1. PURPOSE AND NEED FOR ACTION

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

1.1 BACKGROUND

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

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

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

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

The approach to providing environmental documentation for the Cassini mission, including this mission-specific EIS, has been the product of an evolving process. On February 27, 1991, NASA published a Notice of Intent in the *Federal Register* (56 FR 8219) to prepare a programmatic EIS for future activities under NASA's Outer Solar System Exploration (OSSE) program, as well as for two OSSE missions that were planned in February 1991 - the Comet Rendezvous Asteroid Flyby (CRAF) mission and the Cassini mission. At that time, these two missions as well as other future OSSE missions under consideration (e.g., the Comet Nucleus Sample Return mission and the Neptune Orbiter-Triton Probe), were to share a number of similar requirements for launch energy, electrical power, onboard propulsion, and guidance and control. A common multipurpose, multimission spacecraft design, the Mariner Mark 11, was being developed to satisfy these similar requirements for reducing the overall cost of each OSSE program.

In January 1992, budget proposals deleted funding for the CRAF mission, future OSSE missions were being reassessed, and the multipurpose Mariner Mark 11 spacecraft design efforts were redirected toward lighter, cheaper mission-specific spacecraft. These changes, particularly the move toward mission-specific spacecraft, reduced and/or eliminated many of the commonalities in near-term and future OSSE missions that formed the basis for the Mariner Mark 11 and the programmatic EIS.

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

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

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

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

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

1.2 PURPOSE OF THE PROPOSED ACTION

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

- By what processes did Saturn acquire so much orbital debris, what processes organized the debris into the intricate structure of rings and embedded moonlets now surrounding the planet, and what is the composition of this debris?

- How does the chemical and physical composition of Saturn compare with that of Jupiter and Earth?

- What is the nature of Saturn's magnetospheric interactions with dust and moonlets in the ring plane and what would this information tell us about the interactions of plasma, dust, and radiation environment at the beginning of the solar system?

- What chemical processes produced the atmosphere of hydrocarbons and other organic molecules unique to Saturn's largest moon, Titan, and do these hydrocarbons exist in liquid form on Titan's surface?

- Does the dark hemisphere of Iapetus, one of Saturn's icy moons, consist of organic material, and is this material related to the organic material in Titan's atmosphere and to the dark material on comets, asteroids, and the dark moons of Mars (Phobos and Deimos)?

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

- The Cassini spacecraft would tour and study Saturn, its rings, moons, and magnetosphere over a 4-year period. This portion of the mission would include approximately 35 flybys of Titan for the SRMU configuration (or 21 for SRM launch) enabling detailed studies of Titan's atmosphere and surface.

- A detachable atmospheric entry probe, the Huygens Probe, would be released from the Cassini spacecraft to descend through the atmosphere of Titan. Surface properties of Titan would be measured *in-situ* if the Probe survives the parachuted touchdown. The Probe would relay scientific measurements of the conditions of Titan's atmosphere to Earth via the Cassini spacecraft over the 2.5-hour period it would take for the Probe to descend to Titan's surface.

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

1.2.1 Investigation of Saturn's Atmosphere

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

1.2.2 Investigation of the Moon Titan

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

TABLE 1-1. SUMMARY OF CASSINI MISSION SCIENTIFIC OBJECTIVES

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

Source: JPL 1993a

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

1.2.3 Investigation of Saturn's Icy Satellites

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

1.2.4 Investigation of Saturn's Rings

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

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

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

1.2.5 Investigation of Saturn's Magnetosphere

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

1.2.6 Summary of Mission Purpose

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

1.3 NEED FOR THE ACTION

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

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

1.4 INDIRECT BENEFITS FROM CASSINI MISSION PLANNING ACTIVITIES

1.4.1 Technology Utilization Benefits

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

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

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

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

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

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

Executive Summary

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Chapter 8

Appendix A

Appendix B

Appendix C

Appendix D

Appendix E