineration of an RTG would produce "a spectrum of sizes" and he added "any one of them -- they could all be inhaled. I hope our government will be more cautious in using plutonium."

This is one of the many learned scientists whom NASA is ignoring. This is someone with the facts that NASA would rather pretend not to know.

Next, I read the DSEIS documents.

These documents supplement the original "FINAL" ENVIRONMENTAL IMPACT STATEMENT FOR THE CASSINI MISSION. In that original document, some of the items in these two documents are more thoroughly discussed, but generally it is still a shallow review of the overall mission risks.

These documents are missing a lot of important information. I came up with a list of items that I think should be considered, included, or fixed. Some are major, and I suppose some are minor. But all of them should be considered, every single one, and none should be left unconsidered. I think many of the reasons can stand alone as a reason not to use nuclear power in space and not to fly the Cassini mission. Taken together, I believe NASA's position is **utterly indefensible**.

Cassini can be stopped any time before the FINAL MOMENT when President Clinton signs off and takes final, full, moral responsibility for this dangerous and ill-conceived mission and someone *pushes the button.* I would not push the button...

It is interesting to note that in *every instance* where I found the science appearing to be compromised, the effect allowed NASA to fudge the figures in their favor. Every single instance. **That's a pattern.**

On with the list:

1:

The solar option, which has been disavowed by NASA, would allow us to do *the most interesting and important experiments* which NASA is now **incapable** of doing with the current launch configuration. The rings of Saturn are the most interesting reason to go to Saturn, and only a long-term visit, so we can observe how they change over time, will really reveal anything useful. Yet NASA's Cassini mission will end in 2004 just four years after it arrives in Saturn's vicinity! On the other hand, use of a solar option would have meant that the spacecraft, once it got to Saturn, would be operable there for decades and decades. Then a proper study of the rings would be possible. Failure to use the solar option has meant that the science is not as good or as useful as it could be. 2-1

2:

The solar option which NASA discounts as unmaneuverable requires either four long arms, 140 feet by 11.5 feet each or two long arms, 105 feet by 30 feet. Why isn't NASA considering a circular array mounted on an articulated gimbal instead? The same area as NASA's solar array (6,430 square feet) can be obtained in a 45-foot radius circle, which would be much easier to maneuver than NASA's solar example. And lighter to build. NASA's solar option uses an archaic solar array seemingly *designed for failure*! 2-2

3:

The report gives health guesses for a 50-year period. Because the half-life of Pu 238 is 87.7 years, a 500-year period or even a 1000-year period would be much more appropriate. Additionally I do not believe NASA has accounted for a doubling, or even a 10-fold or 20-fold increase in population during that time. These two factors alone can mean NASA's numbers are off by a factor of 100 or more. 2-3

4:

Plutonium in the food chain is covered by just *one sentence* in these documents and by only a few paragraphs in the original "final" Environmental Impact Statement. They don't project past 50 years, yet over the next few centuries this will become (after the stuff has largely settled back to earth) the most common way that plutonium from an accident will be introduced to living beings -- especially meat-eating humans -- again and again, as part of the food chain. Considering the projection only goes out 50 years, it is clearly a topic that needs more proper analysis. 2-4

5:

There are few descriptions of how NASA came about the many numbers they present. Are human factors such as reliability included when considering the chances of a failure? And the degree of accuracy in each number NASA supplies adds a false sense of confidence. Many of them are "accurate" to three decimal places. That is highly, highly, doubtful. Normally, scientists round these sorts of things to no more than 2 digits and a multiplier, not three digits. 2-5

An appendix containing a *complete* example of how they did their math would at least offer some small proof of NASA's confidence in their guesswork. A table showing the factors considered, and their weights, might go a long way towards earning the public's confidence in NASA's numbers.

6:

Of all the reasons NASA offers for launching Cassini in the first place, probably 99% of them *would still have been accomplished* if the ultimate goal was something like MAG LEV TRAIN SYSTEMS or INTERCONNECTING SCHOOLS THROUGH FIBER-OPTIC TECHNOLOGY. But no. Every thing that NASA has ever accomplished or might accomplish is lobbed into "science at it's best" and the need 2-6

for RTGs and a 'safe' nuclear space policy.

But in reality not only would 99% of the technology still appear, but most of what wouldn't appear, isn't wanted or needed anyway! Civilians will never need to use RTGs on earth, for example (and no one else should). So if the mission's science benefits are largely independent of the use of the RTGs, then the actual reasons for using the RTGs must be that much better if you are trying to use those reasons to justify taking a risk, as NASA is required to do. And the reasons NASA has given -- the reasons that could not be transferred to virtually any other project -- simply aren't that good. 2-6 (Continued)

7:

I wonder how come the maximum worst case scenario NASA describes in the DSEIS is only about 120 latent cancer deaths? 72 pounds of plutonium is just much more deadly than that! What has happened is that before calculating what the effect of the poison will be, they have first eliminated as much as 99% or more of the poison from the calculation. They did this several ways. First, they average the releases from different accident scenarios. On the flyby, their worst-case averaged to a little more than 1/15th of the total fuel pack. This averaging is an inappropriate calculation! Then, they ignore any area that will be damaged below an EPA threshold of .2 micro Curies per square meter. This is also totally inappropriate (more on that later). Then, they further eliminate possible "health effects" by using De Minimis (more on that later too). 2-7

8:

NASA claims that most of the RTGs will not be incinerated even in the worst of scenarios. But they are dealing with an object flying, burning through the air, that is *already* at about 1,100 degrees Celsius (and melts at about 2,300 degrees Celsius) AND which is in a cylindrical container with COOLING FINS which will catch the wind and burn off quickly, leaving numerous holes and cavities to rip open the RTG. Furthermore the RTGs are some of the *most dense* objects man puts into space (put up by some of the *most dense*... oh, never mind).

You can expect them to continue to travel at HIGH SPEED (=hotter) for a long, long time -- all the way to Earth impact, if they don't incinerate COMPLETELY first. They'll come in "hot", they'll come in heavy, and they can come in anywhere on Earth during the flyby. An RTG returning to Earth after a collision with a random piece of space debris or for any other reason is a disaster whether it is entirely incinerated in the upper atmosphere or not, but it is much more of a disaster if it is incinerated. 2-8

Even NASA's own estimates are that a very significant portion of the Pu 238 fuel will be released in the upper atmosphere: From 32% to 34% for all the reentry cases studied (see NASA's FEIS, June 1995, page 4-51). Of this, from 20% to 66% will be in the form of respirable particles. This is from 5 to 15 pounds of Pu 238 released at high altitude, and does not include any low-altitude and ground-level releases. That's for a "normal" reentry scenario. Any number of events can result in an "abnormal" reentry where more -- or even all -- of the fuel is incinerated.

9:

NASA groups flyby accidental re-entries into three broad categories, shallow, steep, and skip (leave the 2-9

atmosphere again). But in reality each angle presents a uniquely different scenario. The shallowest angles (that don't skip) are the most dangerous from the point of view of atmospheric incineration, while the steepest angles are most dangerous for impacts and subsequent fuel release near Earth's surface.

2-9 (Continued)

At the very least, each degree should be calculated separately and the result from each calculation should be graphed. It's thousands of numbers, and the resulting graphic should be presented, NOT just analyzed with only NASA's theoretical interpretation of the data presented, and no data!

10:

NASA's "skip" scenario (mentioned above, in item 9) enters Earth's atmosphere but subsequently leaves earth's gravitational pull completely. In reality, many "skip" scenarios will have the spacecraft slowed enough to fall back to Earth in weeks, months, years -- even centuries later. Some "skip" scenarios actually have the probe skimming through Earth's atmosphere dozens of times--sort of like skipping a stone on the water, but it happens at the innermost portion of a huge elliptical orbital path. NASA's "skip" scenarios appear to never fall back to Earth under any circumstances, a fallacy.

If Cassini stays in orbit around the Earth after a flyby mishap of any sort, it will continuously be subject to the possibility of a collision with some of the existing SPACE DEBRIS and any new space debris we add while Cassini is in orbit. Therefore, "skip" scenarios where the probe eventually falls to Earth are actually the most dangerous. If the probe stays up for centuries, which it **absolutely can do** (NASA admits this) the chances are actually *good* (better than 50/50) that it will collide with existing space debris, at incredible speed and kinetic force. This would break apart the RTGs *prior* to upper atmosphere incineration -- making the final incineration much more thorough and much more damaging. *This* is a situation where 100% of the RTG fuel can be burned.

2-10

11:

It seems that NASA has made the assumption that *all* "skip" trajectories would leave a clean (non-nuclear) vapor trail as they slice through the atmosphere. If NASA thinks this, they are wrong because some damage will occur to the spacecraft including possibly igniting the liquid fuel component; this damage could in turn hurt the RTGs. (But I must stress that few of NASA's actual methods are clearly described in the DSEIS.)

2-11

12:

De Minimis is ridiculous. Since plutonium in any quantity bombards local cells with enormous amounts of radiation, and since recent cloning experiments have shown that any cell with DNA (all but red blood cells, essentially) is capable of producing an entire animal from embryo to adult, it should not be considered a great leap to conclude that all cells are also capable of becoming cancerous when mutated by radiation.

2-12 (a)

Here's the sequence: Cancer is a consequence of cell DNA mutation. Plutonium's radioactivity mutates cell DNA. Inhaling plutonium is *absolutely* the most dangerous way to introduce it to lifeforms, 100's or even 1,000's of times more dangerous than ingesting it. Cassini's Pu 238 is about 280 times *more radioactive* -- yes, that means *much* more deadly -- than the so-called "weapons grade plutonium" which

2-12 (b)

NASA assures us isn't being used. Incinerating plutonium at high temperature and at high altitude is absolutely the "best" way to distribute it around the planet for subsequent inhalation. And finally, incinerating something that starts at over **1,000 degrees Celsius** and hangs out like three sore thumbs from the space probe is just too easy.

2-12 (b) (Continued)

What is a good phrase for it? You might call it a *chain reaction*! And when your chain runs out, you get to be a "health effect". If Cassini fails, a lot of people's chains will run out.

And if Cassini fails, the steps to cancer are not an unlikely sequence of events -- it is what will **actually happen** for thousands, possibly millions of people if Cassini fails. **Possibly many millions.** Vaporized plutonium is just incredibly, unbelievably deadly. Cassini carries enough plutonium that if just 1% of it were vaporized and then inhaled in a clinical lab situation, it would be enough to kill the entire world over without question. All 5.8 billion of us without even **using any of the plutonium twice**. In any actual accident scenario, much of the plutonium would be re-ingested many times. Make no mistake about it -- this is deadly stuff.

2-12 (c)

If Cassini fails, NASA has just three assurances for us against this threat: **First**: That only a little will vaporize. This is argued throughout this document. **Second**: That the world's ecosystem is so vast, that only a little of that which is vaporized will subsequently be breathed in by billions of people. But they won't even present the number they think is valid (see item 13, below). **Third**: That of those who do breath in some plutonium, only a very few will get cancer. But NASA will not use any of the dozens of studies of the effects of minute exposure to calculate how many might actually get cancer that way. Instead they extrapolate from a high exposure level (and relatively few cases) but the effect is *not* linear. Chopping in half the dosage and doubling the exposed population, then calculating that the same number of people will die, is not what actually happens. The more you divide it out, the more people will die.

2-12 (d)

And that's just what NASA's doing. Dividing it out. Here's some for you, and here's some for you. You probably didn't even know NASA was carrying plutonium on board *any* spacecraft before you heard about this web site, and now you think the "science" NASA will be getting will benefit you somehow? Is "worth the risk"? Face it, my fellow couch potatoes: You'll **never** benefit from NASA's possible knowledge gain, **never**, and hardly anyone else will either! And to gain all this "knowledge" NASA must use lies and deceptions, because so many Americans *do* know the truth, and my, they are raising a stink! But the effect is, the knowledge gain from the nuclear option for society is counterbalanced by the knowledge lost to secrecy, lies, and confusions. NASA bad science outweighs NASA good science. And the whole nuclear option -- we loose freedoms to not just nuclear terrorism, but to Government worries about nuclear terrorism. We loose honesty in Government because of the cover-ups and the lies. These we loose even if Cassini succeeds!

2-12 (e)

It's not that science isn't worth dying for, sometimes. Lots of things are worth dying for -- life, liberty, the pursuit of happiness. But this? Is it humanly possible that we cannot draw the line? That we cannot say "Ah ha! At last we have it! A science experiment so dangerous, of so little value, and so expensive, that we will not do it!" Ladies and Gentlemen, this is that science experiment. This draws the line. This is nuts.

2-12 (f)

NASA assurances are hollow. The truth is, a Cassini accident can rank as one of the biggest single manmade ecological disasters in history. Not only that, but **pure chance**, not **fancy engineering**, stands between a successful mission and a disaster. Random pieces of space debris in near earth orbit (put there by mankind, mostly) can impact Cassini and cause a catastrophic failure. Man's own potential failures just add to the risk, from loose nuts in the control room to misprogrammed software programs. We've all seen those, and anyone who writes software (including myself) knows that all software can crash and no

program is perfect. NASA is not perfect. NASA is human (I think).

Is this how we want to challenge God, or *the* gods, or fate, or nature, or just -- the odds? THIS ISN'T SCIENCE IN THE PUBLIC INTEREST. This is roulette. The public should not fund this stuff.

Let's say something unknown to mankind's sphere of knowledge killed off, over a period of a couple of decades, one out of every 5,800 people on the planet by an ailment that manifests itself as cancer. You cannot tell where the cancer came from. You cannot tell, but you die from it just the same. One in 5,800 is very hard to study. No one would notice that an unknown thing was happening. But 1,000,000 people would die around the world from this thing. You would die, but you wouldn't know why. And even if you do suspect why, you can't do *anything* about it, and besides, you'll be dead and can't do *anything* anymore. This thing is Cassini, and it can go on killing and killing for centuries.

2-12 (f) (Continued)

Cassini can do this, and you *still* may not be able to prove, statistically, that it happened! So if statistics are so hard to use, and NASA has used them so badly on the health side -- do you really want to trust them on the engineering side, especially considering all the engineering in the world won't stop a piece of space debris from destroying the mission anyway, during the flyby (or any time, really)? How many times do you think Fate can be tested before it gets sick of us?

2-12 (g)

There is lots of other evidence that there is NO minimum lethal dose of plutonium. Yet NASA uses something they call De Minimis. NASA's uses this De Minimis thing as a way of adjusting the data by eliminating "negligible" amounts of plutonium from the count. And who defines "negligible"? Why, NASA does, of course! .001 rem. NASA doesn't care if **5 billion people** get .001 rem, to them, it *doesn't count*. THAT's what De Minimis and NASA's other averaging techniques does. But that's not what really happens.

2-12 (h)

De Minimis as used by NASA is NOT a standard statistical gimmick. It is a statistical gimmick they **made up** for themselves! De Minimis says (according to the way NASA uses it) that below a threshold of .001 rem per year there will be "no discernible health effects to an individual". Facts prove otherwise, so De Minimis is ridiculous. Besides, by first limiting the area to that contaminated above 0.2 micro Curies per square meter, NASA is taking it's ridiculous De Minimis at least twice!

13:

One of the most important numbers is missing from the report. That number is the MAXIMUM INDIVIDUAL DOS, REM for an accident involving the RTG's during the Earth flyby. This number would show the amount of plutonium that would be expected to be absorbed by each individual on the planet in the event of an upper-atmosphere incineration of the RTGs.

Whenever this value should appear, instead there is a notation indicating the item is "Not available in the current analysis." What that means is that the study was done without one of the most crucial pieces of data! And that piece is missing from about 10 different tables (about 1/3 of the total number of tables in the two documents). A notation in the DSEIS indicated the value will be available in the final report -- but by then it's too late to argue about it! We need it NOW! (So we can argue about it, of course!)

2-13

14:

Where are the graphs? NASA claims they are using sophisticated computer modeling to produce their report. The subcontractor company that did the Nuclear Safety Analysis used for the report, Halliburton NUS, claims (on their web page) to be "an information age veteran... in the business of finding, storing, and communicating vital information... since 1973."

All modern statistical packages generate beautiful three-dimensional graphics, and have for decades. Instead NASA gives us 19th-century tables of exponential numbers! Perhaps NASA is afraid to give us a graphic showing the plume and it's potential consequences! 2-14

By giving us good graphical depictions NASA could present us with some of the **RAW DATA** that they supposedly have analyzed. Then, perhaps THE PUBLIC could make their own informed decisions. But no. NASA gives us one or two numbers which actually represent **complex functions**, and where the very act of averaging does not do any justice to the extremes. It's a way of "punching down" the data. It is commonly used by people who want to sell you a pig in a poke. It is being used *now* to sell us a pig in a poke.

15:

Why are NASA estimates of land area that might be contaminated so small? It is preposterous that only 8 or 15 square kilometers will be contaminated in a "worst case scenario" but that is what NASA's averaging techniques and their other techniques have left us. They are going about it all wrong. A more reasonable approach would be to figure out how BIG an area CAN be contaminated (for example, to a 50% lethal dose) with 72.3 pounds of Pu 238 particles in millions of pieces and millions of sizes, from all altitudes and directions, and *then* figure out what the chances really are of that actually happening. These are separate calculations, which should not be lumped together in a report. Nowhere is the stark reality expressed of what 72.3 pounds of incinerated plutonium can do, least of all, in an informative computer-generated graphic. 2-15

16:

If Cassini is as safe as NASA predicts, then why won't NASA and the United States Government insure it properly? Instead they use the archaic and inappropriate Price-Anderson act, which limits our international liability to just $100,000,000.00 in direct violation of an international Outer Space Treaty we co-wrote and signed. Domestically, Price-Anderson limits liability to about $7.3 billion, also hopelessly inadequate. If Cassini is safe, why do they limit the insurance payout at all? 2-16

17:

Even accepting (more or less) NASA's numbers is NOT a sustainable policy for safe space research (or for plutonium disposal). Some people right now want to put 820 satellites in orbit, for example, for just one communications project. If nukes are OKAY, then all of those might be nuclear powered. Nukes aren't okay for one mission, and they aren't OKAY for all of them. What we really need are fiber-optic cable systems throughout the world, not expensive, failure-prone, corporate-controlled and dangerous satellites. 2-17

18:

SPACE DEBRIS impacts can completely destroy the RTGs prior to (and causing) an Earth re-entry. Where is this specific scenario analyzed? 2-18

19:

You can't just say "each person will get this" or "that" amount -- Some will get larger particles, or more of them, and some will get less. It's a distribution. With BILLIONS of exposures, many people will receive 10 times the "average" dose -- a few unlucky individuals -- thousands, maybe even millions of individuals -- may even receive a hundred times the "average" dose. That's what happens when you irradiate the world through upper-atmosphere incineration of plutonium. So the numbers need to be "crunched" to reflect the varying sizes of the particles *and the distribution* of them. Any incinerating nuclear payload from outer space -- not just Cassini but *any* nuclear payload -- is a fierce fireball of filthy death.

I believe what NASA has done in averaging the doses is wrong. They have taken the amount of plutonium they think might be released, and theoretically spread it *evenly* among the exposed population. But first, they eliminate all who live where they will be exposed to a dose lower than the EPA standard measurement value per meter (using this value at all is inappropriate, but they use it). Then they further eliminate all those who would get less than .001 rem per year (equally inappropriate). Then they eliminate potentially 1/2 the world population -- or more -- for no good reason, by simply using a baseline of the expected population at the time of the flyby. But the damage will continue to occur for centuries after, or may not even start to impact Earth for decades or centuries, and the population will continue to grow in a world crowded today with **5.8** billion people. 2-19

Each step eliminates health effects from view.

20:

The inappropriateness of using the EPA limit mentioned above is clear when you consider **study after study** has shown that there is no minimum lethal dose of plutonium. At least three different ways to study it lead overwhelmingly to the same conclusion. **First**: You can study it by giving extremely small doses to extremely large populations of laboratory animals, large enough to be able to pass standard scientific tests of statistical significance. This is very hard to do, because you need tens of thousands, or even hundreds of thousands (or even millions) of animals to do the study, but to as much an extent as possible, it has been done. **Second**: You can study it by looking at publicly available data from health officials and radiation monitoring officials and compare the two sets of values. Dr. Sternglass, Dr. Gofman, Dr. Gould and many others have published numerous papers and books doing just this. **Third**: You can study the possible mechanisms within the body which would allow plutonium to "do its thing" at extremely low levels. And studies of mechanism after mechanism consistently point to the conclusion that there is no minimum lethal dose of plutonium. Any size particle can kill you. Maybe it will, maybe it won't, but it *can* and studies show that it *does*. Studies NASA won't use in their analysis. 2-20

21:

NASA's use of the EPA guideline is actually even more inappropriate than described above (in item 20). If the EPA guideline says that a cleanup need not be *attempted* below a certain threshold (for whatever reason) that doesn't mean that it's **just fine thank you** to pollute beneath that level. But that is the logic NASA has taken. They have taken a good thing -- an EPA standard (which may be way too high, but at least it's something) -- and turned it into a excuse to pollute! 72 pounds of plutonium is 72 pounds of plutonium no matter how you dress it up or spread it out. 2-21

22:

Out of 400,000+ Ci (Curies) total amount of radioactivity in the RTGs, NASA's worst case accident scenarios will "only" release about 26,000 Ci. Thus, NASA will not present any study on the effect of greater than about 1/15th of the total plutonium fuel being incinerated. This is preposterous. Space debris, as mentioned above, below, and all around the globe, can easily and randomly destroy an RTG. Even if we accept the assumption that it is relatively unlikely that all three RTGs would be hit by space debris (although space debris actually often does come in clusters), still, at the very least, since there are three RTGs, NASA should show health effects for *at least* 133,000 Ci released in an upper-atmosphere incineration. And *at least* a partial burn of the other 2 RTGs. If any of the **other** fuel onboard Cassini is hit, that could then incinerate one or more RTGs. The liquid fuel being carried onboard Cassini weighs more than entire previous probes like Galileo and Voyager (combined)! So that is perhaps 260,000 Ci -- 10 times more than NASA's "average". NASA needs to show the health effects, the geopolitical consequences, and the financial burdens of *these* scenarios!

We can leave it to Hollywood to show the effect of it coming down on New York City, say, on December 31st, 1999. (It can orbit for a while before crashing, so it really can come down anywhere, anytime.)

If Cassini is as safe as NASA claims, why can't they show a computer model of it landing *on a city* and tell us how many would die! A shallow reentry, burning 1/2 the RTGs, the wind to its back so the fallout collects and lands on Manhattan... and it lands on Time's Square, New York, December 31st, 1999... (If I'm around, I'll probably be there, and I'll probably be passing out leaflets.) What would happen? (From my leaflets?) 2-22

If Cassini crashed the world's biggest party: Not one building would get destroyed. But within a few weeks: **50 million people doomed**. That's what would happen. (From the initial event. Decade after decade, people would continue to die.) Oh, and: Maybe a couple of buildings would be destroyed, too. The RTGs will ignite anything they land on, since their "resting" temperature is about 1,100 degrees Celsius, and they would have just flown in from outer space using air friction against blunt surfaces as their only braking force. Okay but what are the chances of that actually happening? Zero if we don't launch!

Why is NASA afraid to show the effect Cassini can have on any teaming metropolis on the planet? Just so we all know what we're talking about: NASA certainly admits it *can* happen. Why won't they tell us what the effect would be? Their little space probe can do all that, and it doesn't take a long chain of events, either. One pea-sized piece of space debris alone can make this an inevitability. One single Random Event. Cassini has a "one hit" capability on a concentrated population center that is so devastating, it should be prevented by being prohibited.

When did we decide we should permit underpaid and overeducated scientists (or vice-versa, or anyone else) to risk random destruction on so vast a scale? They know they can't stop it from happening... It's just chance. They just claim they can reduce the chance. We don't really mind letting scientists blow up *their own* science labs -- fine. Have fun. Knock yourself out. But the proper way to reduce the risk to the planet on something like this is to *eliminate* the possibility of it happening. The money can go towards even higher-tech activities elsewhere.

2-22 (Continued)

23:

I just want to make sure that when NASA says that the RTGs will not break apart if they hit water, only land, that they include ICE as "land". The plutonium RTGs and their subassemblies will smash into fine particles and chunks if they impact on ice. Some would vaporize. Larger chunks and particles would melt through the ice to solid ground, making it almost impossible to retrieve the pieces quickly in places that are snow- and ice-covered at the time of the accident.

2-23

24:

Plutonium in the food chain is bad for people that eat food, but it should not go unnoticed (as it does in all NASA documents) that it is also bad for the food--bad for plants, bad for animals... Mankind will not be the only animal to get cancer and other illnesses should Cassini fail. In fact, for every human injury there will probably be tens of thousands of animal injuries. Do we want to inflict this pain, this suffering, on our fellow creatures, whom we have been charged with protecting, by nature of our being here at the top of the food chain, and (supposedly) being smarter as well? Do we want to inflict this insult on our fellow creatures, while relying on them for our sustenance, for work, for companionship? What are the radiological consequences for cats, dogs, cows, horses, pandas, or our close friend the pig? What are the effects on mice, rabbits, and other science experiment fodder? Then what are the effects on future science experiments? None of this is discussed in any NASA document, and it is devastating.

2-24

25:

RTGs are NOT aerodynamic by any stretch of the imagination, and they are heavy and have a series of pipes, valves, and other hardware. They WILL incinerate, and NASA predictions of just how much should be taken with a healthy dose of salt (with iodine, I presume).

2-25

26:

Speaking of iodine, in the event of an accident at launch, exactly *what* preparations, such as storing *millions* of iodine pills, has NASA taken to mitigate the effects? Since proper steps can reduce the danger, one would think that NASA and DOE have calculated the health effects numbers on the assumption that there will be adequate assistance from NASA after an accident.

But will NASA provide this assistance, worldwide, in a timely manner, 500 years from now when the probe might *still* be capable of falling back to earth? Or will NASA provide this assistance in some war-torn part of Africa in October, 1997, if something goes wrong during early lift-off?

2-26

27:

Since NASA is doing a SUPPLEMENTAL analysis, I think it makes sense that NASA should study the effects of the nuclear-payload-equipped Russian Mars '96 probe which recently incinerated, probably over Chili and Bolivia. This will take, as NASA knows, about 500 years to study properly. But the most crucial time to begin any study is *now*. And, NASA could test its cleanup procedures, starting with seeing if NASA can even FIND a nuclear payload that's been at least partially incinerated in the upper atmosphere, let alone seeing if NASA can actually clean up the mess. If nothing else, NASA has already shown that they are incapable of responding quickly to a changing situation. 2-27

One would think they would want to try to find that plutonium powerpack to see how well it actually survived re-entry. Since Russia sells us the plutonium and works with us on numerous nuclear space projects now, the similarities are probably significant.

Yet NASA is hardly studying it at all! Nothing in the DSEIS indicates they even noticed it. As usual, NASA is making no effort to find out the truth.

28:

There is no discussion of safe disposal of the radioactive byproducts (there are many) from isolating Pu 238. The stuff not destined for Saturn is still capable of poisoning Earth and has half-lives of around 25,000 years, and is highly radioactive. It will be **NASA's responsibility** for the next 500,000 years or so. The risk entailed in that isn't described in this report, and the cost isn't in any accounting reports I've seen, either... 10,000 years from now, even 100,000 years from now, NASA will be demanding money from your descendants for the upkeep on its nuclear waste facility used to store the byproducts being created *today* for "your" Cassini mission. That cost is not reflected in any NASA documents. 2-28

29:

Global implications (1): What if every country started to use the nuclear option? Sooner or later a firey accident would occur which might start a war, if for example an Iranian nuclear satellite plummeted onto Israel (or vice-versa). Nukes have no place in space! If Cassini fails, it could topple governments. If Cassini fails, Mr. Clinton, it will certainly ruin *your* party! 2-29

30:

Global implications (2): Political catastrophes accompanying a failure of Cassini -- these are not discussed in any NASA document I have seen anywhere! What is the appropriate document for these very important considerations? 2-30

31:

Global implications (3): Although NASA describes several clean-up scenarios (costing up to $1,000,000,000.00) it doesn't describe who will pay for this. And the costs given do not include 2-31

loss-of-property and loss-of-life costs, just *clean up* costs. And where does NASA think it can put all that poisoned dirt, anyway? Earth is a closed-loop system.

2-31 (Continued)

32:

Global implications (4): "No effect" is the way NASA describes the "no launch" alternative and it is the way they have *always* described it. But is that correct? NOT AT ALL! $3.4 *billion* dollars to clean up underfunded "Superfund" toxic waste sites, to interconnect the classrooms of America, to lay fiber-optic cable... That's not "no effect", that's progress. And that's just the "counter-balance" to a successful Cassini mission! If *anything* goes wrong, even with no release of plutonium, we're still out the money! If we had invested in kid's education, on the other hand, we would reap the benefits for decades -- including, perhaps, even more important discoveries than anything Cassini will bring if it succeeds completely!

2-32

33:

The DSEIS says that President Clinton has his own separate Cassini impact analysis. But it also says that the President's document is derived from substantially the same databases as the DSEIS and its results should be similar. Are geopolitical implications discussed in the Presidential statement? Can the public see it? Who wrote it for the President? The same company that wrote the Nuclear Safety Analyses for Cassini Mission Environmental Impact Statement Process? Will they give President Clinton another, *unbiased* view?

2-33

34:

What NASA has presented is not DATA to support their claims -- it is just the claims. They have distilled the information into a small set of numbers which is totally inappropriate for the complexity of the problem. They have clipped at every angle, from who should be counted to how much plutonium they might receive. They have held back vital information. They have used inappropriate studies of high-rem damage to extrapolate low-level damage, and they have ignored perfectly well-researched, easy-to-obtain reports in respected and refereed journals, reports which have shown that low-level radiation is 100's to 1,000's of times more dangerous than the large "shock treatments" of 10 to 50 rem which they choose to study.

2-34

This draft, as written, assures us of **nothing**.

35:

The global model that NASA uses to do their modeling divides the world into 720 "grid boxes" of equal size. This is not nearly enough for an accurate model since the incinerated plutonium in millions and millions of tiny particles will be carried by the wind, which exhibits a much-too-complex behavior pattern to determine in just 720 grid boxes. If someone were to try to prove global warming, for instance, with so few grid boxes, they would probably be laughed out of the science halls!

2-35

36:

NASA's contractor on the DSEIS is Halliburton NUS Corporation, a part of NUS Information Services, Inc. They did the basic study under contract to our government. This company describes itself (at it's web site, at the time of this writing (4/9/97)) as doing the following for a living: "Information Services' staff members use a total of more than 50 internal and external data bases and 70 million pages of text to find solutions for more than 660 electric generating units worldwide."

Another thing they do is run a Licensing Information Service, described by them at their web site as "Serving the nuclear industry since 1973 with a variety of regulatory information."

But perhaps the most interesting thing they do is sell a **Computer-Aided Regulatory Library**. It is described **by them** at their web site (at the time this was written) as: "[A] CD-ROM library full of Nuclear Regulatory Commission documents that can be searched and manipulated in numerous ways by the powerful [software]." Manipulated. I couldn't have said it better myself. 2-36

Clearly they are part and parcel a pro-nuclear organization masquerading as an information service. The fox is guarding the henhouse, except here, the henhouse is mother earth. If Halliburton NUS have 70 million pages of text available to them, why oh why don't they know about the hazards of extremely low levels of radiation to woman's breasts, to infants, and to fetuses? Why doesn't NASA know of Dr. Sternglass's work, if this wonderful information company is so thorough at providing information? There is *not one word* in the DSEIS on breast cancer, *not one word* on damage to fetuses, and *not one word* on any *specific* cancers at all! All the studies were done as if the effects were universal -- the same for all people. They aren't. Specifically, woman, fetuses and infants will suffer the greatest insult if Cassini fails. Nowhere -- absolutely nowhere -- is this discussed in any NASA document that I can find. Certainly not in this important one. This document only covers death, and it doesn't even do that very well. Instead it **covers-up** death. It's all a shell game -- but they're using live shells!

In reality NASA's "research" just proves one thing: that NASA does not *dare* to present – or even consider – the true possibilities of the situation.

By Russell D. Hoffman

NASA's draft document will remain open for review until 4:30 pm, (Eastern Daylight Time) May 27th, 1997. So this important next step -- demanding more answers -- is coming to a close soon.

DON'T JUST READ THIS, DO SOMETHING!

You can order a copy of the Draft and accompanying Nuclear Safety Analyses, and the original "Final" EIS and other NASA documents directly from NASA. Or -- since it's getting late (Cassini launches in October, 1997) -- you can **cut right to the chase** and start contacting our elected officials right away. For example, print this document, and circle the points **you** think are most important, and tell NASA you will personally want to see them properly answered in NASA's upcoming SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT. Send the document, with your notes, directly to NASA before May 27th, 1997. Send a copy to your local press. Send a copy to the White House, too! And tell

President Clinton that his "private" Cassini report needs to answers these charges as well. Or save trees and time (and we're almost out of time -- and trees): Email him the same message.

The two documents discussed in this article are the DRAFT SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT FOR THE CASSINI MISSION (APRIL 1997) and NUCLEAR SAFETY ANALYSIS FOR CASSINI MISSION ENVIRONMENTAL IMPACT STATEMENT PROCESS (HNUS-97-0010). *To contact NASA:*
Mark R. Dahl, Program Executive,
Cassini Mission & Payload Development Division
Office of Space Science, Code SD
NASA Headquarters
Washington DC 20546-0001
Comments to NASA must be submitted **in writing** and received at that office no later than **4:30 pm Eastern Daylight Time, May 27, 1997.** This is my answer.

CANCEL CASSINI

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- If you add a link to this document, and you think your visitors can stand a little levity (who can't these days?), you might want to tell them it's an **LQ. test for Space Cadets** which is self-scoring, educational, fun and free, and which they can take in the comfort and privacy of their own home! (It's official title, however, is Laugh, Cry, Be Angry, Do Something...)
- Contact your congressperson. We must tell NASA we will not allow even one more launch based on the unsafe nuclear option!

Related pages at this web site:
Stop Cassini Home Page
No Nukes In Space! Not now, not ever.
Space Debris Home Page
A series of articles on this shameful problem.

This article has been presented on the World Wide Web by:

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http://www.animatedsoftware.com
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Written April 9th, 1997.
Last modified May 23rd, 1997.
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Comment No. 2-a

The commentor is referring to the "hot particle" issue raised in the 1970s. This issue addressed the practice of averaging the dose over the total lung mass. This issue was based on the premise that high dose rates to cells adjacent to radioactive particles deposited in the lungs led to much greater cancer risks than were represented by averaging the dose over the total lung tissue. Experimental animal studies have consistently refuted this premise (ICRP 1994).

The health physics community has generally used the radiation dose model presented in ICRP-30 which used the dose-averaging approach (ICRP 1979). The International Commission on Radiological Protection (ICRP) establishes recommendations and guidelines for assessing radiation doses. The U.S. Department of Energy, the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Environmental Protection Agency (EPA) use these recommendations and guidelines to assess potential radiation doses. The concerns of Dr. Morgan and others have been taken into consideration by the health physics community in developing the ICRP recommendations regarding radiation dose estimates.

REFERENCES

International Commission on Radiological Protection (ICRP). 1979. Limits for Intakes of Radionuclides by Workers. ICRP Publication 30.

International Commission on Radiological Protection (ICRP). 1990. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. 1990.

International Commission on Radiological Protection. 1994. Human Respiratory Tract Model for Radiological Protection. (ICRP-66).

Comment No. 2-1

The Cassini mission as planned and described in Section 1.2 and 2.1 of this Final Supplemental Environmental Impact Statement (FSEIS), and in Sections 1.2 and 2.2 of the June 1995 Cassini Environmental Impact Statement (EIS), includes a four year tour of the Saturnian system beginning in 2004, encompassing important investigations of Saturn, its rings, icy satellites, and magnetosphere. During this four year tour there will also be intensive investigations of Saturn's moon Titan by both the Cassini Orbiter and the Huygens Probe.

The primary purpose of the Cassini mission is to study in detail over a four-year period, the Saturnian system – the planet, rings, magnetosphere, and the moons, particularly the large satellite Titan, which shares many characteristics with prebiotic Earth. The result of the Cassini exploration of the Saturn system will be new scientific knowledge. This in turn will lead to new understanding about how the solar system

formed, how each of the planets evolved, and what conditions are necessary for life to begin. Cassini's findings would also enhance our scientific knowledge for characterizing the forces and conditions that create and drive processes such as volcanism and tectonics, and weather and climate changes.

The limiting factor for spacecraft operational life is the amount of attitude control propellant, not the GPHS - RTG sources of on-board electrical power. GPHS - RTGs have been demonstrated to be very reliable, long-lived power sources for scientific space exploration missions as evidenced by their performance on the Pioneer, Voyager, Galileo, and Ulysses missions.

Please also see response to comments 1-1 and 2-6.

Comment No. 2-2

As noted in Section 2.1.4 of both the Draft and Final SEIS, use of solar power is not viable for the Cassini mission. The commentor is also referred to the JPL Supporting Study - Volume 2 (JPL 1994) referenced in Chapter 8 of both the Draft and Final SEIS. The Jet Propulsion Laboratory analyzed circular solar arrays for NASA early in the development of the spacecraft design. The use of a circular solar array for the conceptual "solar" Cassini spacecraft presented no net advantage over the linear design depicted in the DSEIS. Circular arrays do not "pack" solar cells as efficiently (i.e., fewer cells per unit area, because the cells themselves are rectangular) so the area required for equivalent cell density is greater for a circular array. A circular array would have to be moveable in at least two axes (as opposed to a linear array which can be moveable in one axis) to fit within a launch vehicle payload fairing and would require additional support structure, contributing to a mass greater than that required for the linear array. In addition, when the circular array was pointed at the sun for power, it would often be pointing near Earth, meaning that either the array or antenna would need to be placed on a long deployable boom to avoid obstruction of the antenna or instruments. This would also constitute an additional mass element.

Comment No. 2-3

Extending the consequence analyses beyond 50 years would not yield a substantial increase in collective dose. The estimates do not go beyond 50 years because the availability of the radioactive material potentially released would become limited over time.

The presence of plutonium dioxide within the environment and its availability for exposure following an accidental release would be limited due to the insoluble character of plutonium dioxide and the largely non-inhalable particle sizes of most releases. For releases within the troposphere following launch area or out-of-orbit accidents, most of the dose to exposed populations would occur as a result of direct inhalation during the initial plume passage and the inhalation of resuspended material during the first year following release.

176

The environmental removal mechanism of weathering would effectively remove most of the deposited material from further interaction with the population after the first year. When potential long-term agricultural and garden ingestion pathways are considered, most of the ingestion doses result from direct deposition on above-ground leaf surfaces following the initial plume passage. The insoluble nature of the plutonium dioxide renders the bioaccumlation through root uptake an ineffective contamination mechanism. Subsequent weathering of material from the upper soil layers through runoff or downward percolation, removes such material from the surface.

Any high altitude release of vaporized material following an inadvertent EGA reentry would be gradually removed from the atmosphere over a period of years, primarily by rainout from the lower troposphere, with ground-level air concentration peaking around 5 years following high altitude vapor release. Again, weathering following deposition would effectively remove such material from the environment during subsequent years. Any plutonium dioxide deposited in water bodies or making its way to water bodies by runoff and weathering would be largely tied up in sediment and removed from the water column.

The effectiveness of such environmental removal mechanisms of plutonium dioxide within the atmosphere has been demonstrated by fallout studies of atmospheric nuclear weapons tests. When such factors are taken into account, extending the exposure period beyond 50 years, and even taking population growth into account would not significantly increase (i.e., less than 5 percent increase) collective dose.

Comment No. 2-4

The effectiveness of environmental weathering mechanisms in reducing the bio-availability of PuO_2 within the environment has been addressed in the response to comment 2-3.

It is generally recognized that the concentrations of radionuclides released into the environment (air, water, and soil media) increase in the lower trophic levels of the food chain, while the sensitivity to radiation effects decrease. The greater tolerance to radiation effects is due in part to the shorter average lifetimes of animals which preclude cancer development when compared to humans.

Potential impacts to flora and fauna were discussed in the Final Environmental Impact Statement for the Galileo Mission (Tier 2), distributed by NASA in May 1989. A portion of that appendix is pertinent to this comment, and is summarized here.

The availability of plutonium dioxide to biota in aquatic and terrestrial environments depends on the route of plutonium dioxide exposure to the biota and the physical and chemical interaction of the plutonium dioxide with water and soil of the affected area. These interactions determine whether plutonium dioxide is available for root uptake by plants or for ingestion and inhalation by aquatic and terrestrial fauna. The route of plutonium dioxide exposure differs between the two basic categories of biota, flora and fauna. Flora, in both aquatic and terrestrial environments, can be exposed to plutonium dioxide contamination via surface contamination, root uptake,

and leaf absorption. Fauna can be exposed via skin contact, ingestion, and inhalation of plutonium dioxide particles.

Surface contamination and skin contact do not pose a significant danger to biota. The alpha radiation emitted by plutonium has very little penetration power. Therefore, little penetration can occur through the skin of fauna. In addition, several studies on root uptake and leaf absorption of plutonium dioxide indicate that very little, if any, plutonium dioxide is absorbed by plants.

The significance of ingesting plutonium dioxide can vary between terrestrial and aquatic fauna. Most plants have limited uptake and retention of plutonium dioxide, and the digestive tracts of the animals studied tend to discriminate against transuranic elements. However, ingestion may be significant for small fauna in terms of total exposure. These fauna, especially those that burrow, ingest soil along with food material. If the soil is contaminated, ingestion of plutonium dioxide could result. Although the transfer factor from the intestinal tract to the blood and other organs is small, total activity passing through the tract could be large.

The impact of ingesting plutonium dioxide by aquatic fauna can be significant depending upon plutonium dioxide availability. For example, studies have found that accumulation of plutonium dioxide does occur in benthic organisms that ingest sediments contaminated with plutonium dioxide. Inhalation is considered to be the most critical exposure route for terrestrial fauna.

Inhalation impact depends on several factors, including the frequency of resuspension of plutonium dioxide, the concentration and size of resuspended particles, and the amount actually inhaled. Smaller particles have a greater chance than larger particles for being resuspended and inhaled. Although many of the particles may be subsequently exhaled, the smallest particles have the greatest likelihood of being retained deep in the lung. However, resuspended material available for inhalation is on the order of $1x10^{-6}$ of the ground deposition. Thus high levels of ground concentration would be required to constitute a risk to animals through this route.

Generally speaking, radiation can cause three main types of physical effects on organisms: 1) somatic injury, that is, damage to the normal morphology and functioning of the exposed organism; 2) carcinogenic injury, that is, an increase in the incidence of cancers; and 3) genetic injury, affecting reproductive cells and causing deleterious genetic changes in organism offspring. Any of these three physical effects could cause increased mortality to exposed organisms. Although maximally exposed individual organisms could die as a result of these effects, overall ecosystem structure is not expected to change, and therefore no significant ecological consequences are anticipated.

Response to comment 2-3 addresses the reasons why the consequence analyses were not extended beyond 50 years.

Comment No.2-5

Yes, human factors were included. While human error is not easily quantified and generally not included in many reliability predictions unless specific data is

available, the Cassini RTG Databook has accounted for it as part of the uncertainty estimates and incorporation of flight history. Uncertainty bounds were applied to the failure rate of each failure mode to account for process and human factors errors. This creates a range of failure rates that accounts for uncertainty in the estimated mean failure rate value. This uncertainty range is carried through the calculations to each accident scenario probability. Flight history is also used in the calculations which will contain the results of human error. The failure rates of the launch vehicle are combined with the historical launch success/failure data to produce a refined estimate of failure that accounts for actual flight experience.

The degree of precision reported is necessary to maintain the integrity of the calculations. For details of the analyses, refer to the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997) which have been forwarded to the commentor.

Comment No. 2-6

It should be noted that Section 102(d) of the National Aeronautics and Space Act of 1958, as amended [42 USC 2451 (d)], provides in part the following:

"(d)The aeronautical and space activities of the United States shall be conducted so as to contribute materially to one or more of the following objectives:

(1) The expansion of human knowledge of the Earth and of phenomena in the atmosphere and space; ***
(5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere; ***"

The technology advances created by the U.S. investment in space exploration are considerable. It is a fact that spin-offs from technology development in connection with space exploration find their way into medicine, communications, transportation, and many other facets of our lives.

Comment No. 2-7

While there are about 73 pounds of plutonium dioxide in the Cassini spacecraft RHUs and RTGs, the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997) show that there are no credible accident scenarios which would lead to the release and dispersal of the full plutonium dioxide inventory. The GPHS modules are rugged devices and the plutonium dioxide, does not readily disperse into fine particles because it is a ceramic material. It should be kept in mind that the chances of an inadvertent reentry occurring on the flyby portion of the mission are vanishingly small, about 1 in 1.25 million.

The amount of plutonium that might be released in the event of an accident has not been underestimated as the commentor implies. As noted in the question, the

NASA Draft SEIS presented mean values for the potential releases that could occur in the case of a flyby reentry, but this is not the only value reported in the Draft and Final SEIS information. Larger releases are also reported, but they also have lower probabilities. In conducting the safety analysis of the potential reentry, scenarios were analyzed thousands of times using a distribution of inputs and a sophisticated computer program designed to capture all possible outcomes.

Contamination below 0.2 μ Ci/m^2 (μMi per square meter) is not ignored. The health effects calculations do take into consideration contamination below this level. The 0.2 μ Ci/m^2 level is simply provided as an indication of the land contamination areas for which the requirement for further action should be evaluated.

The commentor suggests that NASA eliminated possible health effects by using the concept of "de minimis". The commentor is in error and should see Section 4.1 of both the Draft and Final SEIS where it is clearly noted that de minimis was not considered in estimating accident consequences reported in either the Draft or Final SEIS.

Comment No. 2-8

The estimates presented in the Draft SEIS were based on the best analysis currently available on the potential consequences of a swingby reentry accident. The current best estimate is (LMM&S b, Vol. II, Book 1, Section 5.4.5) that on the average only a fraction (approximately ½ kilogram) of the RTGs total plutonium dioxide inventory would be in the form of an in-air vapor release. While the analysis considers a wide range of scenarios that encompass both smaller and larger in-air vapor releases, the analysis indicates no credible case that results in an in-air release of the RTGs full inventory of plutonium dioxide.

Comment No. 2-9

The analysis did not involve simply selecting three categories, i.e., "shallow, steep, and skip" trajectories. The angles were selected to characterize the range of angles for which one would expect the outer aeroshell to fail due to ablation and structural loading. The results were then used to predict whether the aeroshells would survive or if the graphite impact shells (GISs) would be released from the aeroshells. Analysis was then conducted to determine the performance of the GISs during the remainder of the reentry trajectory. Please see the recently available Safety Analysis Reports (LMM&S a-j; and EG&G 1997), specifically Volume II Book 1 Section 5 and Volume II Book 2 Section E.

Comment No. 2-10

The assertion that NASA's skip scenarios "never fall back to Earth under any circumstances..." is incorrect. In our analyses, all "skip" scenarios where the spacecraft is sufficiently slowed to be captured by the Earth's gravity field and subsequently

reenter the Earth's atmosphere at a later time are counted as Earth impact scenarios. Our studies indicate that at entry angles equal to or greater than 7.32 degrees at an entry altitude of 122 km (76 miles), the spacecraft would directly reenter the Earth's atmosphere.

At entry angles between 7.16 and 7.32 degrees, the spacecraft would skip out of the atmosphere but lose enough energy to be captured by the Earth's gravity field, reentering after several (but not "dozens") orbits around the Earth. It should be noted that if an accident were to alter the spacecraft's trajectory into an Earth-impacting trajectory, the probability of reentry at angles between 7.16 and 7.32 degrees is about 1 in 500 (JPL 1997). At entry angles less than 7.16 degrees, the spacecraft skips out of the atmosphere still at or greater than Earth escape speed, and is not subject to a short-term reentry. In some of these skip-out scenarios, the spacecraft could still be subject to a long term reentry (i.e. an Earth orbit crossing trajectory) probability; in other cases, the spacecraft could leave the Earth in a direction that would preclude any chance of a long-term reentry.

The implication in this comment that NASA's skip scenarios can lead to the spacecraft being in orbit around the Earth for "centuries" is incorrect. "Skip" scenarios where the spacecraft is sufficiently slowed to be captured by the Earth's gravity field result in reentries that occur within months of the first skip. The only condition that could result in the spacecraft staying in orbit for "centuries" is the Sufficiently High Orbit (SHO) maneuver. A study of the potential effects of orbital debris on the spacecraft in this condition concluded that the probability of the spacecraft posing a threat to Earth due to collisions with orbital debris, either while boosting to or while in SHO, is extremely remote. Over the 2,000 year period of the SHO a total of 14 hits by orbital debris particles of 1 cm (or smaller) diameter is predicted. To impart a rotational speed sufficient to cause the spacecraft to come apart or to "throw off" parts would require many more collisions than what is expected.

Similarly, to alter the spacecraft SHO to the point where other forces would cause the orbit to decay more rapidly (a change in velocity [DV] of approximately 74.6 meter/sec), would require several thousand 1 cm diameter particle collisions, all from the same direction, to produce this large a DV. The probability of collision with a single larger object is similarly remote. Even assuming a difference in relative speed as large as 20 km/sec., a single object would still have to have a mass of approximately 15 kg to produce the needed DV. At typical orbital debris velocities, it would be more likely that the object would rip through the spacecraft, leaving the remnants in roughly the same orbit the spacecraft was in prior to impact. Since there are relatively few spacecraft around the 1200 km (745 mi) altitude, the chances of collision with another object similar in size to Cassini is also remote, especially given that all these objects are tracked and monitored from the ground.

Comment No. 2-11

Analysis of the skip trajectories indicates that localized heating can cause a release of the spacecraft liquid propellants. Ignition of the propellants, however, is not

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expected because they would be rapidly dispersed at the reentry velocities which would prevent significant mixing of the propellants. It is also expected that, for some of the skip trajectories, heating can melt the aluminum case of an RTG and release the individual GPHS modules, which could then reenter and impact the Earth. The outcome of such a reentry would not be different from other reentry scenarios.

Comment No. 2-12 (a) - DOE

Please see response to comment 2-7, final paragraph.

Comment No. 2-12 (b)

The potential consequences of exposure to plutonium were addressed in Appendix C of the June 1995 Cassini EIS.

In the comparisons made in the Draft and Final SEIS, the quantities of Pu-239 are described in terms of curies. A curie is a unit of activity defined in terms of a specific number (3.7×10^{10}) of disintegrations (decays) per second. The 1995 Cassini EIS provides the amount of activity released during the weapons testing program in terms of curies. A curie of activity from Pu-239 is equivalent to a curie of activity from Pu-238, and their radio-biological health effects are nearly equivalent.

Please also see response to comment 2-7, first paragraph.

Comment No. 2-12 (c) - DOE

Potential cancer induction and genetic effects are described on pages C-5 and C-6 of the June 1995 Cassini EIS. The health effects estimator used to estimate excess cancer fatalities reflects consideration of a range of cancer types. The International Commission on Radiological Protection publication, ICRP-60 (ICRP 1990), addresses total detrimental effects, including fatal and non-fatal cancers and severe hereditary effects, in terms of an adjusted estimator of 7.3×10^{-4} effects per person-rem.

The overall approach to radiation health effects has been outlined in ICRP-60, reflecting consideration of the Committee on the Biological Effects of Ionizing Radiation (BEIR), and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) studies. The conclusions in ICRP-60 represent general consensus within the health physics community, although by no means reflective of the viewpoints of all. As such, the approach taken to health effects estimates in both the Draft and Final SEIS is consistent with that taken at the Federal level regarding potential radiological consequences of postulated radioactive releases resulting from nuclear incidents and accidents.

There is much disagreement within the health physics community regarding the effects of low-level radiation. Many of the issues regarding the mentioned effects relate to gamma radiation and are not really relevant when dealing with alpha radiation. While gamma radiation is associated with plutonium dioxide, its contribution to the

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dose is very small (less than 1 percent compared to that associated with alpha radiation).

There are varying viewpoints regarding the effects of low-level ionizing radiation. While a multiplier effect at low doses is promoted by some, such a potential characteristic is not supported by the general health physics community in light of animal studies, human health effects studies, and consideration of changes in natural background radiation from region to region (NAS 1988, NAS 1990, and ICRP 1990).

Comment No. 2-12 (d)

All potential doses were considered in estimating the accident consequences reported in the Draft and Final SEIS.

Comment No. 2-12 (e)

The commentor's accusations are unfounded. The Draft and Final SEIS have been prepared using the best available information. See also responses to comments 2-a and 2-36. The commentor has been supplied with a copy of the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997), which are referenced in this Final SEIS.

Comment No. 2-12 (f)

The comment postulates a non-credible scenario that has no plausible relationship to the possible accidents that could occur with the Cassini mission. Please see response to comment 2-18.

Comment No. 2-12 (g)

There are more than 7,000 objects whose trajectories are known that orbit the Earth within the altitude band from about 200 km (124 mi) to 40,000 km (24,800 mi). There is a much larger population of objects below 10 cm (about 4 inch) in size that is also predicted within this region. The total volume of this region is roughly 100 trillion cubic km (24 trillion cubic mi.). During the Cassini swingby , the spacecraft sweeps out a volume of only 2.3 cubic km (0.55 cubic mi.). When the appropriate particle densities are included in the actual analysis, the probability of Cassini receiving a critical hit (leading to an Earth impact) is calculated at 7.5×10^{-8} for particles of 1 gm or larger, and at 2.2×10^{-5} for particles of size 1 milligram or larger. Additionally, the spacecraft speed is so high at this point in the mission that no collision with space debris could provide enough energy to put the spacecraft or its RTGs on an impact course with Earth.

Comment No. 2-12 (h)

Please see response to comment 2-7 last paragraph and response to comment 2-12 (d).

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REFERENCES

National Research Council. 1988. Health Risks of Radon and Other Internally Deposited Alpha Emitters. Report from the Committee on the Biological Effects of Ionizing Radiation (BEIR IV), National Academy Press, Washington, DC. 1988.

National Research Council. 1990. Health Effects of Exposure to Low Levels of Ionizing Radiation. Report from the Committee on the Biological Effects of Ionizing Radiation (BEIR V), Board on Radiation Effects Research, Commission on Life Sciences. National Academy Press. Washington, DC. 1990.

Comment No 2-13

This Final SEIS now includes this information, which recently became available (See Table 4-2). It should be noted that the "maximum individual dose" refers to a maximally exposed person in the population for each mission segment accident simulation. The maximum individual dose is a useful indicator of the upper limits of radiological risk to which an individual in the population might be exposed due to an accident; whereas the collective dose, which incorporates the maximum individual dose as well as all lesser doses, quantifies the radiological risk in the total potentially exposed population. The maximum individual dose is included as part of the cumulative population dose, which is used to estimate accident consequences.

The commentor is incorrect in implying that the maximum individual dose would be expected to be received by each person in the event of an upper atmosphere release from a swingby accident.

Comment No. 2-14

The analysis performed involved simulating thousands of accident scenarios and thousands of release scenarios. Because it is not practical to generate a graphical presentation for each case, the analysis proceeded on a mathematical analytical basis, as opposed to graphical analysis. The Safety Analysis Reports (LMM&S a-j; EG&G 1997), which were recently completed, make extensive use of graphics to present results of the analyses.

Comment No. 2-15

The estimates of land contamination take into consideration the physical mechanisms that are required to distribute the released material. The recently available safety analyses (LMM&S a-j; EG&G 1997) incorporated among other factors, meteorological factors and particle size distribution of postulated releases, to distribute the released material. The scenario described in this comment could not happen in an accident. The plutonium dioxide is contained within two rugged graphite (carbon-carbon composite) structures and encapsulated within iridium shells. These materials

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are designed to mitigate the effects of atmospheric heating and mechanical loads experienced during reentry and the subsequent impact event. With respect to the commentor's implication that the entire inventory on board the Cassini spacecraft could be released, there are no credible accident scenarios which would lead to the release and dispersal of the full inventory of plutonium dioxide.

Comment No. 2-16

The comment takes out of context the monetary amounts authorized by the Price-Anderson Act for indemnification, and confuses the indemnification authority with insurance coverage. The commentor is referred to the entire text of 42 USC Section 2210 for the proper context of the monetary limitations authority of Price-Anderson. Further, it should be noted that the Price-Anderson Act Amendments of 1988 (Pub. L. 100-408, 103 Stat 1066, August 20, 1988), as amended, is the law of the United States and does not violate treaty obligations under the Outer Space Treaty (i.e., 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies).

Comment No. 2-17

Nuclear power is only used or proposed when it provides technical benefits. The RTG technology has a proven record of long-term reliability in space applications and is the only power system that satisfies all the performance criteria associated with the Cassini mission. The satellite systems mentioned which would support commercial communication networks do not come under NASA's purview, but it is extremely unlikely that any commercial vender would suggest the use of nuclear power for Earth orbiting communication systems. For Earth orbiting communication systems, solar arrays are the power system of choice. This is because the Earth is much closer to the sun and sunlight is sufficiently intense to permit its use in Earth orbit. This is a significantly different scenario than that for the Cassini mission where the sunlight at Saturn is not sufficiently concentrated to permit the use of solar arrays as a power source.

Comment No. 2-18

There are more than 7,000 objects whose trajectories are known that orbit the Earth within the altitude band from about 200 km (124 mi) to 40,000 km (24,800 mi). There is a much larger population of objects below 10 cm (about 4 inch) in size that is also predicted within this region. The total volume of this region is roughly 100 trillion cubic km (24 trillion cubic mi). During the Cassini swingby, the spacecraft sweeps out a volume of only 2.3 cubic km (0.55 cubic mi). When the appropriate particle densities are included in the actual analysis, the probability of Cassini receiving a critical hit is calculated at 7.5×10^{-8} (about 1 in 13 million) for particles of 1 gm or larger, and at 2.2×10^{-5} (about 1 in 40,000) for particles of size 1 milligram or larger. However, the spacecraft

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speed is so high at this point in the mission that no collision with space debris could provide enough energy to put the spacecraft or its RTGs on an impact course with Earth.

Comment No 2-19

As in the Draft SEIS, the NASA Final SEIS and the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997) provide not just the mean but a range of potential doses with the associated probabilities of the doses occurring. This range of doses is presented for the 5-th, 50-th, 95-th and 99-th percentiles. Stated differently, both the Draft and Final SEIS provide the probability that a dose could be equal to or greater than the dose given in each of the percentile tables. The 0.2 $\mu Ci/m^2$ guidance level developed by the U.S. Environmental Protection Agency (EPA) is used in the Draft and Final SEIS only as an indicator of the potential extent of land contamination that may need further evaluation. Potential low doses were not excluded from the health effects calculations. Those calculations incorporated all potential doses, from minuscule to high.

For the population to be exposed to radioactive materials, the material must be transported to areas in which people are located. A significant consideration in the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997), and in the safety analysis process still ongoing, involves transporting of particles using models of wind and weather conditions. That modeling of transport processes produces a range of land contamination values. Because of the varying particle sizes in a potential release, the material would not be evenly dispersed.

The commentor incorrectly implies that the potential effects of a release would continue for generations and perhaps even involve more people as population grows. Please see response to comment 2-3.

Comment No. 2-20

The commentor appears to be confusing the EPA guideline level for land contamination with the de minimis concept.

The implication that NASA has discounted its estimates of consequences by incorporating a "minimum lethal dose of plutonium" is misleading. There is an ongoing discussion within the scientific community as to whether small levels of exposure below 1 millirem per year (0.001 rem/yr) can, over 50 years, induce a cancer fatality. This is referred to as the "de minimis" level. The safety analysis takes no credit for the fact that there could be a dose level below which no effect will be observed. All estimates in both the Draft and Final SEIS of the potential health effects that could occur over 50 years due to exposure to plutonium take into account all exposures to plutonium, no matter how small.

The average individual receives 300 millirem per year (15,000 millirem over a 50 year period) due to natural background radiation. The results reported in both the

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Draft and Final SEIS incorporated all dose estimates and health effect estimates even if they were less than 0.001 rem over 50 years.

Comment No. 2-21

The EPA guidance level is utilized for evaluative purposes in the impact analyses as a land contamination level at or beyond which further evaluations should be considered. It is not a definitive statement regarding the land area that would or would not be considered for mitigation. In the unlikely event that an accident releasing plutonium were to occur, the extent and level of actual contamination would be determined, and appropriate measures implemented. See also response to comment 2-20.

Comment No. 2-22

The analyses considered only credible accident scenarios. Neither the Draft nor Final SEIS provides an estimate of health effects involving the release of material equal to a full RTG because best estimate analysis predicts that only a small fraction of the aeroshells, and in turn the graphite impact shells, would erode sufficiently to result in an in-air release of plutonium. For the most severe reentry case, that associated with an Earth Gravity Assist (EGA) flyby, the analysis performed to date predicts that, on the average, less than two of 54 modules would release their material in the air. In turn, only a portion of that material would be of a form and location such that it would be inhaled by persons around the world. Impact with space debris would not significantly alter this finding. Reentry from an EGA or collision with space debris are of such a low probability that they are not expected to occur.

Neither on-orbit nor reentry release of liquid propellant would result in damage to the RTGs. See also response to comment 2-11.

The potential for plutonium dioxide releases in highly populated areas is included in the collective dose and health effects predicted for the inadvertent EGA reentry accident, but the dominant contribution to these radiological consequences is related to very low dose levels (hundreds to thousands of times less than natural radiation dose levels) received by the global population. NASA has taken extraordinary efforts to reduce the chance of an inadvertent EGA reentry accident to less than one in a million. The probability of hitting a highly populated area is further reduced by several factors. Three-quarters of the Earth's surface is water. An impact onto water would not result in any releases of plutonium dioxide. Further, the areas with high population represent only a small fraction of the Earth's surface. This further reduces the probability of an aeroshell impacting in a populated area. The probability of having such an impact is on the order of less than one in one-hundred million.

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Comment No. 2-23

Ice impacts were accounted for in the analysis (LMM&S a-j, specifically Vol. III, Book 2, Appendix E, page V. III E-8). Impact on ice might produce releases similar to those associated with impacts on rock. Impacts on snow or packed snow would be less likely to produce releases. Overall, the potential for release under ice and snow conditions would not be significantly different than that for impacts on soil and rock, which were addressed in the simulations referenced in the Final SEIS. While recovery of plutonium from icy conditions might complicate the recovery process, the presence of moisture upon impact could lessen the spread of the particulate that is assumed in both the Draft and Final SEIS.

Comment No. 2-24

Please see response to comment 2-4.

Comment No. 2-25

The RTG casing is designed to melt upon reentry, releasing the modules, which in turn reenter individually and reach the ground at the much reduced, terminal velocity (about 49 m/sec). This design protects and contains the module's plutonium dioxide under a wide range of entry and impact conditions. RTGs and RHUs are not nuclear reactors; they are passive devices with no moving parts. The physical appearances and makeup of the RTGs and RHUs were addressed in greater detail in Section 2.2.4 of the June 1995 Cassini EIS, and in the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997). See also response to comment 2-8.

Comment No. 2-26

Emergency response planning for the Cassini mission was referenced in Section 4.2.9 of the June 1995 Cassini EIS.

In accordance with the Federal Radiological Emergency Response Plan (FRERP), comprehensive radiological contingency plans will be finalized before launching the Cassini mission. These plans, similar to the ones developed for the Galileo and Ulysses missions, will ensure that any accident, whether it involves a radiological release or not, will be met with a well-developed and tested response. The plans are being coordinated with Federal agencies including EPA and the Federal Emergency Management Agency, and with the State of Florida and Brevard county organizations involved in emergency response. Pertinent portions of the plans will be exercised to ensure that the various organizations are prepared to respond to any radiological emergency associated with the launch. In accordance with the FRERP, NASA is the Lead Federal Agency (LFA), coordinating the Federal response for accidents occurring within U.S. jurisdiction, and will coordinate with the Department of State and other cognizant agencies, as appropriate, in the implementation of other responses.

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Regarding the use of iodine pills, they would be useful only in blocking the uptake of radioiodine by the thyroid following a nuclear reactor accident. Since no such releases are associated with the type of accidents involving plutonium dioxide addressed in the Draft and Final SEIS, the use of iodine pills would not be planned.

Comment No. 2-27

The Mars 96 accident response was the responsibility of Russia, not the U.S. Any response by the U.S. would have to be requested by the affected countries. Accident scenarios of the Mars 96 - type have been considered as part of the Cassini mission design and safety analysis efforts.

Comment No. 2-28

The June 1995 Cassini EIS and the SEIS are NASA payload NEPA documentation, in compliance with NASA regulations at 14 CFR 1216.305 (c) (3).

Comment No. 2-29

Comment noted.

Comment No. 2-30

Political and geopolitical considerations are outside the scope of the National Environmental Policy Act (NEPA) process.

Comment No. 2-31

In the unlikely event of an accident leading to a release of plutonium dioxide to the environment, the U.S. Government would be financially responsible. Should plutonium dioxide contaminated soil removal be required, it would be disposed of in an approved radioactive waste site.

Comment No. 2-32

Comment noted.

Comment No. 2-33

The commentor mischaracterizes the nuclear launch safety evaluation as a "Presidential Statement." What the June 1995 Cassini EIS and the Draft and Final SEIS reference is a Presidential-level nuclear launch safety evaluation process. The process includes a Safety Analysis Report (SAR) and its evaluation in an independent Safety Evaluation Report (SER). That process is ongoing and is separate from the National

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Environmental Policy Act (NEPA) process. The Department of Energy is responsible for the SAR. The Interagency Nuclear Safety Review Panel (INSRP), supported by national consultants in varied fields of expertise, is responsible for the independent SER.

Comment No. 2-34

The commentor's accusations are unfounded. The Draft and Final SEIS have been prepared using the best available information. See also responses to comments 2-a and 2-36. The commentor has been supplied with a copy of the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997), which are referenced in the Final SEIS.

Comment No. 2-35

The 720 equal-area grid of the worldwide data base was used to represent demographic and surface-type (water, rock, soil) distributions required for the type of modeling being performed for the Cassini mission safety analysis. Much higher resolution was used within each grid cell to develop the following probability distributions used in the analyses:

- Land and water fractions
- Total population and population densities
- Probability distribution over 15 population density classes
- Probability distribution over 7 soil/rock classes
- Probability distribution over 9 land use/cover classes, and
- Joint probability distribution of population density class and soil/rock class.

Comment No. 2-36

The NASA contractor for the June 1995 Cassini EIS and SEIS is Science Applications International Corporation (SAIC).

Please see response to comment 2-12(c).

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Gary L. Bennett
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Telephone/Facsimile: (208) 365-1210

21 May 1997

Mr. Mark R. Dahl
Program Executive, Cassini
Mission and Payload Development Division
Office of Space Science
NASA Headquarters
Code SD
Washington, D.C. 20546-0001

Dear Mr. Dahl:

Enclosed for your consideration are my comments on the Draft "Supplemental Environmental Impact Statement for the Cassini Mission".

If you have any question or need clarification of any comment please contact me at the above address or telephone/fax number.

Sincerely,

Enclosure: Comments on DSEIS

COMMENTS ON THE DRAFT "SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT FOR THE CASSINI MISSION" Document Dated April 1997

Prepared by
Gary L. Bennett

General Comment

This document reads as if all the accidents and all the releases are foregone conclusions. The DSEIS has a strongly deterministic tone when, in fact, there are postulated or hypothetical accidents which may or may not cause releases which may or may not have any measurable health effects. In every statement in the DSEIS where accidents are mentioned the conditional word "postulated" or "hypothetical" should be inserted before the word "accident". A similar statement applies to releases and health effects. There are calculated results they are not foregone conclusions.

The DSEIS would benefit from a short discussion of the foregoing points to ensure that the public understands that the DSEIS is based on calculations and that launching Cassini does not mean that these accidents will automatically happen and cause the listed consequences. Risk analyses needs to be put in context. The results presented need to be put in context; for example, about 20% of all the people alive today will probably die of cancer (~1 billion people) so the health effects calculated for the postulated Cassini accidents are clearly minuscule. Moreover, given the releases there is no assurance that even the calculated health effects will occur. The "true" health effects (given the accidents) are somewhere between zero and the numbers presented. The public needs to know this.

There have been some good, general-interest write-ups prepared pointing out the benefits of nuclear devices (smoke detectors, medicine, etc.). There should be consulted so that a proper balance can be presented in the SEIS.

As a reference point, "Since the first nuclear weapons test at Alamogordo, N.Mex., on July 16, 1945, approximately 360,000 Ci (360 kCi) of ^{239,240}Pu has been injected into the atmosphere. In addition, 17,000 Ci (17 kCi) of ^{238}Pu entered the atmosphere in April 1946 as a result of the high-altitude burnup of a SNAP-9 satellite power source ..." (cf. *Transuranic Elements in the Environment*, DOE/TIC-22800, 1980). Keep this in mind when the critics start saying that there's enough plutonium on board Cassini to give everyone lung cancer. That hasn't happened from the weapons tests which were much more finely and wisely distributed than any of the postulated Cassini accidents.

Specific Comments

Page iii - At the bottom of the page – goes the Cassini spacecraft really "care" if the rings are nearly edge-on to the Earth and Sun? Can it be maneuvered to overcome that alignment? 3-1

Page iv - The first paragraph should be much more positive. Describe what the RTGs and RHUs are and what they do – how essential they are. All anyone gets from this paragraph is how "awful" they are. List the benefits. 3-2

Page v - The first and second paragraphs need words like "postulated" and "potential" inserted just about every place. The last sentence of the second paragraph should replace the word "would" with "are calculated". It is not a certainty that these release will occur. 3-3

Page v - In the second line of the second paragraph the simulations are experimental and analytical are they are not? 3-4

Page vi - In the first paragraph, replace the word "threaten" with "affect" (two places). The health effects are calculated given the postulated accidents occur. This entire paragraph is full of pejorative words. 3-5

Page vi - In the second paragraph why is the time period from T+143 s to T+206 s not considered? Can't there be explosions with fragments released? 3-6

Page vi - In the third paragraph the reader is left dangling as to what these "new" prelaunch accidents are. A sentence or two explaining the situation would help. Also, the reader should be told what exceeding the EPA guideline level really means. The world isn't going to end, is it? 3-7

Page 1-1 - In the second paragraph be much more positive. Describe what the RTGs and RHUs are and what they do -- how essential they are. All anyone gets from this paragraph is how "awful" they are. List the benefits. 3-8

Page 1-1 - In the third paragraph the words "substantial impacts" have a highly negative connotation with no context given for judging if that is indeed the case. Suggest replacing those words with something like "an effect upon the human environment". 3-9

Page 1-2 -In the first full paragraph is there a contradiction between the statement "No pre-launch Phase 0 accidents were identified what could cause a credible release" and the third paragraph of page vi? 3-10

Page 1-2 - Frankly, from the results presented the statement in the last sentence of the fourth full paragraph doesn't seem warranted. In real terms the changes are all in the noise level and the DSEIS probably isn't needed. 3-11

Page 1-4 - Was this page left intentionally blank? 3-12

Page 2-2 - In the paragraph labeled "Changes in Mission Design Since the EIS", some clarification is needed as to why delaying the last trajectory correction increases the biasing. Somewhere it should be clearly stated that at any given time the trajectory will be such that the velocity vector is pointed away from an Earth intercept. 3-13

Page 2-6 - Some more information should be presented on the ESA cells. Fox example, are they concentrator cells and, if so, what is the concentration ratio? Are they just GaAs cells or is there another material (multi-function, multi-bandgap)? What is the efficiency of the cells? How do these cells compare with the U.S. GaAs/GaSb cells that have produced 30% efficiency in laboratory conditions? If the cells are concentrator cells this severely restricts the alignment of the may which means more propellant. 3-14

Page 2-8 - If the cells are GaAs, they should not be as radiation sensitive as Si cells; although the end point in terms if percent power loss may end up being the same. 3-15

Page 2-8 - Diodes are standard part of solar arrays. What's special about diodes on the hypothetical Cassini array? 3-16

Page 2-9 - Section 2.1.5 - Hydrazine by itself is usually not "burned" it is decomposed. | 3-17

Page 2-11 - In the first full paragraph some explanation of Hazards Class 1.3 would be helpful. As it is the lay reader is left with a negative impression. Can a statement be made that these are benign solids (i.e., they won't go "high order" in an impact or explosion; won't detonate). | 3-18

Page 2-16 - In the first full paragraph are there any explosion/fragment issues in Phase2, 3 or 4 (see also page 2-20)? | 3-19

Page 2-16 - In the third full paragraph the entire discussion about cancers is too deterministic and too fatalistic. These are calculated numbers with the "real" value (given the accident) lying somewhere between zero and the number calculated. What is meant by "large number of people worldwide"? Put this in context. The "expectation of latent cancer fatalities" is somewhere between zero and the number calculated. | 3-20

Page 2-17 - In Section 2.4.2, first bullet, second paragraph: Should it say that "The updated analyses use **more** detailed accident descriptions ... "? As it is, the impression is left that the EIS used nothing. | 3-21

Page 2-2 - For comparison with the text, a separate column listing the Phases should be included. Footnoted: These are potential, calculated latent cancers. PUT IT IN CONTEXT!!! Footnote g implies another EIS is coming. How long will this continue? Sometime you have to launch! | 3-22

Page 2-20 - In the first paragraph if the hypothetical prelaunch accidents are now of concern then so should be the postulated accidents in Phases 2,3, and 4 (page 2-16). | 3-23

Page 2-20 - In the second paragraph, what does it mean to exceed the EPA guidance level? The last sentence should include the words "the benefits of" before the word "implementation". | 3-24

Page 2-22 - The No-Action Alternative does have adverse impacts. It means loss of jobs. It means loss of American planetary science preeminence which will hurt U.S. science which in turn will hurt U.S. technological leadership. It means all this hardware was built and the financial/personal/environmental impacts were taken and no benefits achieved. The No-Action Alternative is the most costly of the alternatives. | 3-25

Table 2-3 - For comparison with the text, a separate column listing the Phases should be included. Most people will only read the tables so they need to be clear and in context. | 3-26

Page 4-1 Section 4.1 - Explain that why not including *de minimis* the results are really worst case. Don't leave it dangling. | 3-27

Page 4-3 In the first full paragraph can a statement be made that these types of analyses are fully consistent with U.S. and internationally accepted guidance? This would give the reader the impression that this is an accepted, orderly process. | 3-28

Table 4-1 - Note that these are postulated accidents. | 3-29

Page 4-6 - In the first paragraph of Section 4.1.2.2 note that all of this assumes the accident happens in the first place. The odds are the mission will be a success. | 3-30

Table 4-2 - For comparison with the text, a separate column listing the Phases should be included. Most people will only read the tables so they need to be clear and in context. Footnote d: These are potential, calculated latent cancers. PUT IT IN CONTEXT!!! Footnote g implies another EIS is coming. How long will this continue? (This is clearly a growth industry -- how many trees is this costing us?) 3-31

Page 4-8 - Second full paragraph - is the probability 2×10^{-7} for all time or per year? The time makes a difference. In seven half-lives there will be less than 1% of the ^{238}Pu left. 3-32

Page 4-8 - Third full paragraph – these ideas need to be expressed earlier. This helps put everything in context. 3-33

Page 4-12 - Second paragraph - there won't be much ^{238}Pu left in a few half lives. 3-34

Page B-1- Can Becquerel and Curie be put in context, e.g., related to smoke detectors or something? Mr. & Mrs. Public may decide that 1 disintegration per second is one too many. 3-35

Page B-2 Does generally refers to the total does received not per unit body mass. 3-36

Page B-3 The definition of "initiating event" seems wrong. Are systems failures really required? 3-37

Page B-3 - Why is plutonium singled out as "heavy"? Lead is heavy, too . Plutonium is produced in stellar explosion so it's not strictly artificially produced. In fact, plutonium has been founded on Earth that did not come from weapons test or SNAP-9A. 3-38

Page B-3 - At one time REM = (RBE)*(Rads). Now we have Quality Factors. Just checking. 3-39

Page B-3 - Solar energy usually refers to the energy provided by the Sun; how it's converted or used is another matter. (What's really important is solar power; specifically insolation.) 3-40

Comment No. 3-1

The illumination of Saturn's rings is important and does matter for scientific observations. If the rings are edge-on to the Sun, imaging science observations of the rings would be severely limited. The spacecraft could not be maneuvered to overcome this alignment.

Comment No. 3-2

Comment noted. Please refer to the 1995 Cassini Environmental Impact Statement (EIS), Section 2.2.4.2, and Volume I of the recently available Safety Analysis Reports (SARs) (LMM&S a-j; and EG&G 1997) now referenced in this FSEIS. The SARs have been forwarded to the commentor.

Comment No. 3-3

The commentor is correct in asserting that the postulated release would not be certain to occur. In fact, for a large number of the accidents evaluated for the recently available Safety Analysis Reports (LMM&S a-j; and EG&G 1997), no release would occur. The recommended substitution of "are calculated" for "would" at this location is accepted.

Comment No. 3-4

Yes, the simulations are experimental and analytical. For additional details, the commentor is referred to the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997).

Comment No. 3-5

Comment noted.

Comment No. 3-6

During this time interval there could be explosions with fragments released; however, because the payload fairing has been jettisoned prior to this interval and thus would no longer be in place to contain and direct explosive forces at the spacecraft, there would be no threat to the RTGs and RHUs. See the recently available Safety Analysis Reports (LMM&S a-j; and EG&G 1997).

Comment No. 3-7

The new prelaunch accident considered in the consequence analyses is similar to the Centaur tank collapse accident described in Section 4.1.5.2 of the June 1995 Cassini

EIS. For additional details of the prelaunch scenarios addressed in the updated analyses see the recently available Safety Analysis Reports (LMM&S a-j; and EG&G 1997).

Comment No. 3-8

Descriptions of the RTGs and RHUs can be found in Section 2.2.4 of the June 1995 Cassini EIS and in the recently available Safety Analysis Reports (LMM&S a-j; and EG&G 1997).

Comment No. 3-9

Comment noted.

Comment No. 3-10

There is no contradiction between the referenced paragraphs. This paragraph describes what was presented in the June 1995 Cassini EIS.

Comment No. 3-11

Comment noted.

Comment No. 3-12

Yes the page was left intentionally blank.

Comment No. 3-13

By delaying the final trajectory correction maneuver, the spacecraft remains biased away from the final swingby altitude at Earth for a longer period of time (i.e., an additional 3 days). In addition, the final swingby altitude has been raised to at least 800 km (500 mi) from 500 km (320 mi). These two independent actions were implemented as part of the mission design that ensures that the probability of an inadvertent Earth swingby reentry remains less than one in one million.

Comment No. 3-14

The ESA cells are not concentrator cells. ESA developed both GaAs and Si cells. The efficiency of the cells at Saturn has been estimated at 22 - 24%. In comparison to the U.S. GaAs/GaSb combination cells, the ESA cells exhibit a lower efficiency; however the U.S. cells, because they are actually two cells combined, are approximately 2 to 3 times heavier than the ESA cells. The GaAs/GaSb cells have only been fabricated under laboratory conditions, and have not been tested for LILT effects.

Comment No. 3-15

The commentor's observation that both GaAs and Si cells would be subject to radiation degradation for this type of mission is correct.

Comment No. 3-16

The diodes that would be necessary for the hypothetical Cassini array would require a special design (i.e., would have to be a wafer design rather than the conventional cylindrical design) that is compatible with thin and collapsible (i.e. foldable) solar arrays.

Comment No. 3-17

Comment noted.

Comment No. 3-18

Tests have shown that SRMU propellant cannot detonate (i.e., go high order) under any credible launch accident scenario. Hazard classification 1.3 refers to Department of Defense document DOD 6055.9-STD-DOD, Ammunitions and Explosives Safety Standards, October 1992.

Comment No. 3-19

No. The payload fairing has been jettisoned and is no longer available to contain and direct explosive forces at the spacecraft. See also response to comment 3-6.

Comment No. 3-20

Comment noted. Section 2.4.1 of the Draft and Final SEIS is a summary of Section 4.1.6 of the June 1995 Cassini EIS.

Comment No. 3-21

Text revised accordingly.

Comment No. 3-22

Mission phases were grouped into mission segments for the convenience of the reader. The mission segments consolidate potential accidents which could affect the same portion of the environment. Footnotes "d" and "g" have been updated.

Comment No. 3-23

The accidents postulated during the referenced phases would lead only to water impacts; no releases occur from such an impact.

Comment No. 3-24

In both the June 1995 Cassini EIS and the Draft and Final SEIS, the EPA guideline level is used for illustrative purposes as an indicator of the potential amount of land contamination that could require some level of cleanup. If an accident were to occur the actual amount of land subject to cleanup would be determined as one element of the emergency response. The recommended addition of "benefit of" is noted.

Comment No. 3-25

Comment noted.

Comment No. 3-26

Mission phases were grouped into mission segments for the convenience of the reader. The mission segments consolidate potential accidents which could affect the same portion of the environment.

Comment No. 3-27

NASA did not include consideration of de minimis in reporting potential accident consequences in the Draft and Final SEIS. NASA does not take a position on the issue of de minimis; accordingly the SEIS reports only the consequences estimated by considering the full potential radiation doses.

Comment No. 3-28

The analyses conducted are consistent with established radiological risk assessment methodology and practices.

Comment No. 3-29

Comment noted.

Comment No. 3-30

Comment noted.

Comment No. 3-31

The Draft and Final SEIS text (Section 2.1.7) attempts to explain to the reader that the launch phases used in the June 1995 Cassini EIS were somewhat different from those used in the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997). The breakdown of the phases referenced in the table are those used in the Safety Analysis Report and will better facilitate an understanding of the analyses upon which the Draft and Final SEIS is based

It was not intended that the footnotes convey or imply that another EIS is coming.

Comment No. 3-32

The $2x10^{-7}$ is for 100 years; or slightly more than one half-life of Pu-238.

Comment No. 3-33

Comment noted.

Comment No. 3-34

Comment noted.

Comment No. 3-35

Comment noted.

Comment No. 3-36

The definition as stated in the Draft and Final SEIS is correct.

Comment No. 3-37

The definition as stated in the Draft and Final SEIS is correct.

Comment No. 3-38

Comment noted.

Comment No. 3-39

Comment noted.

Comment No. 3-40

Comment noted.

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ANTHONY EHRLICH
96 HILLDALE AVENUE
ORMOND BEACH, FL 32176

Subject: Supplemental Environmental Impact Statement for the Cassini Mission

May 21, 1997

References: 1. NASA DSEIS transmittal letter dated April 4, 1997 by Mark R. Dahl
2. Letter of correction for DSEIS dated April 8, 1997 by Mr. Dahl
3. Nuclear Safety Analysis for Cassini Mission Environmental Impact Statement Process, HNUS-97-0010, April, 1997

Code SD
NASA Headquarters
Washington, DC 20546-0001

Dear Sirs:

We have just completed a review of the Draft Supplemental Environmental Impact Statement (SEIS) transmitted by reference 1 and amended by reference 2. We are also in receipt of and have read reference 3 (HNUS), transmitted by reference 1. Our review has found what appear to be serious flaws and omissions. Our comments are given below. We respectfully request that you answer our comments and incorporate the results in another SEIS.

Comment 1 below has to do with the use of solar arrays instead of plutonium. Comments 2 through 5 identify missing data or misleading information presented in table 4-2, which on face value would seem to be a compilation of possible hazards. Comment 6 requests an explanation intelligible to the layman of why uncertainty techniques had to be applied to the results of the radiological analysis results and what the results of the uncertainty study mean in tangible terms to the citizens of Florida and the United States. Comment 7 has to do with the timing and content of the contingency plan still being developed. And comment 8 concerns the data presented for potential clean up costs and plans for disposal of any radioactive materials cleaned up.

1. Pages 2-6 through 2-9, Solar Arrays. Despite the "low" estimate of radiological risk in the Draft SEIS for the planned mission, we fell <u>any</u> risk involved with putting plutonium into space is not warranted and that solar arrays provide an acceptable alternate. Page 2-8 includes a statement by "...researchers who developed the ESA [European Space Agency] solar cells," who concluded that, "Low (insolation) intensity and low temperature (LILT) solar cells (including those developed by ESA) are not a viable power source alternative for the presently defined Cassini mission of NASA (H. Hasson, 1996)" This statement of non-viability, however, is not a formal input; the source cited in SEIS Section 8.0, References, merely says, "Hassan H. 1996. Personal communication to D. Kindt, Jet Propulsion Laboratory, regarding ESA assessment of the JPL system study related to the possible use of photovoltaic arrays for the Cassini mission." It is our understanding, however, that some ESA officials have concluded that solar arrays could be used for this mission. Please provide a documented, written, formal response from ESA as to the feasibility of the use of soloar generators instead of plutonium. 4-1

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2. Table 4-2, page 4-7, mission segment VVEJGA (Venus-Venus-Earth-Jupiter-Gravity-Assist, planned trajectory for the primary launch opportunity in October/November 1997). The table contains no value for the maximum individual dose from the Radioisotope Thermoelectric Generators (RTGs) because this information is not yet available. Yet the RTGs contain most of the plutonium on Cassini and are the biggest source of potential radiological risk. Furthermore, as the table indicates, this mission segment is the one with the potential for contaminating the largest land area. The inclusion of individual dose data could have a significant effect on the mission risks shown in this table. And these increased risks would probably affect more people as the area of contamination is greater. 4-2

3. Table 4-2, fourth column, Maximum Individual Dose, rem. The wording of this heading appears to be subjective rather than scientific, that is, to assure rather than to examine. A quick read would lead one to believe that the values given <u>are</u> the maximum doses possible, but the footnote indicates that these values are really the <u>mean estimates</u> of the maximum individual doses. These may be the most likely estimates statistically, but they are less than the possible individual doses at other distribution points. Indeed, table 6-5 of Reference 3 shows a combined overall mission dose at the 99 percentile as 2.4×10^0 (or just 2.4), compared to the 1.1×10^0 (just 1.1) dose shown in the SEIS, about twice as much. 4-3

4. Table 4-2, fifth column, Land Area Contaminated. This data appears to continue with the same intent as above, to assure rather than to present objectively. The values shown here are the estimated mean values, as indicated in the column heading. Why are the estimated values for the 95% and 99% distributions not shown? Table 6-5 in Reference 3 shows a contaminated land area for the combined overall mission to be 4.8×10^0 (just 4.8) at the 99th percentile compared with 4.4×10^{-1} (0.44) for the SEIS value, about 10 times more. 4-4

5. Table 4-2, mean Mission Risk. The presentation of this "low" mean mission risk would seem to be an oversimplification of the results of this analysis to all but statisticians. The mean mission risk shown is merely a predicted best guess. The public and decision makers should be informed as to the possible, credible mission risks at the 95 and 99 percent points even though these risks may be less likely on a probabalistic basis. To ignore risks at these points will lead many to think they are not possible, an implication that serves neither the government or the people. From the data given in Reference 3 and the methodology given in table 4-2 (risk equals probability times health effects), the overall combined mission risk at the 99 percent point would be 4.4×10^{-3} (0.0044) compared with the value given in the SEIS, 3.2×10^{-4} (0,00032), about 10 times worse. 4-5

6. Paragraph 4.1.2.3, page 4-8, and table 4-3, page 4-9, uncertainty. The text acknowledges the "uncertainty" of the analyses summarized in table 4-2 and tells us that still another statistical tool, an "uncertainty analysis," was used, the results of uncertainty being given in table 4-3. The text, however, provides no explanation of the ramifications of this uncertainty, but just states the obvious: that the 95 percent confidence level is two orders of magnitude higher than the best estimate, etc. What does this uncertainty mean in human terms? Because this mission as currently planned involves the largest amount of plutonium ever to be deployed in space and 4-6

because plutonium is the most toxic substance known to man, the meaning of this uncertainty should be stated in clear terms that the layman, be he politician, government official, or ordinary citizen, can understand and evaluate. Please add such an explanation to the SEIS. 4-6 (Continued)

7. Paragraph 4.1.2.4, page 4-9, contingency plan. The text mentions a comprehensive radiological contingency plan that "...is being developed." This plan "...would ensure that any accident...could be met with a well-developed and tested response." The text states that the contingency plan is being developed by federal, state, and local organizations. Who in my city, Ormond Beach, and my county, Volusia, is participating in the formulation of this plan? Who is participating at the state level? When will the contingency plan be available and will there be provisions for public review and input? We are most curious as to what actions will be suggested or mandated for us, our children, our wives, and other residents of our area in the event of an accident releasing plutonium dioxide if the winds should blow in our direction. Will the contingency plan cover only the time frame immediately after an accident or will it address actions in the following weeks and months, etc.? Please include the answers to these questions a much as is applicable in the SEIS. 4-7

8. Paragraph 4.1.2.5, page 4-9, and table 4-4, page 4-10, potential clean up costs for contaminated land. The table shows the predicted areas of contamination at the mean, 95%, and 99% distribution points for accidents that might occur in the pre-launch and early launch mission segments. Why are no estimates and costs for accidents during the VVEJGA segment shown in the table? This is the mission segment that would involve the largest area of contamination according to table 4-2. Do the costs that are shown include the cost of disposal of contaminated materials? What might the location of disposal site be and what might be the means of disposal? 4-8

We respect the professionalism and competence of the team planning and intended to operate the Cassini mission, but as recent events remind us, the unexpected, and catastrophic do sometimes occur. Because of the potential harm from an accident involving airborn plutonium particles and the long half life of plutonium (which I believe to be 24,000 years), we feel that this version of the SEIS must be considered flawed. Until the data and explanations that are missing per the above comments are included in the SEIS, no conclusion could be reached as to the estimated risks of Cassini and no decision should be made whether to launch as currently planned. We are therefore sending copies of this letter to our local, state, and federal officials. 4-9

We understand that this letter will be included in the final SEIS and that that document will incorporate those comments that are deemed correct and applicable. We look forward to the final SEIS and to the contingency plan.

Respectfully yours,

Anthony Ehrlich
(address above)

Harvey G. Baker
Harvey Baker
538½ Magnolia Avenue
Daytona Beach, FL 32114

cc: President Bill Clinton, Governor Lawton Chiles, Senator Bob Graham, Senator Connie Mack, Representative Tillie Fowler, Representative Corrine Brown, Representative Evelyn Lynn, Senator Burt Locke, County Councilman Stan Rosevear, Mayer Bud Asher, Mayor Dave Hood, Commissioner Jeff Boyle

Comment No. 4-1

For the convenience of the reader the entire Hassan reference, which is a technical evaluation of the JPL solar Cassini concept, has been included in the Final SEIS as Appendix C. Mr. Hassan is the European Space Agency (ESA) Cassini Project Manager. Please also see response to comment 1-1.

Comment No. 4-2

The maximum individual doses for an inadvertent reentry during Earth swingby are now available and included in this Final Supplemental Environmental Impact Statement (SEIS). The effects of individual dose were already included and accounted for in the values reported in the Draft SEIS; therefore, there is no need to adjust the mission risks. The doses that contributed to maximum individual dose were accounted for in the original analysis, but the maximum individual doses were not available at the time of the Draft SEIS.

Comment No. 4-3

The maximum individual doses are mean values and are presented as the best representation of the highest dose that an individual might receive for a given accident segment. The estimates are obtained by accumulating the highest doses for each of the accident simulations for a mission segment and obtaining the average for that segment. The 95% and 99% values are presented to provide an indication of the distribution of the mean doses that might be expected if an accident were to occur. In total, this information is presented to provide a more complete indication of the potential doses that might be received in the event of an accident. All doses are accounted for in the risk and health effects estimates.

Comment No. 4-4

The 95-th and 99-th percentile land contamination values were included in the draft SEIS. See Section 4.1.2.2 of this SEIS.

The commentor also refers to a difference between the overall mission land contamination values reported in Table 4-2 of DSEIS and Table 6-5 of the HNUS supporting document. Table 4-2 of the DSEIS is reporting the mean value for the overall mission, while Table 6-5 of the HNUS supporting document addresses the 99th percentile values. As one would expect, the 99th percentile value is larger than the mean.

Comment No. 4-5

The overall mission risk given in Table 4-2 of the Draft SEIS is the probability weighted health effect consequences summed over all mission segments. This measure

of potential radiological consequences includes the information contained in all health effects probability distributions determined from the individual accident scenarios that contribute to each mission segment. Additionally, the Draft SEIS presented information on the distributions of health effect consequences by mission segment at the 5-th, 50-th, 95-th, and 99-th percentile levels to inform decision makers and the public on the elements used in the determination of mission segment and overall mission risks.

The calculation provided in the comment is not correct. It is important to understand that the Cassini mission nuclear safety analyses considered a broad range of outcomes to minimize the possibility of overlooking possible high radiological consequence outcomes even at extremely low probabilities of occurrence. The health effects distributions in Table 4-2 provide such information, but they need to be interpreted carefully. Except for mean health effects, the values listed under each percentile level are upper bound health effects associated with the percentile level. For example, the nuclear risk analyses predict less than 0.92 health effects for the overall mission at the 99-th percentile level, given the postulated occurrence of a plutonium dioxide release as a result of an accident. An alternative interpretation is that given an accidental release there is a 1 percent probability of 0.92 or more health effects for the Cassini mission.

The overall mission probability for 0.92 or more worldwide health effects is then 2.8×10^{-5} (or about 1 in 36,000), which is obtained from the product of the total probability of a plutonium dioxide release accident during the mission (2.8×10^{-3}), and the conditional probability of observing 0.92 or more health effects as the outcome of plutonium dioxide release accidents (1.0×10^{-2}). The health effects risk includes this information, because it is based on all predicted health effect outcomes with consideration of their probability of occurrence.

Comment No. 4-6

While plutonium is a heavy metal with known chemical toxicity, it is not the most toxic substance known. The radiation effects of plutonium would be manifested well before chemical toxicity effects.

In response to the expressed desires of the commentor, the following brief explanation of uncertainty is provided: By their nature, consequences for a potential accident scenario can vary over a wide range. To reflect this variable nature, the Draft and Final SEIS present a range of analytical estimates of potential consequences (e.g., 'best estimate', 95-th percentile, 99-th percentile). The uncertainty analysis establishes bounds which enclose the consequences of potential accidents, to a high level of confidence. For a more detailed technical discussion of uncertainty, the commentor is referred to the recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997), specifically "h" - Supplemental Analyses. These reports have been forwarded to the commentor.

Comment No. 4-7

Radiological contingency plans are being developed by NASA/Kennedy Space Center (KSC) and USAF/Cape Canaveral Air Station (CCAS) to address specifically the initial response that would be required in the unlikely event of an accident affecting the launch site. Similar plans already exist at the State and county (Brevard) levels in Florida, and are in the process of being updated for the Cassini mission. While Ormond Beach and Volusia county have not been specifically represented at planning meetings held for purposes of development of contingency plans, planning activities have been accomplished in concert with representatives from the State of Florida Division of Emergency Management, Office of Radiation Control, and Emergency Management and Public Safety representatives from Brevard County. The NASA/USAF and State of Florida plans are also being closely coordinated with the DOE, which maintains its own set of emergency response instructions for radiological accidents of many kinds, to ensure a coordinated initial response to any accident. Emergency response would be coordinated through local government contacts.

NASA/KSC and the Department of Energy (DOE) are coordinating closely with the State of Florida on development of recommended protective actions that could be implemented in the unlikely event of a release of radioactive material, both for the launch site and the general public in affected areas. Because there is a range of variables influencing the outcome of potential accident situations, there is a range of potential protective actions. Protective actions for the general public would be announced by the State of Florida after consideration of the specific circumstances accompanying any accident.

The NASA/KSC and USAF/CCAS contingency plans currently under development deal primarily with the initial response to a radiological contingency, although there is some discussion of the concept of operations for longer-term actions such as recovery of the radioactive material and facilities. Long-term actions will depend on the facts and the circumstances surrounding an accident, and will be responsive to such circumstances.

Comment No. 4-8

No cost estimates were developed for cleanup of potential land area contamination as a result of a VVEJGA accident as they would be highly speculative because of the many variables involved. Regardless of where any contamination occurred, the United States would respond appropriately and assume responsibility for cleanup, as needed.

As stated in Section 4.1.2.5 of both the Draft and Final SEIS, an upper estimate was used to illustrate the potential costs associated with removal and disposal in an appropriate repository. Should plutonium dioxide contaminated soil removal be required, it would be disposed of in an approved radioactive waste site. The selection of location and method of disposal or storage would be dependent upon the location of the release, quantity of material, level of contamination and Federal regulations.

Comment No. 4-9

The commentor notes the half-life of plutonium as 24,000 years. The half-life of Pu-238, which comprises 71 percent of the plutonium dioxide (See Table 2-3 of the June 1995 EIS; and Section 1.1 of the Draft and Final SEIS) in the RTGs and RHUs, is 87.7 years. The recently available Safety Analysis Reports (LMM&S a-j; and EG&G 1997) are referenced in this Final SEIS.

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John Robert Lehman
2975 Hostetter Road
San Jose, CA 95132

May 24, 1997

Mr. Mark R. Dahl
Cassini Program Office
Office of Space Science (Code SD)
NASA Headquarters
Washington, DC 20546-0001

Dear Mr. Dahl:

I write as a citizen concerned about risks associated with the Cassini mission's flyby of Earth. I heard that if any of the types of failures or errors that have occurred in other space missions were to occur during or before Cassini's Earth flyby, it could result in Cassini's load of plutonium being distributed throughout the atmosphere; and, that this plutonium is not only radioactive with a long half-life, but is highly poisonous aside from its radioactivity; and that this would be a disaster of global proportions. 5-1

E-77

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Five of my friends and acquaintances formed a group to study the Environmental Impact Studies (EIS) and other documentation which they could find about the Cassini mission. They met several times over the course of a month. Included within this group were a scientist, an engineer, and an architect. The group had two PhD degrees among them. The members of the group had radically differing opinions on whether the Cassini mission should go on as planned.

One early discovery, which was not disputed, was that the mission could be redesigned to not have an Earth flyby at all. This would eliminate the risk of the global catastrophe, at the cost of a few years' delay in Cassini's arrival at Saturn, hence a delay in the scientific returns of the mission. 5-2

At the end of their study I asked members of the group about the risks associated with the flyby. This was during a long discussion at which were present the three people of the study group who I expected would be most likely to give a coherent summary of the risk analysis.

I spent most of this discussion time listening to a member of the study group who was adamantly in favor of allowing the Cassini mission to proceed as planned (including the Earth flyby). He broadened the discussion to include long explanations of how we face risks all the time in life. Another member explained, too, that some materials deemed hazardous are only hazardous in unusual concentrations. The implications are that the danger associated with the possible dispersion of Cassini's plutonium through the atmosphere should be considered with the appropriate perspectives on its probable concentration at time of ingestion by living beings, the relative likelihood that such an event would actually occur as compared to other risks we face on a daily basis, the relative danger, and so on. What was missing in all this discussion was any good estimate of probability of an event, though I did ask for this repeatedly. More about this is related below.

Though I am not an expert on space missions, plutonium, or atmospheric modelling, I'm no dummy about risk, in comparison to most people. I tell

you this to distinguish myself as a reasonable person who might be expected to give a good response to a request for Public Comment such as this on regarding Cassini; as distinct from the knee-jerk crackpots who think any risk is unacceptable. I studied probability and risk while getting a masters degree in Engineering management Science (Operations Research) in an Industrial Engineering department of a university.

These friends and acquaintances who have studied the EIS would have me believe that there are no verifiable estimates of probability of the catastrophic event of Cassini's load of plutonium being dispersed through the atmosphere, in the EIS. By that I mean that the underlying formulas and data were left out of the EIS. Is this true? If so then there is little hope that the public can give an informed response to the request for Public Comment. 5-3

Unfortunately I don't yet personally have

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the resources to track this down, but I'll tell you what I think. By designing the mission to have an Earth flyby, the Cassini team places humanity at significant risk in order to shave a few years off flight time to Saturn. The risk is either not adequately understood, or, covered up. Either way, the public is widely unaware of it. Those who suspect it cannot confirm, because formula and doc'n are left out of the EIS. 5-4

Furthermore, I suspect that squelching of information is happening similarly to what happened in the Challenger disaster. If this is not the case the make the full risk analysis available.

The disaster is much worse and the affected victims unconsenting, as compared with Challenger.

Sincerely,

John Robert Lehman
2975 Hostetter Road
So. Jose, CA 95132

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Comment No. 5-1

For accidents other than the Earth flyby, the quantities of plutonium that would be released are small. The flyby is the only accident scenario that has a potential for releasing an average fraction estimated at less than eight percent, of the total inventory of plutonium dioxide on board the spacecraft. Because of this potential for release, NASA has taken extensive steps to reduce the probability of this accident to the point that it is not likely to occur, i.e. to a probability of less than one in one-million. If such an accident were to occur, the carbon-carbon aeroshells and graphite impact shells are designed to limit the release of the plutonium dioxide. If released, most of the material would fall in the oceans where, due to the chemical stability of the plutonium dioxide, its solubility in the oceans would be very limited. The dominant radiation released from plutonium is in the form of alpha particles which can only travel a very short distance through the air. In fact, the primary way for an individual to receive an exposure from plutonium is to breathe it in. The fraction of material that would be inhaled by the population in total, let alone any one individual, is small.

As the Draft and Final Supplemental Environmental Impact Statement (SEIS) indicate, there is a very low probability that an individual could receive high doses.

Taking the above into consideration, a potential accident during the Cassini flyby would not result in "a disaster of global proportions." For additional related information see response to comments 2-7 and 6-2. For information related to plutonium toxicity, see response to comment 4-6.

Comment No. 5-2

The commentor is referring to the 2001 mission alternative discussed in the June 1995 Cassini EIS (Section 2.3) and in the Draft and Final SEIS. The primary launch opportunity alternative would use a Venus-Venus-Venus-Gravity Assist (VVVGA) trajectory to Saturn. This alternative would need 10.3 years to reach Saturn as opposed to the Proposed Action's 6.7 year trajectory. In addition, the 2001 mission alternative would lead to reduced opportunities for science investigations and would require development and flight testing of a new spacecraft engine. With the primary VVVGA trajectory, there would be no opportunity for a short-term inadvertent reentry but a long-term inadvertent reentry risk would remain. However, with the backup Venus-Earth-Earth-Gravity Assist (VEEGA) trajectory for the VVVGA primary, both short- and long-term inadvertent risks would be present and be approximately the same as indicated for the (VEEGA) trajectories of the secondary and backup to the primary launch opportunity presented in Section 4.1.2.4 of the Draft and Final SEIS. A more detailed discussion of the impacts of the 2001 alternative can be found in Section 2.7 of the June 1995 Cassini EIS. Additional details of the reduction in science return can be found in Section 2.7.5 of the June 1995 Cassini EIS.

Comment No. 5-3

The recently available Safety Analysis Reports for the Cassini mission (LMM&S a-j; and EG&G 1997) are referenced in this Final SEIS. The commentor is referred to these Safety Analysis Reports for details of the extensive analyses performed for this mission. The Safety Analysis Reports have been forwarded to the commentor.

Comment No. 5-4

There is historical experience of many planetary and satellite flybys executed with high precision by the JPL Navigation Team over the past three decades. For two of these flybys, the Galileo spacecraft swung by the Earth twice for gravity-assist purposes before reaching Jupiter. The first Earth swingby occurred at a closest approach altitude of 952 km (590 mi), and the second occurred at 304 km (188 mi). Tracking data after each of these swingbys showed that the actual trajectory was controlled to an accuracy or 8 km (5 mi) for the first swingby, and an accuracy or 1 km (0.6 mi) for the second swingby. The Earth swingby altitude for Cassini will be 800 km (496 mi.) or higher, depending upon the launch date, and the navigation precision is expected to be slightly better than that for Galileo.

See response to comment 5-3 above.

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Commentor 6: Marc M. Cohen

MARC M. COHEN
4242 POMONA AVENUE
PALO ALTO, CA 94306-4337

May 21, 1997

Mr. Mark R. Dahl
Cassini Program
Office of Space Science (Code SD)
NASA Headquarters
Washington, DC 20546-0001

Dear Mr. Dahl:

This letter is in response to the NASA invitation for public comment on the Cassini Mission Draft Supplemental Environmental Impact Study (DSEIS). I am deeply concerned about some of the assumptions, methods and conclusions pertaining to the potential release of Plutonium 238 into the earth's environment. It is a question of simple justice. People sitting in offices in Washington and Pasadena propose to take a risk -- however small -- that would have the consequence (according to its own original, "Final" 1995 EIS) of giving 2300 people a carcinogenic dose of vaporized Plutonium 238 or (according to the "Supplemental" 1997 DSEIS) giving 120 people such a dose who have no say and who may never know who they are. The Cassini decisionmakers bear no personal liability for the consequences of their decision, should Cassini release plutonium. Victims of carcinogenic or toxic releases of Plutonium 238 would have no recourse or due process of law to seek compensation from the decisionmakers or NASA.

I reviewed the three key documents that your Office provides on potential environmental impacts from Cassini:

> Office of Space Science, (April, 1997) Draft Supplemental Environmental Impact Statement for the Cassini Mission, Washington, DC: National Aeronautics and Space Administration.
>
> Haliburton NUS Corporation, (April, 1997) Nuclear Safety Analyses for Cassini Mission Environmental Impact Statement Process, HNUs-97-0010, Gaithersburg, MD: Haliburton NUS Corporation.
>
> Solar System Exploration Division, (June, 1995) Final Environmental Impact Statement for the Cassini Mission, Washington, DC: National Aeronautics and Space Administration.

OVERALL EVALUATION

As an overall evaluation of these documents, I was disappointed that none of them provided the mathematical models for their findings nor the key assumptions from which they derived. The DSEIS states: 6-1

> "The analysis makes wide-scale use of probability distributions. It uses *best estimate* values for certain key parameters, and more comprehensive modeling to determine PuO_2 particle dispersion, uptake but people and the potential for latent cancer fatalities." [pp. 2-17 – 2-18, emphasis added].

I question whether these "best estimates" truly are the "most representative mathematical models, parameter values used in the models and probability distributions to describe inherent variability as inputs to the analysis" [p. B-1, from definition of a "best estimate"]. I question further whether the authors applied this probability distribution approach in a fair, impartial, and consistent manner.

6-1 (Continued)

I found the near total reliance upon probabilistic risk assessment techniques disturbing, while the DSEIS neglects completely the empirical data available for the failures involving recent NASA planetary probes. Since the early years of this decade, NASA launched four planetary probes: Galileo, Mars Observer, Mars Global Surveyor, and Mars pathfinder. Three of the four (all except Mars Pathfinder) suffered mission threatening or mission limiting failures - a rate of .75. Galileo suffered a stuck main antenna that would not open, imposing severe penalties on data rate and computer performance. Mars Global Surveyor suffered a stuck solar array that may yet affect its ability to maneuver into Mars orbit. Mars Observer suffered a catastrophic failure when undergoing a fuel tank pressurization procedure shortly before orbital insertion around Mars, and may have impacted upon the Mars surface. Then the empirical catastrophic failure rate for NASA planetary probes in this decade is .25. IF Cassini suffered such a pressurization failure in preparing for the Earth Fly-by maneuver, it could fail like Mars Observer, lose all guidance, and most likely plunge into the Earth's atmosphere. I expected to see the DSEIS address the Mars Observer-type scenario which most closely resembles Cassini's proposed Earth fly-bys. How could the EIS and DSEIS omit such an essential empirical data point?

6-2

The DSEIS's probabilistic analysis places the probability of a comparable failure of Cassini during an Earth fly-by to be .0000008, less than one in one million. How do the DSEIS authors explain this enormous discrepancy between the empirical mission data and the probabilistic wishful thinking? Have we forgotten NASA's most painful experience with probabilistic crystal-gazing: the Challenger Accident? NASA's estimate for catastrophic failure was .00001, but the failure occurred on the 25th launch, giving an empirical catastrophic failure rate up to that time of .04. The DSEIS brags: "The updated analyses include the most extensive evaluation of the uncertainties of accident consequences ever attempted for a space mission." What good is all the Monte Carlo simulation in the world if the key parameters ignore all the empirical data, and experimental design assumptions are either unavailable or wrong?

The EIS and DSEIS do not meet the standard for scientific, scholarly publication. No respectable scientific or technical journal would allow an author to publish a paper offering such precisely defined numerical conclusions without showing how he obtained those results - without providing the "most representative mathematical models" promised in the definition of a "best estimate." Several of the key parameters, upon which the most important issues turn, rest solely upon undocumented "personal communications;" specifically from H. Hassan of ESA to D. Kindt of JPL on the unsuitability of high efficiency solar cells to replace the RTGs, [DSEIS p. 2-9] and C.E. Kohlhase to L.E. DeFillipo [Haliburton, p. 5-7] on the probability distribution for reentry angle and reentry latitude. Neither is this reliance upon unsupported personal communications instead of documented evidence allowable for scholarly publication. In the absence the DSEIS and EIS providing these models, data and parameters, it is difficult to accept the EIS and DSEIS authors' analytical process to produce the probabilistic risk analysis. The absence of their mathematical and methodological models is particularly difficult to understand in light of their claim to have performed "the most extensive evaluation ... ever attempted." The exclusion of their vaunted probability distributions (ANOVAs or whatever) and tests for validity further undermine this report.

6-3

RISK BENEFIT ANALYSIS

Instead of the EIS and DSEIS dubious and obfuscating probabilistic risk assessment, I propose a simple, common sense risk-benefit analysis. There are two occasions for catastrophic failure during the Cassini Mission: the launch sequence and the Earth fly-by.

The *benefit* of launching the Cassini Mission is to obtain the Science. The *risk* is to dump the Plutonium in the ocean. If NASA does not take the risk of launching: no science.

The *benefit* of the Earth fly-by maneuver is to obtain the Science data a few years sooner. The *risk* of failure is to disperse 73 pounds of Plutonium 238 oxide in the atmosphere, with fatal cancers that the contractors estimate very conservatively at a "mean" of from 120 to 2300 people AND No Science return. Avoiding the fly-by maneuver eliminates the threat of an accidental reentry at the cost of a few years delay in returning the Science data. All the flyby maneuver does is get the Science data faster.

The Cassini vehicle design is an anomaly in this era of "Faster, Better, Cheaper." Because Cassini is so big and heavy, it pushes conventional launch capabilities beyond their limit, and making necessary the complex multiple planetary ply-by trajectory to Saturn. Why has NASA not replaced it with a small, inexpensive, reliable New Discovery or millennium class mission that would not pose so many difficulties and hazards, and would use more advanced instrument and sensor technologies? I hope the answer is not "throwing good money after dad." 6-4

TECHNICAL EVALUATIONS

I found five areas in which I question the technical approaches of the three EIS reports: Plutonium isotope aerothermodynamic heating, atmospheric transport mechanism, the radiobiological health effects, and the solar power option.

PLUTONIUM ISOTOPE

The 1995 EIS devotes a great deal of attention to the amount of Pu239 released or consumed in nuclear weapons test before the Test Ban Treaty in 1963, as if to say "Nuclear tests released thousands of kilograms of Plutonium, what does another 20 or 30 Kg of Pu238 isotope matter?" However the fissionable isotope is Plutonium 239, which has a half-life of 22,000 years, and is a relatively weak alpha emitter. The RTG fuel for Cassini is a different isotope, Plutonium 238, which is a very strong emitter, corelating to its half-life of 88 years. Chemically, their toxic effects as a heavy metal are the same, but the radioactive and carcinogenic characteristics may be different. However, the 1995 EIS does not appear to distinguish sufficiency between the two isotopes, and refers back several times to nuclear testing as a source of environmental (fissionable) Plutonium 239, which it seems to equate to Plutonium 238. To what degree do the EIS and DSEIS rely upon a generalizability of the two isotopes to characterize carcinogenicity? The DSEIS does not clear up this situation. 6-5

AEROTHERMODYNAMIC HEATING RATE

In the event of an Earth atmosphere reentry during a flyby maneuver, the Cassini spacecraft would enter the atmosphere at 19.4 km/sec for the preferred option of a VVEJGA trajectory 6-6

and at 17.4 km/sec for the secondary or backup mission options. All three reports express considerable uncertainty about whether the Cassini probe would vaporize and go to some lengths to speculate about the probability of a small or large piece striking the ground intact. In this respect, the authors seemed to have difficulty in distinguishing between a reentry from orbital decay at ~7km/sec to 11 km/sec and a fly-by VVEJGA reentry at 19.4 km/sec [Haliburton. P. 5-7]. Perhaps this uncertainty is not surprising because the neither the EIS or DSEIS teams included an expert aerothermodynamicist. Instead, they relied upon probablistic scenarios, using "CFD data" that they do not provide, without expert qualification, in ways that are not clear.

I was disappointed and surprised to not find any informed discussion about the aerothermodynamic heating rate, which varies as the cube of the velocity. I expected to find a discussion of the Fay-Ridell equation, and associated computations. Fay-Ridell is an approximation for convective heating to a general stagnation point of a vehicle undergoing atmospheric entry. However, at higher velocity, it may apply less because of the contribution from the radiation heating that is not taken into account (the convective heating is diminished by the complex nature of the flow which is in non-equilibrium and very likely causing a chemical phase change on the surface(. The other complication is that the vehicle would be rumbling, and hence the stagnation point' would be rotating - thus lowering the energy delivered to a particular point at a function of time. How do the EIS and DSEIS account for these aerothermodynamic considerations? 6-6 (Continued)

It is not clear from the three reports for which late launch orbital decay reentry velocity Cassini was designed. The Haliburton Report refers obliquely to the "most severe launch reentry accident," but does not stipulate its parameters. All other things being equal, the aerothermodynamic heating rate on a vehicle entering at the flyby gravity assist rate of 19.4 km/sec is 5.48 times greater than the heating rate on a vehicle entering at the "maximum" orbital decay rate of 11km/sec. However, it is far more likely, that a vehicle would suffer a "late launch" orbital decay failure because it had insufficient velocity of about 7 km/sec -- not because it achieved maximum velocity, sufficient or nearly sufficient for earth escape. In this case, the aerothermodynic heating rate for the flyby reentry is 21.48 times greater than for the minimum and most likely launch reentry velocity. The consequence -- at a range of oblique incident angles - is certain vaporization and release of all the Plutonium 238 into the atmosphere. Instead of taking a hard look at the aerophysics, the DSEIS attempts to answer all questions with its probablistic analysis, without really answering most of them. The key question is at what attitude this vaporization and release of Plutonium dioxide would occur. Why do the EIS and DSEIS offer no guidance in this regard?

ATMOSPHERIC TRANSPORT AND PARTICLE SIZE

The three reports make vague speculations about how the Plutonium 238 would travel from the place in the atmosphere to disperse around the world. Nowhere do the reports cite any literature involving modem models of aerospheric transport mechanisms. In the short term that attitude of release is key for disperse patterns. Release in the troposphere -- up to about 12.3 km (41, 000 ft) -- indicates circulation around the globe in a matter of weeks, in the matter of particles from Chernobyl, which were detected worldwide about three weeks after that accident. Release at the top of the atmosphere could take up to several years to disperse the particles worldwide. However, there is no doubt that even from the top of the ozone layer, the Plutonium 238 would eventually come down to Earth. The real issue is what sort of probability distribution of particle densities are likely to occur, based upon the altitude and particle size. These distribution densities would contribute in turn to the human population's exposure to Plutonium 238. It is not clear from reading the three reports what 6-7

model of altitude, atmospheric transport, and particle density -- if any -- the authors employed to obtain their results.

Perhaps this uncertainty is not surprising, given the absence of an atmospheric scientist from the EIS and DSEIS teams. One need only look to the Cretaceous/Tertiary terminater, associated with the last mass extinction of species 65 million years ago marked worldwide by a thin deposited layer of Indium, to recognize the potential for world-wide distribution of an element by atmospheric transport mechanism. 6-7 (Continued)

I believe that should the Cassini probe enter the atmosphere on a flyby, at the most likely capture angles, it would vaporize entirely. It appears that despite all the probablistic models, the EIS and DSEIS fail to take this outcome properly into account.

BIORADIOLOGICAL HEALTH EFFECTS

The particle size and density relate to inhalation and dose absorption into human body. In this regard, I found it difficult to accept the way in which NASA shrugged off some of the public comments in the Appendix of the 1995 EIS. Dorothy Scott Smith wrote to NASA, quoting Dr. Helen Cadicott:

> "... it [Plutonium] is so toxic that less than one-millionth of a gram (an invisible particle) is carcinogenic dose.
>
> One pound, if uniformly distributed could hypothetically induce lung cancer in every person on earth."

The EIS response to Dorothy Scoot Smith quibbles about Dr. Caldicott's particle size, treating it as a precise value rather than as an approximation of figure of speech. What we would expect from Plutonium 238 vaporized in the atmosphere would be population of particles with a distribution of values across a range of sizes. However, neither the EIS nor DSEIS apply their proud probablistic distribution techniques in this instance when, perhaps, it does not suit them to show a range of particle sizes. Why do the EIS and DSEIS fail to discuss the particle population?

Human health effects constitute the area that ultimately generates the most concern. The EIS and DSEIS define the "health effect" of Plutonium exposure very specifically as an excess (above normal rate) latent cancer fatality within 50 years after release of the Plutonium 238. This approach presents several possible shortcomings, which are not surprising, given the absence from the EIS/DSEIS teams of a medical doctor. 6-8

First, the notion of excess latent cancer fatalities is extremely limited; it rules out a range of other, and possibly more common health effects of radiation, including possible "prompt" effects upon the endocrine system (damages in hormone production), neurological system, reproductive system including sterility and birth defects, and other non-fatal effects. Why is there no discussion of non-cancer health effects?

Second, the EIS and DSEIS ignore the direct toxic affects of Plutonium, a heavy metal that is one of the most toxic substance shown. Why is there no discussion of Plutonium toxicity?

Third, it omits any discussions of the "quality favor" for the absorbed radiation dosage. The problem with giving absorbed dose values in centiSyverts (rems) is that it is not a generic measure, and it is the one that assume that the radiobiological damage effects from a

centiSyvert from Plutonium 238 is equal to a centiSyvert of dental x-rays. One important difference is that plutonium 238 keeps emitting radiation for years after a human absorbs it, creating a situation in which the body's natural repair mechanism may not be able to keep up with the tissue damage from its ionizing particles. Why is there no discussion of quality factor for an inhaled or absorbed dose of Plutonium?

Are the EIS and DSEIS ignoring and downplaying the real health consequences of Plutonium exposure because they use a probabilistic model that can calculate only one kind of hypothetical outcome, the defined "health effect" only as a latent excess cancer fatality? Table 4-2 Summary of Radiological Consequences and Mission risks plays some further funny games with the numbers for the health effects. Distinguishing between the Plutonium 238 in the RTGs and in the LWRHUs, makes possible the "probability weighting" of these two sources separately. Thus, for the mean predicted health effects of a VVEJGA reentry, the RTGs alone would cause 130 mean "health effects" and the LWRHUs alone would cause 13 mean "health effects." Yet, combined, RTG and LWRHU cause only the 120 mean "health effects" because of the manipulative probability weighting. However, common sense dictates that if the whole Cassini spacecraft must vaporize on reentry, probability weighting is meaningless and the two sources are additive, yielding 143 mean "health effects."

6-8 (Continued)

SOLAR POWER ALTERNATIVE

The 1995 EIS [p. 2-53 -- 2-58] presents a strawman design for a solar array system that might replace the RTGs. This strawman design is the worst possible array configuration with the longest moment arm, the greatest need to stiffen the arrays against thermal flux and oscillation, and the worst vibratory modes, reminiscent of the arrays that the astronauts replaced on the Hubble Space Telescope because they created so may problems. The strawman comparison is not honest because it is not a "best estimated" as defined in the DSEIS but a contrived worst case that requires substantial added mass to correct (although the authors never state how much mass). This artificial worst case has only one purpose, to stack the deck by setting up an easy comparison to the RTGs so that the EIS can say they looked at solar power and it was so bad everyone can dismiss it from their minds.

6-9

A valid comparison would require an optimized, compact design that did not suffer from the obvious structural problems of the EIS strawman. At the same time, the authors fail to raise the most obvious operational difficulty for the solar power option: that with the unidirectional solar arrays, the spacecraft would need to fly in a solar-inertial orientation (pointing toward the sun). Departures from solar-inertial mode would require a corresponding increase in battery mass to store the power to yield the approximately 800 watts necessary to sustain the oversized, power guzzling Cassini. Why did the EIS overlook so obvious a critique of a mission-limiting aspect of solar power? Did NASA or its contractors ever make an honest attempt at designing an optimal solar power alternative for Cassini?

CONCLUSION

The computed probability of a malfunction causing the spacecraft to reenter the Earth's atmosphere may be small, but the negative consequences are obviously great. The consequences of this failure mode may well outweigh the benefits of success for Cassini. I therefore recommend that the Cassini launch be postponed. This delay would allow further consideration and implementation of either of two feasible alternatives which would substantially reduce the risk: adoption of the triple Venus flyby VVVGA trajectory in 2001

6-10

which does not involve an Earth fly-by or the installation of a solar power supply in lieu of the RTGs. I also recommend the development of a much more efficient and powerful upper stage booster to reduce or eliminate the need for complex planetary fly-by trajectories, so instead we can launch space probes direct to their destinations. 6-10 (Continued)

I support Space Science. I support planetary exploration. I support the Space Program. I support NASA. I do not oppose the responsible use of nuclear power systems for deep space probes and planetary exploration. However, I cannot support biased research, incomplete and inconsistent analysis involving bogus comparisons, and substandard documentation. I am also concerned that the poor quality of the EIS and DSEIS will place NASA in a poor light should there be a reentry accident and subsequent investigation. 6-11

If a builder submitted an Environmental Impact Report of this quality to support the construction of a shopping center or a housing project, it would have no chance of passing the scrutiny of a modem municipality due the the absence of the input data, the key assumptions, and the methods of analysis. While delaying the Cassini launch would delay the receipt of valuable scientific data I believe the increase in safety, and in the public perception of NASA's dedication to safety would be much more valuable. 6-12

Thank-you for your consideration in this matter.

Sincerely,

Marc M. Cohen

Marc M. Cohen

Comment No. 6-1

Details of these models and parameters are in Volume II, Book 2 and Volume III, Book 2 of the recently available Safety Analysis Reports (SARs) prepared for the Cassini mission (LMM&S a-j; and EG&G 1997), and have been forwarded to the commentor.

Comment No. 6-2

The spacecraft trajectory is specifically designed to avoid Earth's atmosphere (JPL 1993b; JPL 1997: see Chapter 8 of the Final SEIS). The trajectory is biased 5000 km (3106 miles) or more away from the swingby altitude (not less than 800 km; about 500 miles) for all but 7 days prior to the swingby. The possibility of an Earth reentry only becomes conceivable if an extremely unlikely sequence of events and failures occur. The vast majority of potential spacecraft failures do not alter the spacecraft's trajectory. To initiate an impact trajectory, a failure would have to cause a change in the spacecraft's velocity of exactly the right magnitude and direction. For this reason, it is extremely unlikely that a misfire of the Cassini rocket system would result in an inadvertent Earth reentry. Another fact to keep in mind is that a number of spacecraft maneuvers will have to be successfully conducted just to bring the spacecraft within tens of thousands of kilometers of Earth. A maneuver at 7 days before swingby will ensure that the spacecraft arrives at the desired point in space for the gravity-assist but does not come closer to Earth than 800 km (about 500 miles).

All relevant failures encountered on previous U.S. planetary missions have been accounted for in the analysis and were considered in the design of the spacecraft's propulsion system, other spacecraft engineering subsystems, the swingby trajectory, and the overall mission design. Much of the Cassini design was driven by an effort to minimize the probability of an earth impact. Trajectory biases and flyby distances were increased, additional micrometeoroid shielding was added, a number of on-board fault protection monitors were incorporated into the design, propulsion subsystem operation during the swingby period was constrained to a benign mode, and ground system procedures and constraints were modified, all to minimize the probability of Earth impact. Flight experience was used in deriving the propulsion, electronic and ground system failure rates and common mode and design errors were incorporated. Key failure rates of concern are those that cause both a change in velocity or direction, or loss of commandability. Even though these failure rates are on the order of several percent, the trajectory bias, spacecraft redundancy and on-board fault protection, result in Earth impact probabilities of less than one in a million. The Galileo stuck antenna and Mars Global Surveyor stuck solar array would not have had any effect on an Earth swingby. It should be noted that Galileo successfully performed two Earth swingbys and is now gathering science information from Jupiter and its environment. To eliminate the threat of a Mars Observer type failure, the Cassini propulsion system was modified to enhance control of vapors. In addition, during the swingby phase of the mission, the propulsion system will be operated in a benign mode (i.e., a mode in which the system is not further pressurized until after the swingby).

Comment No. 6-3

The recently available Safety Analysis Reports (SARs) (LMM&S a-j; EG&G 1997) for the Cassini mission are now referenced in this Final Supplemental Environmental Impact Statement (SEIS). The Hassan reference is included as Appendix C to this Final SEIS.

Comment No. 6-4

The Cassini mission was approved in October 1989 and redesigned to reduce costs early in 1992. The Cassini mission is a comprehensive study of the Saturnian system – the planet, rings, magnetosphere, and the moons, particularly Titan. The objectives of this mission could not be accomplished with a smaller spacecraft.

Comment No. 6-5

Nowhere in the 1995 Cassini EIS or SEIS does it say or imply as the commentor suggests, "what does 20 - 30 kg of Pu-238 isotopes matter?" The primary purpose of preparing and issuing the 1995 Cassini EIS and Draft and Final SEIS has been to address the potential impact of plutonium dioxide release on the quality of the human environment.

Second, the statement that Pu-238 is a strong emitter of alpha particles and Pu-239 is a weak emitter of alpha particles is not a scientific characterization of the radioactive decay properties of the two isotopes. As noted previously, Pu-238 has a half-life of 87.75 years. Pu-239 has a half-life of approximately 24,400 years. Both are alpha particle emitters. The energy of the alpha particles from both are about the same: i.e., about 5.5 MeV for Pu-238, and about 5.2 MeV for Pu-239. The statement concerning one being a stronger emitter of alphas than the other relates to the half-lives of the two isotopes. This means that for the same mass of material, Pu-238 emits 280 times the energy per unit time as Pu-239.

In the comparisons made in the Draft and Final SEIS, the quantities of Pu-239 are described in terms of curies. A curie is a unit of activity defined in terms of a specific number (3.7×10^{10}) of disintegrations (decays) per second. The 1995 Cassini EIS provides the amount of activity released during the weapons testing program in terms of curies. A curie of activity from Pu-239 is equivalent to a curie of activity from Pu-238, and their radio-biological health effects are nearly equivalent.

The amounts of material released from weapons testing and the potential releases from Cassini accidents are both expressed in terms of curies; thus a one to one comparison between these two releases is appropriate. Three factors affecting the primary cancer risks are the level of activity, the energy, and the type of the decay particles or photons emitted. When described in terms of curies, the risk presented by a curie of Pu-238 and Pu-239 are about the same. This is the comparison that is made in the 1995 Cassini EIS.

Comment No. 6-6

A detailed reentry analysis was performed in support of the Cassini safety analysis process. That information is described in the Cassini General Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG) Final Safety Analysis Report (SAR) in Volume II, Book 1, Section 5 and in Volume II, Book 2, Appendices E and F and Volume III, Book 1, Sections 4.3 and 4.4, which are being made available to the public. This SAR was only recently available after issuance of the Draft SEIS.

The analysis differentiates between the orbital and VVEJGA (EGA swingby) reentry conditions. A team of experts from Lockheed Martin and the John Hopkins University Applied Physics Laboratory (JHU-APL) performed the reentry analysis contained in the SARs for the Cassini mission. For Earth orbital reentry, the analysis uses a later formula by Lees which is functionally similar to the equations developed by Fay and Ridell. The use of Lees equation is described in the RTG SAR Volume II, Book 2 Appendix F (LMM&S c). The SAR contains a detailed discussion of the aerothermodynamic heating and computational fluid dynamic (CFD) methodologies used to develop the results presented in the Draft and Final SEIS for the EGA reentry scenarios. The analysis does take into consideration a full range of the phenomena encountered by ablating reentry bodies, including convective and radiative heating plus structural analysis which was not mentioned by the commentor. The modeling addresses the issue of tumbling. Tumbling is the less severe condition as the heating and ablation is distributed over the surface of the reentering body.

The GPHS-RTGs modules and the Light Weight Radioisotope Heater Units (LWRHUs) were designed to withstand reentry from Earth orbit. The carbon-carbon composite of the RTG aeroshells and graphite impact shells (GISs) mitigate the effects of the EGA accident reentry. The reentry conditions for the VVEJGA reentry were analyzed using the CFD methodologies with the findings predicting that most of the GISs from the RTG modules would remain intact during reentry.

No RTG module in-air failures were predicted for the Earth orbital reentry scenarios. Details of the findings are discussed in the SAR. All potential plutonium dioxide releases were taken into consideration in developing the health effects and the risks presented in the Draft and Final SEIS.

The John Hopkins University Applied Physics Laboratory (APL) performed the analysis for the LWRHUs. The results of the analysis are reported in Appendix VI of the Cassini LWRHU SAR (EG&G 1997) and summarized in Section 7.7 of the same document. A significant fraction of the LWRHUs are predicted to release their materials depending upon the LWRHU orientation and the VVEJGA reentry angle.

For the RTGs, the 90 degree reentry angle is the most severe. The differences in reentry velocities are taken into consideration in the analysis used to develop the results presented in the Draft and Final SEIS. The analysis did consider shallow (oblique) angles and no RTG module in-air failures are predicted for reentry angles less than 16 degrees. A discussion of the equation used for altitude of release is contained in the RTG SAR Volume III Section 4.4.1 EGA Consequence Analysis Process (LMM&S d).

Comment No. 6-7

The list of preparers and contributors to the Draft and Final SEIS document is not meant to indicate the full extent of the expertise involved in the analyses. The models used for dispersion and transport were all developed by experts in their field, and were applied by the engineers and scientists doing the analyses. The 1995 Cassini EIS and Draft and Final SEIS take into account the degree to which vaporization would occur in the unlikely event of an Earth swingby accident (see RTG SAR Volume II, Book 1, Section 5.4.5, pg. V II 5 - 102, and Table of particle sizes (5.4-8) on pg. V II 5 - 104, LMM&S b.) The analyses indicated partial vaporization under certain reentry scenarios. Models of atmospheric transport mechanisms were used in estimating the dispersion of any plutonium dioxide released during an inadvertent Earth swingby reentry (see RTG SAR Volume III, Book 2, Appendices F, G, H, LMM&S e). High altitude releases would result in near-global distribution (see RTG SAR Volume III, Book 1, Section 4.4.1.2, pg. VIII 4-38 and Volume III, Book 2, Appendix H, LMM&S e).

Please also see comments 2-7, 2-8, and 2-9.

Comment No. 6-8

The EGA inadvertent reentry analysis predicts a mean release of 3 percent of the plutonium dioxide inventory at high altitude, consisting of 1.4 percent as vapor and 1.6 percent in particulate form characterized as a particle size distribution (see the recently available Safety Analysis Reports; specifically Table 5.4-8, of the RTG SAR Volume II, Book 1, pg. VII 5-104, LMM&S b). The vapor portion is initially dispersed at high altitude. The inhalation of the particulate portion of the release is taken into account using particle-size dependent dose conversion factors. Dilution of the high altitude vapor release within the atmosphere globally, coupled with the small fraction of the air in the atmosphere inhaled by people prior to its removal by deposition on the Earth's surface, result in only a small fraction of the release being inhaled. This is estimated to be less than 1.3×10^{-17} grams inhaled by an individual per gram of plutonium release (See the 1995 Cassini EIS, Appendix D, pg. D-25; response to comment 4B).

Regarding potentially non-fatal health effects, see response to comment 2-12 (d). Regarding medical expertise, while the EIS team did not include a medical doctor, the team did include members with extensive experience in health physics (expertise related to radiation protection and radiation health effects).

The particle-size dependent internal dose factors for plutonium dioxide used in the analysis are based on an internal dosimetry model of the International Commission on Radiological Protection (ICRP) documented in ICRP Publication 30 (ICRP 1979). These dose factors are widely accepted at the Federal level by the Department of Energy, the Environmental Protection Agency, and the Nuclear Regulatory Commission (DOE 1988). The internal dose factors for plutonium dioxide incorporate a quality factor of 20 which reflects the relative biological effectiveness of alpha radiation compared to a quality factor of 1 for x-ray, gamma, and beta radiation. The internal dose factors take into account the time integration of doses within the body for a period

of 50 years following exposure (termed the "50-year dose commitment period"). In addition, the metabolic characteristics (particle size, solubility, respiratory region clearance rates, and organ clearance rates) are taken into account.

Regarding the allegations of "downplaying the real health consequences of plutonium exposure," see response to comment 2-12 (c).

The combined mean health effects of a VVEJGA reentry of 120 health effects for the GPHS-RTG and the RHUs represents a probability weighted mean, calculated as follows [then rounded]: $[(8.0\times10^{-7})(13) + 6.3\times10^{-7}(140)] / 8.0\times10^{-7} = 120$

The results of 13 health effects for the RHU and 140 health effects for the GPHS-RTG can not be simply added. The difference in the total release probabilities of 8.0×10^{-7} for the RHU and 6.7×10^{-7} for the GPHS-RTG, reflects the situation that given a VVEJGA reentry with a probability of 8×10^{-7}, there is a conditional probability of 1.0 that there would be a consequence from the RHU and a conditional probability of $(6.3\times10^{-7}/ 8\times10^{-7}) = 0.79$ that there would be a consequence from the GPHS-RTG. This difference in conditional probabilities is associated with the larger number of RHUs (157 considered in the analysis) compared to the number of GPHS modules (54) that reenter.

Comment No. 6-9

The linear design depicted in the DSEIS was based on a flight proven design which had been modified and ground tested with Advanced Photovoltaic Solar Array (APSA) technology to achieve the highest possible specific performance (lowest weight per output power) using existing or near term real technology. The design depicted conforms to existing proven designs for large area, high power solar arrays, and has been optimized for the factors pertinent to use of solar arrays for spacecraft.

In the course of solar design studies conducted for the Cassini mission several arrangements for the solar arrays were investigated, including designs using circular arrays and those using additional linear arms each of shorter length. The purpose of these studies was to optimize the array design while accounting for the following:

- requirements for spacecraft structure stiffness and strength, spacecraft instrument fields of view and navigation;
- minimizing the stowed launch volume, the number of drive motors, and the overall complexity of the design; and
- maximizing the ease (simplicity) of deployability, array packing (solar cells per unit area) efficiency, and array specific performance.

Comment No. 6-10

The only perceived advantage of the 2001 primary launch opportunity is that the Cassini spacecraft would not execute an Earth swingby maneuver, thus alleviating the need to address potential environmental impacts that could occur in the unlikely event of reentry during an Earth swingby. It should be noted, however, that the 2001 launch opportunity employs a Venus-Earth-Earth-Gravity Assist trajectory as a backup. In the unlikely event that the spacecraft could become uncommandable any time after

injection and before Saturn Orbit Insertion, the probability of a long-term Earth impact is estimated to be about 1.7×10^{-7}, or about 1 in 5,800,000. For additional details regarding the long-term impact scenario, see chapter 4.1.5.2 of the 1995 Cassini EIS.

Additional details regarding the 2001 mission are addressed in the Section 4.2, third paragraph of this Final SEIS, and Chapter 2 of the 1995 Cassini EIS.

The 2001 launch opportunity requires substantial spacecraft propulsion system design changes, and is minimally acceptable with respect to the science objectives.

Also, solar power is not a viable alternative to RTGs for the Cassini mission (see Section 2.1.4 of the Draft and Final SEIS, and response to comment 1-1).

Comment No. 6-11

The environmental and nuclear safety assessments conducted for Cassini are the most comprehensive and rigorous studies ever conducted for any space mission.

Comment No. 6-12

Copies of the recently available SARs (LMM&S a-j; EG&G 1997) have been forwarded to the commentor.

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Commentor 7: Thomas W. Chao

May 23, 1997

Thomas W. Chao
1555 W. Middlefield Rd., Apt 99
Mountain View CA 94043

Mr. Mark R. Dahl
Cassini Program Office
Office of Space Science (Code SD)
NASA Headquarters
Washington, DC 20546-0001

According to President Marc Cohen, Architect, National Federation of Federal Employees, Local 997, the Cassini Investigating Committee nor the General membership meeting Wednesday May 21 could reach an agreement on a recommendation for action about the Cassini probe which is powered by 73 pounds of Plutonium 238. According Mr. Cohen, the general meeting voted to inform membership of the above address to send comments on the Environmental Impact Studies by 4:30 pm EST May 27, and Mr. Cohen apologized for the lateness of this news update.

Enclosed is e-mail correspondance from myself as a member of this Committee, and as a non-expert, layperson, compared to the other scientists, who are considered to be experts on this topic.

1. The first letter talks about natural radioactivity, and the measures of radioactivity in Curies and radiation or dosages in roentgen equivalents for man (rem) or RADS (ergs). Also discussed are certain natural radiactive elements, and then Helen Caldicott's recent book, 'Nuclear Madness' which talks about the problems with radwaste and Plutonium, emphasizing how toxic the radioactive Plutonium is. Note that Dr. Caldicott argues that a department for radioactive waste disposal should be created, and that radioactive wastes should be quantified according to biopathway equivalence. Also Dr. Caldicott proposes more stringent standards for exposure from 5 rems to 2 rems for workers handling radioactive materials and wastes, as well as establishing epidemiological life-cycle studies for these nuclear workers. 7-1

2. The second letter to Paul Davis, Chair, Cassini Investigating Committee, argues that the longpathway remote sensing, abstract experiment is not realistic from the point of view of time-wise projected probability. A serious need to delay and investigate further on the Cassini probe exists, as was delineated by the resolution of the Marin County Board of Supervisors, which also declared Marin County to be a 'nuclear free zone.' There is reasonable concern & fear of the incineration of Plutonium 238 if there was either a launch of Earth fly-by mishap. In light of recent problems with 7-2

the unmanned remote-sensing space-craft, this is a reasonable fear. Questions as to (a) the atmospheric models for transport and dispersion or aerothermodynamic effects with respect to the orbital decay of the craft, and incineration, as it travels through the atmosphere [is a reasonable objection to the statistical summary of the EIS draft], (b) the possibility of impacting space debris or other objects in its pathway, (c) the statistical probability of high-energy particles or electromagnetic waves damaging onboard computers(?), (d) the apparent relatively safer alternative 2001 launch which eliminates the Earth Gravity Assist (EGA) with a Venus-Venus-Venus Gravity Assist (VVVGA) [what are the objections to the 2001 launch?], (e) a better statement as to the toxicity of the Plutonium-238 is in order, (f) the source of the Plutonium-238 is Russian, and the risks involved in the manufacture, and with nuclear energy need to be emphasized, and finally, (f) the mission-risks included in actual costs are probably under-exaggerated.

7-2 (a)
7-2 (b)
7-2 (c)
7-2 (d)
7-2 (e)
7-2 (f)
7-2 (g)

3. The third letter explains the limits for the remote sensing unmanned spacecraft should be the limits of the energy of the sun, thermodynamically. In other words, the unmanned craft really should be solar powered only.

7-3

4. This letter, again to Marc Cohen, President, NFFE, Local 997 states that there is concern that NASA public policy making could be a part of the reason that the fight for the environment is a losing one, as according to the news media. The concern for the technology being a useful complement for improving the 'quality of life on earth' is that 'life in space' be enhanced is the criteria for future projects. So, this is consistent with the bio-astronomy program currently at NASA Ames Research Center. I propose NASA studies in bio-astronomy on radiation & environment & human health. Perhaps, Dr. Caldicott, the Doctors for Social Responsibility, who are concerned about the proliferation of a nuclear environment just from the use of nuclear energy, but also with the earlier nuclear arms race, should from a PARTNERSHIP with NASA to address this nuclear problem within the earth's ecosystem.

7-4

5. This letter, I noted that even though I objected to the Plutonium-238 power and request that it be replaced by solar cells, that the gravity-assists are probably energy-saving in that the acceleration gained by the planetary gravitational field could be a savings. Again I request a bio-astronomy program with respect to nuclear energy.

7-5

In summary, I am supporting of the Marin County Board of Supervisors resolution to delay the Cassini flight until there is more investigation on the health dangers of the Plutonium-238 energy source. I am in favor of replacing the radio-isotope thermo-electric generators (RTGs) with thermonuclear fusion powered solar cells. This is consistent with bio-astronomy

principals in exploring our solar system.

Thank you for considering my opinion.

Sincerely,

Thomas W. Chao

I

Commentor 7: Thomas W. Chao

pkdavis, 09:12 AM 5/5/97, NFFE Cassini Committee

To: pkdavis
From: Thomas Chao <tchao@mail.arc.nasa.gov>
Subject: NFFE Cassini Committee
Cc: mcohen, trivell
Bcc:
X-Attachments:

Paul,

You have a copy of the final Environmental Impact Statement (EIS) for the Cassini mission. I hadn't read through it, and the technical or statistical analysis is where the controversy is. Over the weekend I read through Helen Caldicott's revised 'Nuclear Madness.'

I have the measures that Marc went over with me on the phone from earlier.

radioactivity in Curies (Ci) or milliCuries
radiation or dosages in roentgen equivalents for man (rem) or RADs (ergs)

The information I have is old, and is from an earlier Remington's Pharmaceutical, some introductory physics books, the Encyclopaedia Britannica,
and Helen Caldicott, MD., and Tom R's internet handout.

According to the old Encyclopaedia Britannica sea level has .02 -.04 RADs per year of cosmic radiation exposure. At about 5,000 ft this increases
to .04 -.06 RADs per year. According to Caldicott the current health standards
give permissible levels not-to-exceed 170 rems.

Carbon-14, Potassium-40, Radium have natural radioactivity which is quantized in curies, and as to type such as alpha or beta particles or gamma rays, and has certain physiological affects. Note the natural occurrences
of radium, thorium and uranium.

EXTERNAL DOSE DUE TO NATURAL RADIOACTIVITY

SOURCE	DOSE in RADs/year
Ordinary regions	.025-.160
Active region Granite in France	.180-.350
Houses, Sweden Alummina shale	.158-.220
Monazite alluvial Deposits, Brazil	Mean .500 Max 1.00
Monazite sand Kerala, India	.37-2.8

Commentor 7: Thomas W. Chao

pkdavis, 09:12 AM 5/5/97, NFFE Cassini Committee

As Marc pointed out, the Plutonium-238 has a half-life of 87.7 years, and the radioactive by-products have 25,000 years half-life total!!!! Caldicott has a chapter in her book on Plutonium and has that 'Plutonium is one of the most carcinogenic substances known... ...So toxic that less than one-millionth of a gram... ...is a carcinogenic dose. Irradiation of mouse and hmaster cells by plutonium alpha particles creates chromosomal abnormalities that appear only after several generations of cell divisions.'

According to Caldicott the 1969 industrial fire at a military reactor site in Rocky Flats, Colorado released forty-four pounds of respirable plutonium, and that it was disruptive to the local ecosystem.

Also at present there is 5 tons of plutonium thinly dispersed over the earth from nuclear bom testing, satellite re-entries and orbital decay, and effluents from nuclear testing. The tragedy at the Chernobyl reactor added 1/2 ton.

The amended Price Anderson act limits liability in case of a nuclear accident to 7.8 billion/accident. The doubling dose for incidence of bone marrow cancer is 3.6 rads per lifetime, and is 33-38 rads per lifetime for other forms of cancer.

Caldicott's book talks about the problem with radioactive wastes. The difficulty of this is interestingly not different from the carcinogenic compounds of the organic chemistry based technology such as pesticides. However, the radioactive compounds are orders of magnitude more potent in that respect. Possibly the strong forces, compared to electromagnetic forces or to weak forces, and possibly to gravity, might be the first approximation as to strength.

In Chapter 11, 'Waste Cleanup,' 'In the 1950's the United States possessed only a few hudred curies of radioactive waste. By 1984, it has accumulated 14.7 billion curies stored in interim centers; by the year 2000, experts predict a total of 42 billion curies--overkill for every human

pkdavis, 09:12 AM 5/5/97, NFFE Cassini Committee

To: pkdavis
From: Thomas Chao <tchao@mail.arc.nasa.gov>
Subject: NFFE Cassini Committee
Cc: mcohen, trivell
Bcc:
X-Attachments:

Paul,

You have a copy of the final Environmental Impact Statement (EIS) for the Cassini mission. I hadn't read through it, and the technical or statistical analysis is where the controversy is. Over the weekend I read through Helen Caldicott's revised 'Nuclear Madness.'

I have the measures that Marc went over with me on the phone from earlier.
radioactivity in Curies (Ci) or milliCuries
radiation or dosages in roentgen equivalents for man (rem) or RADs (ergs)

The information I have is old, and is from an earlier Remington's Pharmaceutical, some introductory physics books, the Encyclopaedia Britannica,
and Helen Caldicott, MD., and Tom R's internet handout.

According to the old Encyclopaedia Britannica sea level has .02 -.04 RADs per year of cosmic radiation exposure. At about 5,000 ft this increases
to .04 -.06 RADs per year. According to Caldicott the current health standards
give permissible levels not-to-exceed 170 rems.

Carbon-14, Potassium-40, Radium have natural radioactivity which is quantized in curies, and as to type such as alpha or beta particles or gamma rays, and has certain physiological affects. Note the natural occurrences
of radium, thorium and uranium.

EXTERNAL DOSE DUE TO NATURAL RADIOACTIVITY

SOURCE	DOSE in RADs/year
Ordinary regions	.025-.160
Active region Granite in France	.180-.350
Houses, Sweden Alummina shale	.158-.220
Monazite alluvial Deposits, Brazil	Mean .500 Max 1.00
Monazite sand Kerala, India	.37-2.8

pkdavis, 09:12 AM 5/5/97, NFTE Cassini Committee

on earth.'

Note the parallels to Rachel Carson's 'Silent Spring' which I read a long time ago.

The suggestions that Caldicott gives at the end of her book is: (in my own words, approx.)

1. Create a department of radioactive waste dispoal (NASA would be ideal for this position!)

2. Radioactive waste must be quantified according to biopathway equivalence.
(I made this suggestion earlier in my paper to the basic research council)

3. Establish more stringent exposure standards 'from 5 rems to 2 rems for workers handling radioactive materials and waste.' Establish epidemiological studies on these nuclear workers at the life-cycle level. Open Dept. of Energy radiation exposure & releases data to the public.

--Thank you.

Tom Chao

pkdavis, 04:01 PM 5/7/97, No Subject

To: pkdavis
From: Thomas Chao <tchao@mail.arc.nasa.gov>
Subject:
Cc: mcohen, trivell
Bcc:
X-Attachments:

Paul Davis, Chair, Cassini Investigating Committee

Courtesy of Tom Rivell, I got a chance to browse through all the various
Environmental Impact Statement drafts at the Law Library in Building 19.

Since obviously the staff at Ames are experts on this topic, I'll input
some of my layperson perception [or misconception] of the problem.

The distances or (1/r)(1/r)(1/4) are vast [if we can get away with it] and the velocity impossibly high (EGA swing-by, 19.4 kilometers/sec). And
the craft is impossibly loaded with fuel & oxidizers.

You might theoretically consider that it should have an artificial ecosystem
so that it's more than a missile. Here it has physics remote sensing tools and a high gain attenna. Because initially, you would have success,
but eventually this kind of system with probability would eventually catch
up to you on motivation as well as in errors that could conceivably meet tragic results. Again, the astrobiology question is posed. [The pictures at an
exhibition of the planets is satisfying only at first????)]
['By entropy it wins at first, but then it loses'][Repetition in this circumstance is not desired]--Reasonable? At the limits of technology anyway. (I must be dreaming)

Questions:
1. On the EGA (Earth Gravity-Assist), the analysis of transport and dispersion
   of radioactive particles, as was argued by opponents--The question as to
   why the incineration of the iridium clad Plutonium-238 would not occur,
   and [I might be misreading] why it would descend & impact the earth
   or fall into the ocean [approx 3/4 surface?]. That seems improbable without
   computations to support it. [I guess that a missile envelope shield

pkdavis, 04:01 PM 5/7/97, No Subject

for the Plutonium-238 would not help if the 'steering failed[?]'}

2. Other questions are that is there space debris as was pointed out and
what is the probability of impacting such? Also, can the debris be anticipated at least in near earth orbit. Then can early detection systems & steering mechanisms be built to avoid these micrometeroids
or anthropogenic space age debris?

2a. If there is a RTG or other Plutonium-238 sources onboard, then is there statistical probability of high-energy particles or electro-
magnetic waves damaging onboard computers? Of course as with distributors, which have electromagnetic shields, they obviously shield the electronics. Then, the same question is posed for cosmic
radiation.

3. Since the 2001 alternative launch involves a Venus-Venus-Venus Gravity
Assist (VVVGA), then what is the objection to this alternative launch?

4. Since the environmental health is a reasonable issue, then perhaps, delaying until solar cell alternatives can be achieved for this kind
of an experiment [if not critical to the course of space science] would be a reasonable pathway for the space program. Remember the bioastronomy problem, with all the concern about nuclear [rad] wastes.
[Cosmic radiation as the source of the nuclear energy.]

5. Perhaps, a clarifying statement on the biopathway toxicity of the Plutonium-238 or of its fission byproducts is in order.

6. The source of the Plutonium-238, and perhaps liability with respect to the US initiated international space treaty(?) according to animated software. What is the risks occurred in creating this plutonium,
conceivably with a breeder reactor(?)[I don't really understand this]

7. Are the risks under-exaggerated? Remember that this venture has to be costed. Whole cost accounting includes sources of the plutonium,
and then considering the fuel & such, etc., the costs/risks/benefits
has to be questioned. Aren't there other problems that could be relevant to NASA's bio-astronomy program which might be even more

pkdavis, 04:01 PM 5/7/97, No Subject

worthwhile investments?

--Thank you.

Tom Chao

mcohen
trivell

2.

pkdavis, 08:26 AM 5/15/97, NFFE Local 997 Cassini Investi

To: pkdavis
From: Thomas Chao <tchao@mail.arc.nasa.gov>
Subject: NFFE Local 997 Cassini Investigating Committee
Cc: trivell, mcohen
Bcc:
X-Attachments:

'[The] sun's the reason...'

The thermodynamic equation for costs/risks/benefits of a manned or unmanned spacecraft might be conjectured to take in consideration 'heterotrophic' and 'autotrophic' considerations, as the heat of sun's thermonuclear fusion and C-N-O cycle is the energy source of the earth's ecosystem. Observing the sun's 11 year cycle or correlating solar flares to disturbances of the earth's electrical field is what I've read in the news media. Possibly looking at the reversal of the Earth's Southern hemisphere coreolis in the Pacific Ocean, or the 'El Nino,' which is observed by the height and temperature of the Ocean surface, and brings rains and drought to the continents, and relating highs and lows in atmospheric pressure to phenomena on the sun's surface(?) is today's science.

'Day speaks unto day. Night with night shares it knowledge.'

For an abstract space experiment, operating on solar energy might make that
thermodynamic equation go forward, I would guess.

Thank you. [This is just my own opinion]

--Tom Chao

mcohen, 10:23 AM 5/19/97, COMMENTS, Cassini Investigatin

To: mcohen
From: Thomas Chao <tchao@mail.arc.nasa.gov>
Subject: COMMENTS, Cassini Investigating Committee Draft
Cc: pkdavis, trivell
Bcc:
X-Attachments:

Marc,

1. I always read in the news media that there is a 'losing battle for the environment.' I am concerned that that NASA public policy making is a part of this problem. As critics have written, the lack of concern for environment & health problems is not reasonable for pure research with respect to abstract space science. The benefits/costs/risks assessment or the EPA would have to concede that to a layperson this is an abstract space experiment; and considering the health of ecosystem life on the planet earth--The consideration as to environment has to weighed over remote sensing phenomenal observation benefits derived from the experiment. Note that NASA is a civilian organization that is under international laws, i.e., United Nations. There should not be unnecessary jeopardy.

2. The limits of any abstract solar system exploration are the limits of the thermonuclear fusion energy release of our sun. This would appear to myself as an obvious thermodynamic equation of energy conservation. I think that thermodynamically, the equation doesn't go forward otherwise. I could be mistaken on this matter though. Therefore, solar cells should be the power source--SUSTAINABILITY.

3. The 'solar powered sailing' of any abstract unmanned spacecraft would be deemed to be 'environmentally-friendly.' Solar powered spacecraft appear to be advantagious, naively. However, building more powerful boosters to launch instead of taking advantage of the accelerative gravity-assists from the planets would probably lose some of the energy conservation for these abstract solar system unmanned spacecraft. Possibly the gravity-assists or planet swing-bys are some kind of breakthrough in

orbital mechanics theory. This is my own guess.

4. Also the bio-astronomy consideration that NASA Ames has publicized, has it that life in the solar system or perhaps in the galaxy or universe is what is important for determining the goals and objects for the space program. The consideration of life in space is what is to be achieved or enhanced. The limits of the space program is the limits of life in that respect. At this time, improvements in the earth's biosphere is possibly. NASA should be supporting work in this respect. As part of its bio-astronomy program, NASA needs to disseminate information to the public on the problems of radiation. This is a part of the bio-astronomy problem, and the natural radio-isotope environment in the ecosystem, as well as radiation encountered in aerothermodynamic flight, as well as space flight needs to be addressed as part of NASA program along with problems with anthropogenic sources of radiation--NASA BIO-ASTRONOMY STUDIES ON RADIATION & ENVIRONMENTAL AND HUMAN HEALTH.

5. Another problem to be addressed by the bio-astronomy program should be the problem of radwastes (NUCLEAR WASTES). The recent protests of 'activists' concerning the secret transport of nuclear fuels from Japan to Cherbourg, France, or England (reprocessing plutonium), and use of reactors for nuclear weapons (Plutonium or tritium) are of concern also. The problems at Three Mile Island, and the tragedy at the Chernobyl reactor are evidence that the 'FEAR OF' a nuclear accident is a very REASONABLE one. The environmental health can be improved by establishing 'nuclear free' zones. In some sense, space should be 'nuclear free.' I guess that this is ironic, as the space program was formed in part as a response to survival in a nuclear age; and obviously without the protective atmosphere of the earth, near & outerspace is a radioactive environment at best. The 'Doctors for Social Responsibility' with Dr. Helen Caldicott should form a PARTNERSHIP with NASA to address this nuclear problem within the earth's ecosystem.

Commentor 7: Thomas W. Chao

mcohen, 10:23 AM 5/19/97, COMMENTS, Cassini Investigatin

Taking this BIO-ASTRONOMY or earth-friendly approach to space research
is the only viable pathway for the space program, as then the program will
be concerned about the QUALITY OF ECOSYSTEM LIFE on the planet earth.

Sincerely,

Tom Chao

cc: pkdavis
trivell

Marc M. Cohen, 03:40 PM 5/19/97, Re: COMMENTS, Cassini Investig

To: "Marc M. Cohen" <mcohen@mail.arc.nasa.gov>
From: Thomas Chao <tchao@mail.arc.nasa.gov>
Subject: Re: COMMENTS, Cassini Investigating Committee Draft
Cc: pkdavis, trivell
Bcc:
X-Attachments:

Marc Cohen, President, NFFE Local 997

[I could very well have more than a few misconceptions on this problem.] However, I think the gravity-assist might be an energy-efficient journey for these remote-sensing, unmanned spacecraft. [However, I don't remember whether the rocket boosters from earlier were larger.] It's just the Plutonium-238 power supply I'm concerned about [or the Earth Gravity Assist (EGA) in this circumstance.]

Note the uncertainty or statistics involved in the failure analysis is that science appears to say that there must be some. In physics, we were taught the Heisenberg Uncertainty Principle; and this plays in the nuclear physics. Also 'curved space-time' in both special & general relativity seem to have this problem. Also, in parallel, behavioral human psychology also allows for errors as a part of learning. So I think that problems have to be allowed for in space flight, especially for a sustainable, realistic program.

The other suggestion was for insertion of a bio-astronomy program for the study of radiation & problems with nuclear energy so far as the health of the ecosystem & humans is concerned. At the same time, the radwaste issue has to be addressed as a current international problem, and also one of physics.

The manufacturing of this kind of Plutonium-238 is one of the questions that I would have. Whether it requires a breeder reactor, etc... Then if the source if international, then what kinds of safety, health considerations pertain? Also, what kinds of international law apply? What happened to our sense of history? [Space historian?]

Mostly, I'm in support of the letter. I appreciate the Union applying its expertise, knowledge, and physical adeptness in the space sciences

Marc M. Cohen, 03:40 PM 5/19/97, Re: COMMENTS, Cassini Investig

in considering the Marin County sBoard of Supervisors Resolution.

Thank you.

Tom Chao

Marc M. Cohen, 11:24 AM 5/23/97 , Cassini Committee Outcome

>From mcohen@mail.arc.nasa.gov Fri May 23 11:24:06 1997
Return-Path: <mcohen@mail.arc.nasa.gov>
Date: Fri, 23 May 1997 11:24:00 -0700 (PDT)
To: Recipient.List.Suppressed:;
From: "Marc M. Cohen" <mcohen@mail.arc.nasa.gov>
Subject: Cassini Committee Outcome

To the NFFE member,

Neither the Cassini Investigating Committee nor the General membership meeting this week could agree on a recommendation for action about the Cassini probe and its 73 pounds of Plutonium 238.

Instead, the general meeting voted to inform the membership of the address
to send comments on the Environmental Impact Studies by 4:30 EST May 27.
I'm sorry for the lateness of this news update. The EIS is available in
the Ames Law Library on the second floor on Bldg N19, at the end near the
post office.

The address is:

Mr. Mark R. Dahl
Cassini Program Office
Office of Space Science (Code SD)
NASA Headquarters
Washington, DC 20546-0001

Here are to Web Sites: Cassini Project at JPL and the Stop Cassini Action
group.

http://www-hpcc.astro.washington.edu/mirrors/solar/cassini.htm

http://www.animatedsoftware.com/cassini/actionpl.htm

Sorry we were not able to achieve a more specific resolution for the concerns that members had brought up to the union.

Sincerely,

Marc

Marc M. Cohen, President
National Federation of Federal Employees, Local 997
NASA-Ames Research Center
Mail Stop 19-13

Marc M. Cohen, 11:24 AM 5/23/97 , Cassini Committee Outcome

Moffett Field, CA 94035-1000

TEL (415) 604-0068
FAX (415) 604-0673

Comment No. 7-1

Comment noted.

Comment No. 7-2(a)

Please see response to comments 2-9, 2-10, 2-11 and 6-7.

Copies of the recently available Safety Analysis Reports (SARs) (LMM&S a-j; EG&G 1997) have been forwarded to the commentor.

Comment No. 7-2(b)

Please see response to comment 2-18

Comment No. 7-2(c)

As part of the failure analyses conducted for the Cassini mission design, various spacecraft failure modes were examined for their potential to adversely affect the functionality of the spacecraft and cause a mission failure. The Cassini spacecraft electronics have been especially selected and/or built and packaged into the spacecraft to improve their resistance to and protection against radiation damage during its flight. The radiation field emitted by the RTGs and RHU's is also taken into account in this design- and-build process for both the spacecraft and spacecraft instruments.

Refer to the 1995 Cassini Environmental Impact Statement (EIS) Supporting Studies Volume III (JPL 1993 b).

Comment No. 7-2(d)

Please see response to comment 6-10.

Comment No. 7-2(e)

Please see response to comment 6-8.

Comment No. 7-2(f)

All of the Pu-238 used for Cassini is of domestic (U.S.) origin. The Department of Energy has prepared separate National Environmental Policy Act (NEPA) and safety documentation for each facility involved in the processing of Pu-238.

Comment No. 7-2(g)

Only potential cleanup costs are addressed in the Draft and Final SEIS.

Comment No. 7-3

Please see response to comments 1-1, 2-1 and 2-2.

Comment No. 7-4

Comment noted.

Comment No. 7-5

Comment noted.

Victoria Nichols
2230 53rd Ave.
Vero Beach, FL 32966
May 22, 1997

Mark R. Dahl, Program Executive, Cassini
Mission and Payload Development Division, Office of Space Sciences
Code SD
NASA Headquarters
Washington, DC 20546-0001

RE: Comments to Draft Supplemental Environmental Impact Statement for Cassini Mission

Mr. Dahl:

In January 1997, a Delta II rocket exploded at Cape Canaveral, releasing a toxic cloud that spread to Vero Beach, Orlando and beyond. This explosion, of what you at NASA promote as a very reliable rocket, emphasizes to Florida residents the very real and grave consequences of a launch explosion involving deadly plutonium. It is clear from the events in January that no amount of "emergency management" could protect anyone from an accident at the Cape involving nuclear material. The County Emergency Management agency was totally unable to adequately inform the citzenry of Indian River County that there was a toxic cloud of gas in the vicinity -- in fact, even the people who did learn of the situation (and then only by rumor and word of mouth) did not become aware of it until the gas cloud was already overhead. Many people were exposed without even knowing it. Telephone calls to Emergency Management revealed an extremely casual attitude about the situation and a startling lack of information as to the exact nature of the toxins. It is obvious that a similar explosion of the Cassini mission or any other mission with a nuclear payload could not be "managed" by any definition of the term. The only adequate safety measure would be total evacuation of the major portion of central Florida and the coastal areas before launch. 8-1

In November 1996, a failed Russian Mars 96 spacecraft re-entered Earth's atmosphere over South America and might have released as much as 200 grams of toxic aerosol plutonium particles. Again we are made aware of the fallibility of space technology and the very real danger presented by the use of nuclear materials in spacecraft. No amount of "science" is worth this risk.

As a citizen who is under immediate threat from NASA's insistence on using unreliable and dangerous technology, I call on you to cancel the Cassini mission and all future missions involving nuclear materials.

In peace,

Victoria Nichols

Victoria Nichols

Comment No. 8-1

Launches of radioactive materials from Kennedy Space Center (KSC) or Cape Canaveral Air Station (CCAS) require special planning to address the presence of radioactive materials and the potential for accidents involving those materials. Accordingly, for Cassini, radiological contingency plans are being developed by NASA/KSC and USAF/CCAS to address specifically the initial response that would be required in the unlikely event of an accident affecting the launch site. Similar plans already exist at the State and county (Brevard) levels in Florida, and are in the process of being updated for the Cassini mission. Planning activities have been accomplished in concert with representatives from the State of Florida Division of Emergency Management, Office of Radiation Control, and Emergency Management and Public Safety representatives from Brevard County. The NASA/USAF and State of Florida plans are also being closely coordinated with the DOE, which maintains its own set of emergency response instructions for radiological accidents of many kinds, to ensure a coordinated initial response to any accident. Additionally, NASA/KSC and the Department of Energy (DOE) are coordinating closely with the State of Florida on development of recommended protective actions that could be implemented in the unlikely event of a release of radioactive material, both for the launch site and for the general public and affected areas . The plans under development include coordination of public affairs information with public media, sophisticated predictive modeling tools to assist in the emergency response, and the predeployment of significant resources including people and equipment. A tabletop walkthrough and a command post exercise are planned prior to the launch, to ensure that the multiple plans being developed mesh together to provide a unified response plan to a launch accident with the potential to release radioactive materials.

DOROTHY SCOTT SMITH
155 E. Colonial Court-C, Indian Harbor Beach, FL 32937-2035

5-3-97

Nasa
Code L.D.
Nasa Headquarters
Wash. D.C. 20546-0001

Dear Nasa:

Thank you for the Nasa information. Please notice that I no longer live in Satellite Beach but have moved to Indian Harbor Beach.

Since the Persian Gulf War when we killed thousands of people over oil I leave only, except in an emergency, only gone where I can walk, which at eighty-eight (in June) plus several accidents isn't very far. However, I told Bruce Gagnon, Director of the Florida Coalition for Peace & Justice that if he wanted me to do civil disobedience again to protest plutonium in space & militarization of space.

Published by Fellowship of Reconciliation (Nyack, N.Y. 10960)

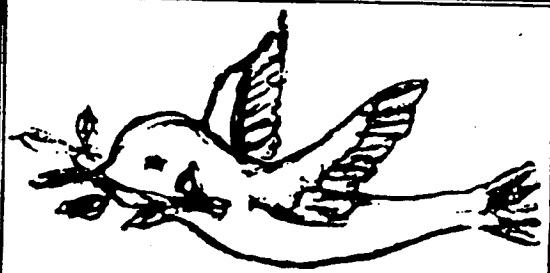
to support its worldwide work for peace and nonviolent action.

I would do so again. The month I spent in jail I almost froze to death but I can think of no way I'd rather die than to die for peace. my daughter sent me warm clothes but they wouldn't let me have them because they could be worn outside.

If you read my book-mark 'Every life is precious' (enclosed) you will know how I feel about most of our priorities. Sometimes I feel science + technology is not only destroying people but also our beautiful earth. and why are we spending millions to go up in the air when we can't even shelter the homeless on earth? The greatest crime is poverty. 'There should be no poor among you.'

Peace, love + joy to all -

Dorothy Scott Smith



Every life is precious.
Why do we permit people RAS
to make a fortune
by making, selling and using
Things that kill, injure and destroy?
Every life is precious.
Why is having an adventure or a thrill
more important than saving
every precious life from injury or death?
If it were a disease that was
doing this destruction we
would do everything we could
to find the cause and eliminate it.
Why is our convenience
more important than another's life?
What kind of role models
are we for our children?
Why do we provide other countries
with weapons that kill, injure and destroy?
Their opponent's lives are all precious too.
If you believe we are all made in God's image,
then why are we killing the divinity in us?
We pride ourselves on our inventions
cars, planes, trains, buses, boats
They all kill and injure.
Birds were made to fly.
We were made to walk or run.
Every life is precious.
Peace is not made with a gun
or a bomb or a mine.
Peace is made with love and forgiveness.

Dorothy Scott Smith

Thank you for your letter.

MAY 19, 1997

NASA:

HALT THE CASSINI PROBE UNLESS THE PLUTONIUM IS REMOVED.

ACCORDING TO DR. HELEN CALDICOTT: "IT (PLUTONIUM) IS SO TOXIC THAT LESS THAN ONE-MILLIONTH OF A GRAM, AN INVISIBLE PARTICLE, IS A CARCINOGENIC DOSE. ONE POUND, IF UNIFORMLY DISTRIBUTED, COULD HYPOTHETICALLY INDUCE LUNG CANCER IN EVERY PERSON ON EARTH."

HOW DANGEROUS COULD 73 POUNDS BE, IF RELEASED ACCIDENTLY DURING THE CASSINI MISSION? 10-1

CONSIDER THESE, AND STOP THE OCTOBER 1997 LAUNCH:

A) THE ENORMOUS COST OF THE MISSION;
B) THE DANGERS OF ON-BOARD PLUTONIUM;
C) THE AVAILABILITY OF ALTERNATIVE ENERGY SOURCES;
D) KEEPING NUCLEAR MATERIALS OUT OF SPACE KEEPS NUCLEAR WEAPONS OUT OF SPACE;
E) SPACE SHOULD NOT BE A LUCRATIVE NEW MARKET FOR THE NUCLEAR INDUSTRY.

Jeanne Vicini

Jeanne D. Viocini
770 Deer St. Apt. 110
Plymouth, MI 48170-1728

Comment No. 10-1

NASA's and the Department of Energy's extensive analyses of both launch and Earth swingby accidents that could potentially result in a release of plutonium dioxide, indicate that only a small fraction of the 73 pound inventory is likely to be released. The analyses of potential accidents indicate that there are no credible scenarios that could result in a complete release of the full inventory on-board the Cassini spacecraft. The consequences of potential releases have been provided in the Table 4-2 of the Draft and Final Supplemental Environmental Impact Statement (SEIS).

509 Wisconsin Drive
Browns Mills, NJ 08015
May 23, 1997
Margaret N. Spallone

Mark R. Dahl, Program Executive
Cassini Mission and Payload Development Division
Office of Space Science, Code SD
NASA Headquarters
Washington, DC. 20546-0001

Dear Program Executive Mark R. Dahl:

I regret that I was not informed of the public comment period on the Cassini mission in time to do other than rush this to the post office. Please inform me of future comment periods on Cassini. Please also send the "Environmental Impact Statement for the Cassini Mission". I am very much opposed to the mission as a severe public health threat. Also please send the "Supplemental" information.

Here are some comments which I endorse:

1. Waiting a relatively short time until the solar option could be used would be much safer and also would allow for a much longer study of Saturn. 11-1
2. NASA hasn't considered the best available solar options. 11-2
3. Health effects are estimated for 50 years when the actual effects of plutonium accident would last more like 1000 years. 11-3
4. Plutonium in the food chain was insufficiently considered. 11-4
5. NASA's mathematics was insufficiently presented. 11-5
6. The lack of clarity of the purpose for this very dangerous mission leads one to wonder if there is something the public isn't being told. Is there a military goal which some might being using to justify such a terrible risk? Studying rings doesn't cut it. What is the purpose of Cassini supposed to be? 11-6
7. The worst case scenerio is grossly underestimated. 11-7
8. How can NASA be sure that an RTG which might collide with space debris during the proposed flyby won't produce radioactive pollution? 11-8
9. Consideration of accidental re-entries needs to be 11-9

(over, please)

studied for each angle as different angles would produce different consequences. | 11-9 (Continued)

10. Did NASA forget that a "skipping" probe may eventually fall to earth? The RTGs, colliding with debris, could break before incineration | 11-10

11. How does NASA assume "skip" trajectories would be benign? | 11-11

12. Does NASA make the false claim that there is a low, safe level below which plutonium exposure would be harmless? Low level exposure can kill by cancer. | 11-12

13. The impact statement is seriously incomplete without inclusion of data on the Maximum Individual Dose in REMs for a flyby accident. | 11-13

14. It is standard practise to use comprehensible graphs in presenting statistics. Why hasn't NASA done so? It would indicate a desire to obscure the facts. | 11-14

15. Data is missing on the largest possible contamination area. | 11-15

16. Why is the Price-Anderson act being used for insurance? Its history has been to help foist nuclear power on the public when other insurance prospects recognized that nuclear power was too risky. Have insurance companies recognized the bad risk of Cassini and refused to insure? Does this violate an Outer Space Treaty? | 11-16

17. Would Cassini, if no disaster befell, set a precedent for many more similar hazardous missions? | 11-17

18. Has space debris risk been sufficiently analyzed? | 11-18

19. What justification, other than convenience, is there for averaging doses, when not all would receive the same dose and the earth's population is changing? | 11-19

20. Why has NASA rejected studies which prove that there is no minimum lethal dose of plutonium? | 11-20

21. EPA guidelines should not be interpreted to mean that pollution which is difficult to attempt to cleanup is therefore benign. | 11-21

22. What would be the mental health effects of an orbiting disaster, that is, if we would know a hit RTG was coming down, but not when, where, or the consequences? What would be the consequences to a major city if impact was made? | 11-22

509 Wisconsin Drive
Browns Mills, NJ 08015

May 23, 1997

Mark R. Dahl, Program Executive
Cassini Mission and Payload Development Division
Office of Space Science, Code SD
NASA Headquarters
Washington, DC 20546-0001

(continued)

23. Has NASA sufficiently considered re-entry impact on ice- or snow-covered areas? | 11-23

24. What are the projected consequences of a disaster on non-human species? | 11-24

25. Is NASA assuming RTG's will be unlikely to incinerate in case of impact? | 11-25

26. Does NASA have sufficient iodine pill stocks and adequate emergency plans in place for distribution? | 11-26

27. Has NASA learned all it can from the recent incineration of the nuclear-payload-equipped Russian Mars '96 probe? Has the plutonium powerpack been accounted for? This is relevant since it would show the survival factor for at least one angle of re-entry under one set of circumstances. | 11-27

28. What are the environmental impacts of the radioactive byproducts associated with the mission which are not going into space? | 11-28

29. Would we feel safe if other countries wanted to follow the Cassini example? Cassini sets an example. What are the environmental consequences of such an example? | 11-29

30. Political decisions impact the environment. How will Cassini affect world politics, in apparent success or in disaster? | 11-30

31. Who would be responsible for cleanup off a disaster? How would it be financed? A plan for cleanup is not valid unless it has included plans for financing and safe disposition of poison. | 11-31

32. Has NASA considered that women, fetuses and infants have been shown to be most at risk of extreme low level radiation? | 11-32

Please answer these questions and concerns in your Supplemented Environmental Statement.

Sincerely yours,
Margaret N. Spallone

Comment No. 11-1

Please see response to comment 2-1.

Comment No. 11-2

Please see response to comment 2-2.

Comment No. 11-3

Please see response to comment 2-3.

Comment No. 11-4

Please see response to comment 2-4.

Comment No. 11-5

Please see response to comment 2-5.

Comment No. 11-6

The Cassini mission is an international scientific mission for peaceful purposes and has no "military goals." The objectives of the mission have been addressed in Section 1.2 of the Draft and Final Supplemental Environmental Impact Statement (SEIS), with further details provided in Section 1.2 of the 1995 Cassini EIS. Briefly stated, the Cassini mission involves a four year tour of the Saturn system to scientifically investigate the planet, its rings, satellites and magnetosphere. The commentor has been provided with a copy of the 1995 Cassini EIS, and this Final SEIS.

Comment No. 11-7

Please see response to comment 2-7.

Comment No. 11-8

Please see response to comment 2-18.

Comment No. 11-9

Please see response to comment 2-9.

Comment No. 11-10

Please see response to comment 2-10.

Comment No. 11-11

Please see response to comment 2-11.

Comment No. 11-12

NASA makes no claim that there is a low, safe level of plutonium exposure. All potential doses were considered in estimating the accident consequences reported in the Draft and Final SEIS.

Comment No. 11-13

Please see response to comment 2-13.

Comment No. 11-14

Please see response to comment 2-14.

Comment No. 11-15

Please see response to comment 2-15.

Comment No. 11-16

Please see response to comment 2-16.

Comment No. 11-17

The Cassini mission sets no precedent. It would be the 25-th mission since 1961 to be launched with nuclear power sources on board. For additional details, refer to Table 2-2 of the 1995 Cassini EIS.

Comment No. 11-18

Please see response to comment 2-18.

Comment No. 11-19

Please see our response to comment 2-19.

Comment No. 11-20

NASA has not rejected such studies. The analyses reported in the Draft and Final SEIS took into account all potential doses in estimating accident consequences. The Draft and Final SEIS report only results without de minimis, i.e. the estimated consequences reported account for all potential doses received.

Comment No. 11-21

Please see response to comment 2-21.

Comment No. 11-22

The psychological impacts to the general population of a potential accident involving release of plutonium dioxide are not within the scope of the National Environmental Policy Act (NEPA).

Please also see response to comment 2-22.

Comment No. 11-23

Please see response to comment 2-23.

Comment No. 11-24

Please see response to comment 2-24.

Comment No. 11-25

Please see response to comment 2-8.

Comment No. 11-26

Please see response to comment 2-26.

Comment No. 11-27

Please see response to comment 2-27. NASA and DOE have no knowledge as to whether the Russians have recovered their own radioisotope power source from Mars 96.

Comment No. 11-28

Please see response to comment 2-28.

Comment No. 11-29

Cassini does not set an example. There is a successful history of the use of plutonium dioxide - fueled RTGs onboard U.S. spacecraft as noted in the response to comment 13-1. The environmental consequences of the Cassini mission have been addressed in the June 1995 Cassini EIS and the Draft and Final SEIS.

Comment No. 11-30

Please see response to comment 2-30.

Comment No. 11-31

Please see response to comment 2-31.

Comment No. 11-32

NASA has included all members of the potentially exposed population in estimating the consequences of a potential accident involving the release of plutonium dioxide. The increased sensitivity of women, fetuses, and infants to low level radiation with respect to detrimental effects (fatal cancers, non fatal cancers, and severe hereditary effects) has been addressed by ICRP-60. The recently available Safety Analysis Reports (SARs) (LMM&S a-j; EG&G 1997), referenced in the Final SEIS used the health effects estimator from ICRP-60. The SARs have been forwarded to the commentor. See also response to comment 2-12 (c).

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(2 PM)
April 11, 1997

Mr. Dahl,

Hello on a cold/overcast afternoon in eastern Pennsylvania. I'm just basically writing back to say thanks for all the Cassini information I have received this week. However, I must mention that, due to a lot of severe pain I have been in recently, I don't want any more large reports. Trying to read them while in pain caused severe eyestrain as well as migraine. However, my support for Cassini remains intact, even if I am liberal, and still hope said probe can be launched during the first month and a half window later this year. I will end now my chronic pain is getting very severe, Mr. Dahl

Sincerely,
Edward D. Ramsberger

Thank you for your letter. Request noted.

rec'd 5/2/97

FLORIDA SOUTHWEST PEACE EDUCATION COALITION

1312 Whispering Lane • Venice, FL 34292

Founded in 1983
by Mary Black

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Librarian
Annabelle Duisberg
941-474-5204

Past President
Malcolm Chubb
941-488-6451

Affiliated with the
Florida Coalition
for Peace and Justice
Gainesville, FL

Mark R. Dahl
NASA Headquarters
Washington, DC 20546-0001

Dear Mark Dahl,

Thank you for mailing the safety analysis and the draft for the impact statement for the Cassini Mission.

This launch is a particularly dangerous one with 73 lbs. of Plutonium on board. Our organization has opposed this launch before the recent crash of the Russian Mars 96 spacecraft crashed somewhere in Chili or Bolivia. A few weeks ago the headlines read, "Space shuttle makes a safe and early return." The record for successful missions is not good and now NASA plans to put 73 lbs of PLO_2, the most dangerous substance know to man in space with a potential danger to the whole world. 13-1

We have had many redioactive releases from failed spacecraft spreading debris around the earth causing who knows how many cases of cancer? I remember Transit 1 5BN-3 where 2.1 lbs plutonium vaporized in the atmosphere and spread around the world, Nimbus B-1, Apolo 135.5, Cosmos 954 and now Mars 96. Why risk spreading 73 lbs of cancer causing plutonium around the world? We have enough cancer here on earth already. None of these accidents was supposed to happen, but they did! 13-2

For the trip to Saturn Cassini will circle Venus twice then plunge toward earth to gain speed for its 7 year trip to Saturn. It will pass within 320 miles of the earths surface. It is this flyby, according to NASA risk assessment that carries the greatest potential danger because the probe could burn up if it should veer into the earths atmosphere. 13-3

The environmental study admits that in a worst case accident 5 million people could be exposed to radiation and 2,300 could suffer health effects as a result. Before the Challenger accident NASA said the likelihood of an accident was less than 1 in a million. After the accident the estimate was revised to 1 in 76.

Michio Kaku, a nuclear physics professor at the City College of New York said, "These numbers are a scientific fraud, I don't know the exact probality of failure, but neither does NASA."

I do not believe the US should be playing "Russian Roulete" with the health of the world.

Please hold up this launch until solar power for the mission is developed. Kaku says NASA's own plans call for a mission that would travel out beyond the orbit of Pluto, using only solar power. Is enough being done to develope this alternative? Probaly not. 13-4

Peace and Justice,

Malcolm Chubb
1312 Whispering Lane
Venice, FL 34292
Ph: 941-488-6451
April 29, 1997

Comment No. 13-1

The comment appears to imply that all five of the cited missions/spacecraft deposited plutonium into the atmosphere. This is not correct. Of the five spacecraft cited in the comment, the Transit BN-3 in 1964, Nimbus B-1 in 1968, and Apollo 13 in 1970 were U.S. spacecraft and carried earlier generations of RTGs. (Cosmos 954 and Mars 96 were Russian not U.S. spacecraft, with Cosmos 954 carrying a reactor).

The three U.S. missions cited were part of the total 24 U.S. missions to date to carry RTGs. A complete listing of all U.S. missions to date can be found in the Table 2-2 of the 1995 Cassini Environmental Impact Statement (EIS). Of these three missions, two involved accidental reentrys (Transit BN-3 and Nimbus B-1; Apollo 13 was not an accidental reentry, as is well known through the recent movie of the same title.) The early design SNAP-9A RTG on board Transit BN-3 burned up upon reentry as noted in the comment. This early type of RTG was designed to burn up under these conditions. The two SNAP-19B2 RTGs onboard Nimbus B-1, and the SNAP-27 onboard Apollo 13 performed as designed, did not burn up, and fell into the ocean intact. The two SNAP-29B2 RTGs were recovered, and the SNAP-27 lies at the bottom of the Tonga Trench in the Pacific Ocean. Of the total 24 U.S. missions to date, only those three were not successfully completed. In each case, the malfunction was neither caused by nor related to the presence of RTGs on board.

Cassini carries the current generation RTG design - the General Purpose Heat Source. This generation RTG is designed to survive reentry from Earth orbit without release of the plutonium dioxide inventory. For additional details regarding RTG design, see Section 2.2.4 of the 1995 Cassini EIS.

Comment No. 13-2

Please see response to comment 6-2.

Comment No. 13-3

The comment cites the results of the preliminary analyses performed for the 1995 Cassini EIS, not the updated analyses upon which the draft and Final Supplemental Environmental Impact Statement (SEIS) were based. The "5 million" people exposed to radiation, presumably as a result of an Earth swingby accident, was cited in the 1995 Cassini EIS as 5 billion worldwide receiving some level of radiation exposure. A swingby accident of the type analyzed for the Draft and Final SEIS would potentially result in exposure of about the same number of people. In this accident scenario, only a tiny fraction of the released plutonium would be breathed in or consumed and retained by humans. The small amount that would be taken in and retained by people would be distributed among approximately 5 billion people. Over a period of 50 years, on the average, individuals would take in less than one trillionth of a gram and receive less than 1 millirem of radiation. Over the same period of time, individuals would be exposed to approximately 15,000 millirem from natural background radiation.

The 2,300 health effects cited by the commentor was the estimate developed for a swingby accident. The recently available Safety Analysis Reports (LMM&S a-j; EG&G 1997) estimated the mean consequences as 120 health effects.

The overall probability of an accident resulting in a release from the RTGs and RHUs is about 2.8×10^{-3} or about 1 in 360. The probability of an Earth swingby reentry accident resulting in a release is less than 1 in a million.

Please also see response to comment 6-2.

Comment No. 13-4

Please see response to comment 1-1.

Cassini Mission
Final Supplemental Environmental Impact Statement

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