National Aeronautics and Space Administration

Draft
Environmental Assessment for the Dragonfly Mission

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Science Mission Directorate
National Aeronautics and Space Administration
Washington, DC 20546

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Acronyms and Abbreviations

Acronym	Definition
°F	degree(s) Fahrenheit
µCi/m^2	microcuries per square meter
APL	Johns Hopkins University Applied Physics Laboratory
ARPA	Archaeological Resources Protection Act
CCAFS	Cape Canaveral Air Force Station
CCSFS	Cape Canaveral Space Force Station
CEQ	Council on Environmental Quality
CFR	*Code of Federal Regulations*
CNS	Canaveral National Seashore
CRM	cultural resource manager
CZMA	Coastal Zone Management Act
DHS	U.S. Department of Homeland Security
DOE	U.S. Department of Energy
DSM	Deep Space Maneuver
EA	environmental assessment
EDL	entry, descent, and landing
EGA	Earth gravity assist
EIS	environmental impact statement
EO	Executive Order
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FAA	Federal Aviation Administration
FDEP	Florida Department of Environmental Protection
GPHS	general purpose heat source
HPO	Historic Preservation Officer
IAEA	International Atomic Energy Agency
ICRMP	Integrated Cultural Resources Management Plan
ICRP	International Commission on Radiological Protection
INL	Idaho National Laboratory
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
KSC	Kennedy Space Center

lb	pound(s)
LC	launch complex
LWRHU	light weight radioisotope heater unit
MBTA	Migratory Bird Treaty Act
MEI	maximally exposed individual
MINWR	Merritt Island National Wildlife Refuge
MMPA	Marine Mammal Protection Act
MMRTG	multi-mission radioisotope thermoelectric generator
MSL	Mars Science Laboratory
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act of 1969
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NOA	Notice of Availability
NPS	National Park Service
NRHP	National Register of Historic Places
NSPM-20	*Presidential Memorandum on a Launch of a Spacecraft Containing Space Nuclear Systems*
OSIRIS-REx	Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer
Pu-238	Plutonium-238
Pu-238	Plutonium-238
RADCC	Radiological Control Center
rem	Roentgen Equivalent Man
RHU	radioisotope heater unit
RPS	radioisotope power systems
RTG	radioisotope thermoelectric generator
SHPO	State Historic Preservation Office
SJRWMD	St. Johns River Water Management District
SLC	space launch complex
SLD 45	Space Launch Delta 45
SMD	Science Mission Directorate
SpaceX	Space Exploration Technologies Corporation
U.S.	United States
U.S.C.	*United States Code*
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force
USFWS	U.S. Fish and Wildlife Service
USSF	U.S. Space Force

SECTION 1

Purpose and Need for the Proposed Action

1.1 Introduction

The National Aeronautics and Space Administration (NASA) has prepared this Environmental Assessment (EA) to analyze the environmental impacts of launching the proposed New Frontiers Program's Dragonfly mission, which would use radioisotope power systems (RPS). The Dragonfly mission would include a multi-rotor vehicle, hereafter referred to as a rotorcraft lander, which would land on the surface of Saturn's largest moon, Titan. The mission would explore multiple locations on the surface of Titan and investigate the surface chemistry, atmospheric and surface properties, subsurface properties, liquid reservoirs, and areas where liquid water and complex organic materials that are key to life may have once existed. The launch would take place at the U.S. Space Force's (USSF's) Cape Canaveral Space Force Station[1] (CCSFS) or NASA's Kennedy Space Center (KSC) in Brevard County, Florida, in June 2027; however, the launch schedule is subject to change.

NASA is the lead federal agency for this Proposed Action. The U.S. Department of Energy (DOE) and the USSF are cooperating agencies. DOE's cooperating agency role stems from its responsibility in producing special nuclear material and its ownership of RPS, including the multi-mission radioisotope thermoelectric generators (MMRTGs) and the radioisotope heater units (RHUs) used by NASA. USSF is a cooperating agency because it manages the launch facilities at CCSFS and the Eastern Range and additionally has expertise in launches that include the use of nuclear materials at these locations. This EA has been prepared in accordance with the National Environmental Policy Act of 1969 (NEPA), as amended (*United States Code* [U.S.C.] Title 42, Section 4321, *et seq*.); the Council on Environmental Quality (CEQ) regulations for Implementing the Procedural Provisions of NEPA (*Code of Federal Regulations* [CFR] Title 40, Parts 1500 through 1508); and NASA's NEPA implementing regulations (14 CFR Subpart 1216.3) and policy. The NEPA process for the Dragonfly mission began prior to the promulgation of the 2020 CEQ revisions to 40 CFR Part 1500; consequently, this document has been written in accordance with the preceding 1978 regulations. This EA covers the potential use of radioisotope power and heating sources associated with the Dragonfly mission; all aspects associated with routine launches at either KSC or CCSFS are covered under existing NEPA documentation (NASA, 2011).

1.2 Background

1.2.1 New Frontiers Program

The Dragonfly mission is a part of NASA's New Frontiers Program (referred to as the Program) managed by the Planetary Missions Program Office under NASA's Science Mission Directorate (SMD). In 2002, the U.S. Congress approved NASA's establishing a program named in honor of John F. Kennedy's 1961 speech in which he stated, "We stand today on the edge of a new frontier." The Program encourages national and international scientific teams to propose missions in response to an Announcement of Opportunity developed based on the National Research Council's 2013-2022 Decadal Survey, *Vision and Voyages for Planetary Science in the Decade* (National Research Council, 2012). The objective of the Program is to use innovative and effective approaches to accomplish specific solar system exploration goals that add to humankind's understanding of the solar system. The goals are prioritized by the planetary science community and the missions are awarded on a competitive peer-reviewed basis. The Program seeks to improve performance through the use of validated new technology and through commitment to, and

[1] On December 9, 2020, the Cape Canaveral Air Force Station (CCAFS) and Patrick Air Force Base were both redesignated as Space Force installations. Subsequently, on May 11, 2021, the 45th Space Wing was redesignated as Space Launch Delta 45.

control of, design, development, and operations costs. The Decadal Survey advises NASA to conduct two New Frontiers Program missions per decade (National Research Council, 2012).

In 2019, NASA selected the Dragonfly mission as part of the Program from a 2016 competitive announcement of opportunity. Dragonfly is the fourth mission approved under the New Frontiers Program. Previous missions under the Program include the following:

- **New Horizons** launched from Cape Canaveral Air Force Station (CCAFS) in January 2006 and flew through Pluto's system in 2015. The mission conducted scientific investigations of Pluto and its moons. The spacecraft arrived at and observed Kuiper Belt object Arrokoth (original designation 2014 MU69) in January 2019 and continues to explore the Kuiper Belt at this time.
- **Juno** launched from CCAFS in August 2011, began orbiting Jupiter in July 2016, and will continue mission operations through September 2025 or until the spacecraft's end of life. Juno is studying the gas giant's gravitational and magnetic fields and vast atmosphere, as well as several of its moons.
- **Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx)** launched from CCAFS in September 2016, approached the asteroid Bennu in 2018, and collected a sample of surface material in 2020. OSIRIS-REx will return to Earth in September 2023 carrying the sample from the asteroid. This will be a historic first mission achievement for the United States (U.S.).

1.2.2 Understanding Titan

Previous NASA missions to Saturn include Pioneer 11 (1973), Voyager 1 (1977), Voyager 2 (1977), and Cassini-Huygens (1997). The Cassini-Huygens mission included flybys to map Titan's surface and the deployment of the Huygens probe to perform in situ measurements of the atmosphere and surface of Titan. Data from the Cassini-Huygens mission indicate that Titan may contain the prebiotic chemistry necessary for life. Since the end of the Cassini-Huygens mission, NASA has identified a knowledge gap regarding the chemistry and the potential for life on Titan (Lorenz et al., 2018).

Saturn's largest moon, Titan, is the second largest moon in the entire solar system. Because the surface consists of rock-hard water ice, Titan is classified as an icy moon, and because of its deep interior water ocean, it is classified as an ocean world. Titan's dense atmosphere supports a methane cycle of clouds, rain, lakes, and seas, similar to Earth's water or hydrological cycle. The abundant complex organic material accessible on Titan's surface makes it an ideal destination for studying the conditions necessary for extraterrestrial life and the kinds of chemical interactions that occurred before life developed on Earth (APL, 2020a; National Research Council, 2003).

A few notable facts about Titan include the following (APL, 2020a):

- **Atmosphere:** Dense and extended (four times denser than Earth's) and composed of nitrogen (95%) and methane (5%), with small amounts of carbon-rich compounds.
- **Average Surface Temperature:** 94 Kelvin (-290 degrees Fahrenheit [°F]).
- **Bedrock:** Primarily water ice.
- **Three Liquid Systems:** Water, methane, and ethane.
- **Length of Day:** One Titan day is equal to approximately 16 Earth days.

1.3 Purpose and Need for the Proposed Action

NASA needs to fulfill the congressional mandate to carry out the Program objective. The proposed Dragonfly mission would satisfy this mandate by exploring Titan in partnership with the Johns Hopkins University Applied Physics Laboratory (APL). Additionally, the Planetary Science Decadal Survey identified Titan as a high priority for the planetary science community because it is an ocean world and the only moon in our solar system with a dense atmosphere. Titan is potentially the most Earth-like world in our solar system, which makes it an ideal location for studying prebiotic chemistry and the potential for extraterrestrial life.

1.4 Organization of the Environmental Assessment

NASA has prepared this EA to provide an efficient and comprehensive analysis of the potential environmental effects associated with the implementation of the proposed Dragonfly mission.

This EA is organized as follows:

- **Section 1**, ***Purpose and Need for the Proposed Action***, provides background information relevant to the Proposed Action, the purpose and need for the Proposed Action, and a brief description of how the document is organized.
- **Section 2**, ***Description of the Proposed Action and Alternatives***, presents detailed descriptions of the Proposed Action and the No Action Alternative.
- **Section 3**, ***Affected Environment and Environmental Consequences***, provides a description of the existing conditions of the environmental resources potentially affected by the Proposed Action and presents an analysis of potential direct, indirect, and cumulative impacts to environmental resources.
- **Section 4**, ***Summary of Impacts***, describes the potential impacts associated with the Proposed Action and the measures that would be implemented to avoid or minimize those impacts.
- **Section 5**, ***Distribution***, provides a list of agencies and individuals who were contacted for information in the preparation of this document and to whom the EA will be distributed.
- **Section 6**, ***List of Preparers***, provides a list of the names and qualifications of the document preparers.
- **Section 7**, ***References***, lists the references used in preparing this EA.

1.5 Public Outreach and Involvement

The Notice of Availability (NOA) of the Draft EA was advertised in the *Florida Today* and *Orlando Sentinel* newspapers on April 24, 2022. The Draft EA and associated NOA are also posted on the NASA NEPA Public Reviews webpage maintained by the NASA Environmental Management Division at NASA Headquarters (https://www.nasa.gov/content/public-reviews). Public comments will be accepted through May 24, 2022. Copies of the Draft EA were provided to the public at the following library locations:

- Central Brevard Library and Reference Center, 308 Forrest Ave, Cocoa, FL 32922
- Cocoa Beach Public Library, 550 N Brevard Ave, Cocoa Beach, FL 32931
- Melbourne Library, 540 E Fee Ave, Melbourne, FL 32901
- Merritt Island Public Library, 1195 N Courtenay Pkwy, Merritt Island, FL 32953
- Port St. John Public Library, 6500 Carole Ave, Cocoa, FL 32927
- Titusville Public Library, 2121 S Hopkins Ave, Titusville, FL 32780
- Satellite Beach Public Library, 751 Jamaica Blvd, Satellite Beach, FL 32937

NASA has also printed a limited number of hard copies of the Draft EA, which are available upon request by contacting hq-draftdragonflyeacmts@mail.nasa.gov.

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SECTION 2

Description of the Proposed Action and No Action Alternative

This section identifies and describes the Proposed Action and the No Action Alternative.

2.1 Proposed Action

During its 3.3-year (40-month) mission[2], the Dragonfly mission would explore diverse Earth-like environments on Titan, bringing scientists closer to understanding the habitability of other planets and the origin of life itself. The rotorcraft lander instruments would study how far the development of life or pre-biological chemistry has progressed and investigate Titan's atmospheric, surface, and subsurface properties, including its methane ocean and liquid reservoirs. A detailed explanation of the Earth-like environment of Titan, as well as a description of Dragonfly mission, can be seen at this website: https://www.nasa.gov/dragonfly/dragonfly-overview/index.html.

The Dragonfly mission's science objectives include the following (Turtle et al., 2020):

- Analyze chemical components and processes that produce biologically relevant compounds.
- Measure atmospheric conditions, identify methane reservoirs, and determine transport rates.
- Investigate processes that mix organics with surface liquid water reservoirs or subsurface oceans.
- Search for chemical evidence of water-based or hydrocarbon-based life.

The mission would also take scientific measurements of Titan's surface and atmosphere during flights over the surface of Titan throughout the mission. The Dragonfly mission's surface and atmospheric science activities include the following (APL, 2020b):

- Analyze samples of surface materials with a mass spectrometer to search for chemical compounds that produce biologically relevant processes.
- Measure bulk elemental surface composition with a neutron-activated gamma-ray spectrometer.
- Monitor atmospheric and surface conditions, including diurnal and spatial variations, with meteorology instruments.
- Use imaging to characterize geologic features.
- Perform seismic studies to investigate subsurface activity and structure.

In-flight scientific activities include the following (APL, 2020b):

- Atmospheric measurements.
- Aerial images of surface geology.
- Surface measurements and scouting of sites of interest.

2.1.1 Mission Description

The Dragonfly mission's vehicle consists of an eight-bladed rotorcraft lander (Figure 2-1), the size of a subcompact car measuring approximately 3.4 meters (approximately 11 feet) by 1.6 meters (approximately 5 feet), which is designed to visit multiple sites across Titan's varied terrain. The mission would include four

[2] The mission duration starts at launch and includes cruise and surface operations.

distinct phases: (1) launch phase; (2) cruise phase; (3) entry, descent, and landing (EDL) phase; and (4) the surface operations and science mission phase (APL, 2020a).

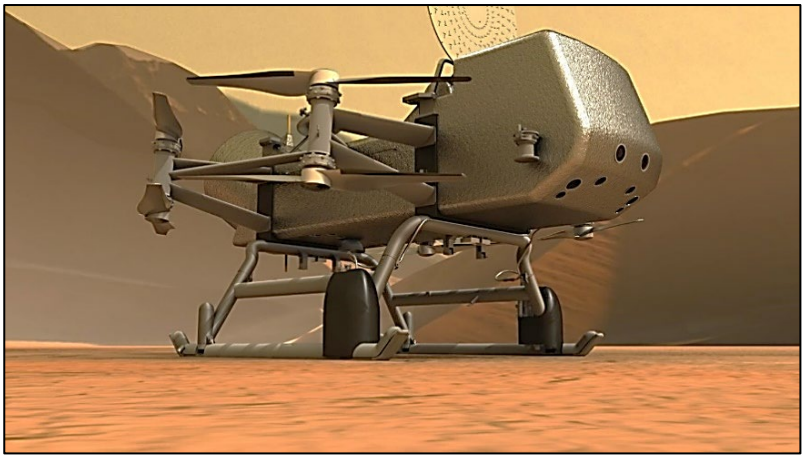
The first phase of the mission is the launch phase. The Dragonfly spacecraft would be launched from CCSFS or KSC in Brevard County, Florida, in 2027. However, this launch date is subject to change. Launching at a later date will not affect Dragonfly's science return or capabilities once at Titan (NASA, 2020d), and it would not change or cause an increase to the consequence analysis discussed in this EA.

The second and longest phase of the mission is the cruise phase. The mission cruise phase would begin when the spacecraft separates from the launch vehicle and would end prior to atmospheric entry at Titan. The cruise phase would last up to 10 years, depending on the spacecraft's cruise trajectory. The spacecraft's cruise trajectory from Earth to Titan is discussed further in Section 2.1.6, *Cruise Trajectory*.

The third phase of the mission, the EDL phase, would begin when the entry vehicle reaches an altitude of approximately 1,270 kilometers (km) (789 miles) above the surface of Titan and would end with a soft touchdown of the rotorcraft lander on Titan's surface.

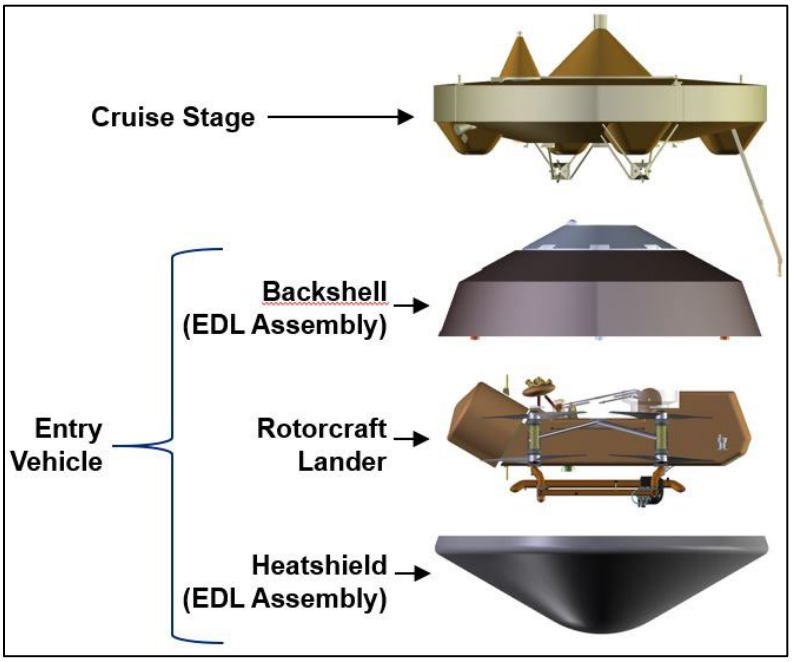
The final mission phase begins when the spacecraft lands on Titan. The initial landing site would be in a dune field, known as the Shangri-La Sand Sea, near Titan's equator. This location provides a relatively safe initial landing location and provides for diverse sampling opportunities. Once landed, the rotorcraft lander would explore nearby locations in short flights, building up to a series of longer "leapfrog" flights. Eventually, the rotorcraft lander would reach the Selk impact crater on Titan's surface, where past liquid water may have mixed with complex organics. During the 3.3-year duration of the mission, the rotorcraft lander would fly up to 180 km (108 miles) (APL, 2020b).

Figure 2-1. Conceptual Rendering of Dragonfly Rotorcraft Lander



2.1.2 Spacecraft Description

Figure 2-2. Conceptual Rendering of Dragonfly Spacecraft Components



The design of the spacecraft and its science payload considers the science objectives and the unique environment of Titan. The spacecraft design is based on previous successful designs and would include three main components: the cruise stage, the EDL assembly, and the rotorcraft lander, as shown on Figure 2-2 (APL, 2020a).

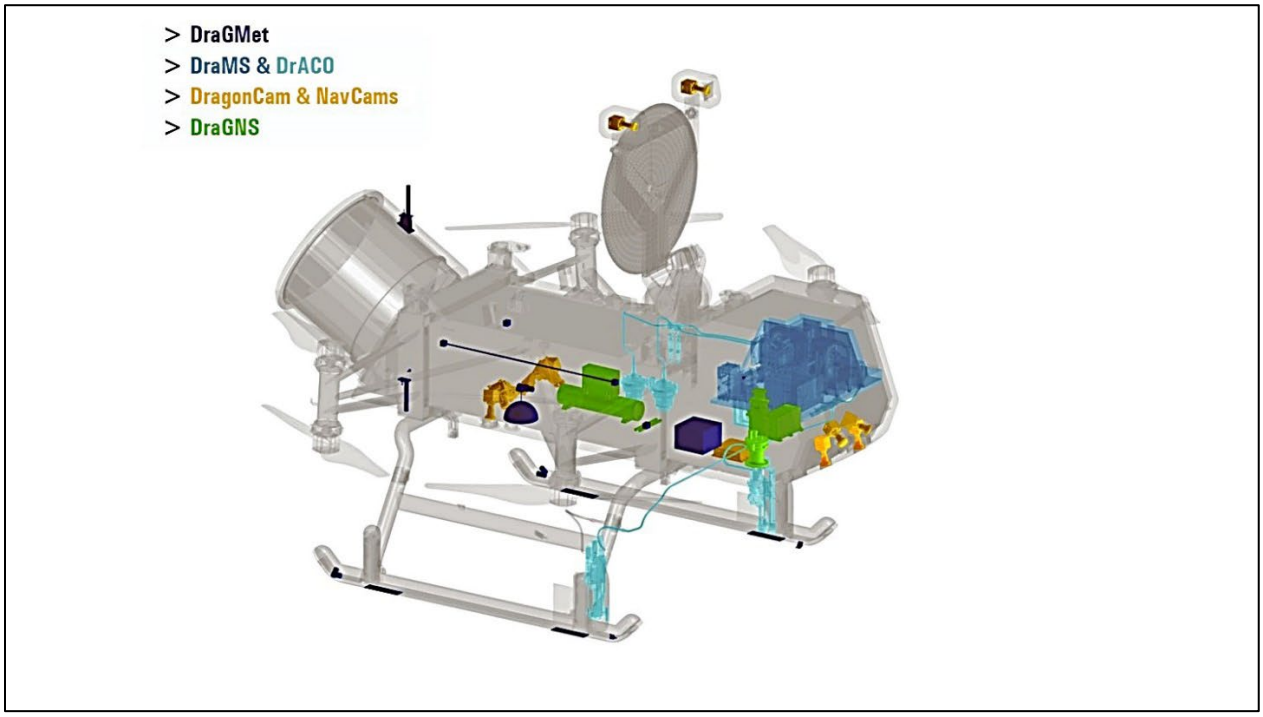
The cruise stage supports the necessary services to support the cruise trajectory from Earth to Titan. Supported services include communications with Earth, propulsion, and thermal control of the vehicle. The cruise stage is a relatively simple structure similar to the system used by NASA on missions such as the Phoenix Mars mission (2007) and the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) Mars mission (2016). The cruise stage separates from the entry vehicle as it reaches Titan's atmosphere. The cruise stage is not protected and will burn up as it enters Titan's atmosphere.

The entry vehicle would contain the systems that enter Titan's atmosphere and deliver the rotorcraft lander to its designated landing site on the surface of Titan. The entry vehicle is made up of the EDL assembly with the rotorcraft lander inside. The EDL assembly is the aeroshell that includes a heatshield as its thermal protection system, a backshell that houses the parachute deceleration system, a low gain antenna, and the separation systems. The EDL assembly protects the lander during atmospheric entry and descent and delivers it to a specific release point approximately 1.2 km (0.75 mile) above Titan's surface, at which point the lander drops off from the backshell and uses its rotorcraft lander flight system to safely land on the surface.

The rotorcraft lander carries several scientific instruments, as shown in the conceptual rendering included as Figure 2-3. Each instrument serves a specific and important purpose, described as follows (APL, 2020a, 2020b; NASA, 2020a):

- **Mass Spectrometer (DraMS)**: An instrument used to analyze material from the surface directly under the lander, identify chemical components relevant to astrobiology and to detect patterns and functionalities in the molecules present, even if they are not carbon-based.
- **Drill for Acquisition of Complex Organics (DrACO)**: A sample acquisition and delivery system used to capture Titan's surface and near-surface material to deliver to DraMS.
- **Gamma-Ray Neutron Spectrometer (DraGNS)**: An instrument used to help analyze surface composition around the lander.
- **Geophysics and Meteorological Package (DraGMet)**: A suite of geophysical and meteorological sensors, including a seismometer, to detect Titanquakes and understand the moon's interior and its liquid subsurface ocean.
- **Camera Suite (DragonCam and NavCams)**: A variety of cameras used to image Titan's terrain and help the rotorcraft lander navigate and determine landing areas of scientific interest.

Figure 2-3. Conceptual Rendering of Dragonfly Rotorcraft Lander Instruments



2.1.3 Launch Location

The Dragonfly mission spacecraft would be launched from either CCSFS or KSC, both of which are located on the east coast of Florida in Brevard County. Previous NASA SMD missions using RPS have launched from these locations, and KSC and CCSFS have the trained personnel and the contingency requirements in place to appropriately approve, conduct, and respond to missions using radioisotope-based systems.

2.1.3.1 Description of CCSFS

CCSFS is operated by Space Launch Delta 45 (SLD 45) at Patrick Space Force Base, which is located 24 km (15 miles) south of CCSFS (Figure 2-4). SLD 45 provides launch facilities and services to support NASA, the U.S. Department of Defense, and commercial launch service providers, and is responsible for overseeing the preparation and launching of U.S. Government and commercial spacecraft from CCSFS. SLD 45 also operates the Eastern Range for the USSF. The Eastern Range Operations provide the resources and activities for safe flight, airspace restrictions, range instrumentation, infrastructure, and schedule to support space launches. The Eastern Range consists of tracking stations at CCSFS, mainland annexes, and down-range tracking stations on islands in the Caribbean Sea and the South Atlantic Ocean. All launch countdown activities and many NASA operations use Eastern Range Operations.

CCSFS encompasses 66 square kilometers (km^2) (16,198 acres); its northern boundary abuts KSC, and its southern boundary abuts the City of Port Canaveral, a tourist and cruise ship port. CCSFS is bordered to the east by the Atlantic Ocean and to the west by the Banana River. These water bodies serve as natural buffers to the launch facility operations. Natural areas near CCSFS include the Merritt Island National Wildlife Refuge (MINWR) and the Canaveral National Seashore (CNS), both of which contain biological and cultural resources (USAF, 2020a, 2020b).

CCSFS has four active space launch complexes (SLCs): SLC-37, SLC-40, SLC-41, and SLC-46. An additional landing site, referred to as SLC-13 (Landing Zone-1 and Landing Zone-2), is leased to Space Exploration Technologies Corporation (SpaceX) specifically for landing reusable boosters. Three additional SLCs are in various stages of design or construction: SLC-16, SLC-20, and SLC-36.

The land uses within CCSFS include open fields, an airfield, SLCs, supporting infrastructure, and areas of native habitat, including scrub habitat and coastal dunes. Several SLCs lie just inland of the beach dune community on CCSFS, but most of these SLCs are not active and are abandoned in place (USAF, 2020a).

2.1.3.2 Description of KSC

KSC is NASA's main space launch location and is home to NASA's Launch Services Program. Its core competencies are rooted in its 50-year history in space flight and include the following:

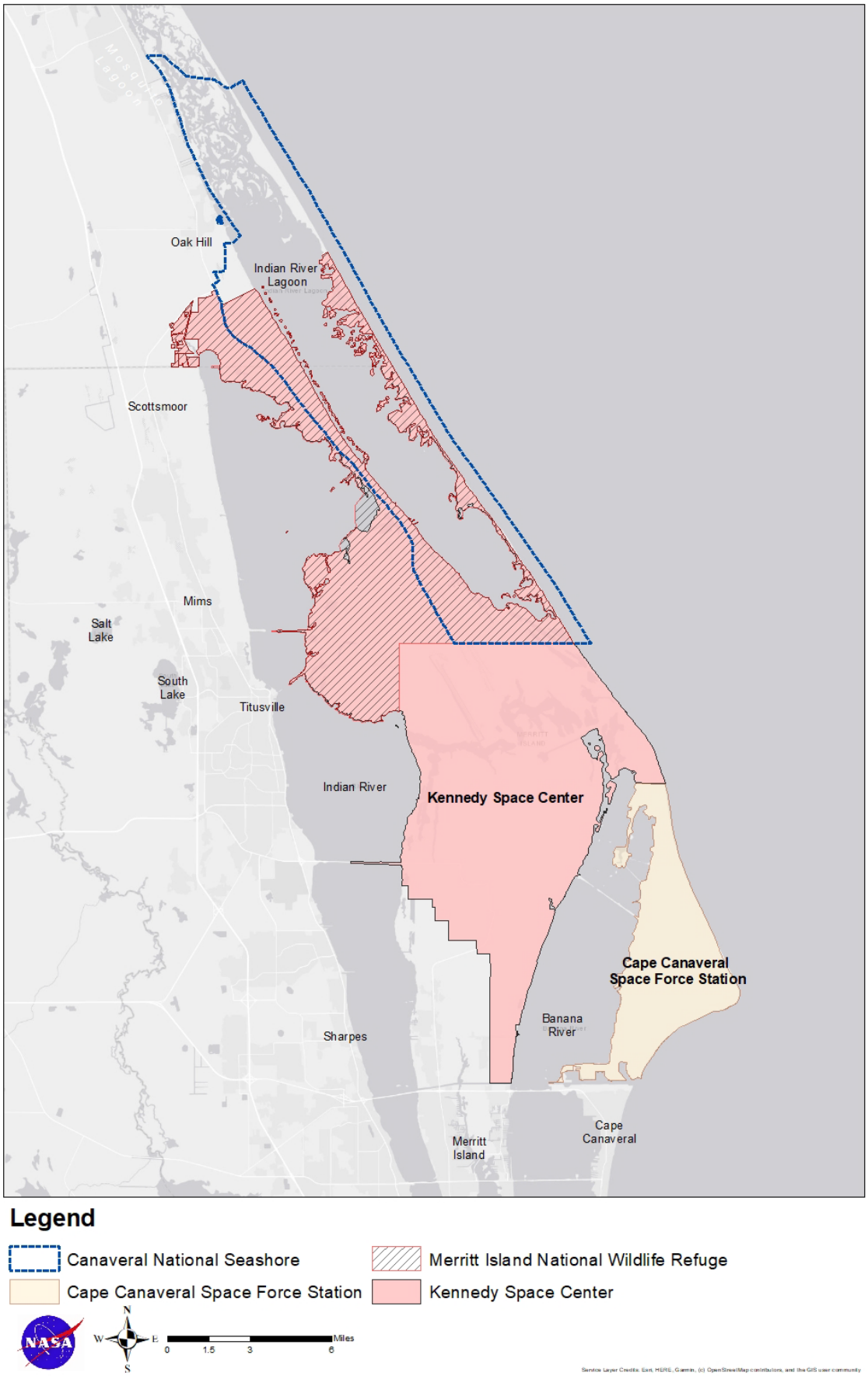
- Acquisition and management of launch services and commercial crew development.
- Launch vehicle and spacecraft processing, launching, landing and recovery, operations, and sustainment.
- Payload and flight science experiment processing, integration, and testing.
- Designing, testing, operating, and sustaining flight and ground systems and infrastructure.
- Developing, testing, and demonstrating advanced flight systems and transformational technologies.
- Developing technology to advance exploration and space systems.
- Producing the Launch Vehicle Databooks used by DOE in its Nuclear Risk Assessments, which supported previous NEPA documents.

KSC has three active launch complex (LC) sites: LC-39A, LC-39B, and most recently, LC-48. The remaining LCs are either deactivated or inactive (USAF, 2018). As of 2013, the former Shuttle Landing Facility, now the Launch and Landing Facility, has been transferred over to Space Florida for non-government use under a property agreement with NASA. Commercial aerospace companies frequently use KSC's LCs for launches.

KSC is bordered on the west by the Indian River (a brackish water lagoon) and on the east by the Atlantic Ocean and CCSFS. The northernmost end of the Banana River (another brackish water lagoon) lies between Merritt Island and CCSFS and is included as part of KSC submerged lands. The southern boundary of KSC runs east-west along the Merritt Island Barge Canal, which connects the Indian River with the Banana River and Port Canaveral at the southern tip of Cape Canaveral. The northern border lies in Volusia County near Oak Hill across Mosquito Lagoon, the Indian River, Banana River, and the Mosquito Lagoon system. A portion of the seashore on the easten edge of the KSC is available for public recreational purposes on a non-interference basis (NASA, 2016).

KSC is a major central Florida tourist destination and is an approximately 1-hour drive from the Orlando area. The visitor complex offers public tours of KSC and CCSFS. Because much of the installation is a restricted area and only 9% of the land is developed, the site also serves as an important wildlife sanctuary. The Indian River Lagoon, MINWR, and CNS are other natural features of the area. KSC workers and the visiting public can encounter bald eagles, American alligators, wild boars, eastern diamondback rattlesnakes, bobcats, and Florida manatees, among other wildlife (NASA, 2016).

Figure 2-4. KSC and CCSFS Launch Infrastructure



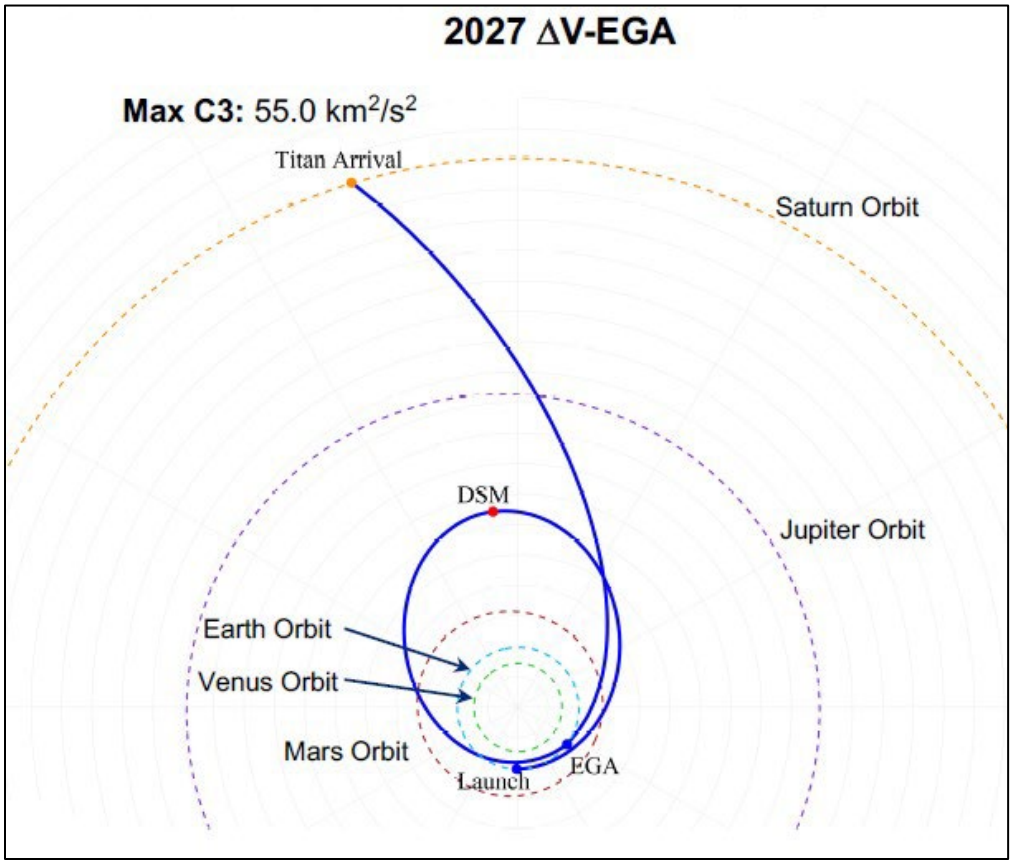
2.1.4 Launch Vehicle

A launch vehicle, also known as a rocket, provides the lift and velocity needed for a spacecraft to achieve the desired trajectory. The launch vehicle for the Dragonfly mission has not been formally chosen. It is reasonably foreseeable that environmental impacts associated with launch vehicles would be in keeping with the impacts disclosed in the environmental document of the selected vehicle and additionally in compliance with NASA's launch vehicle certification process. Because the environmental impacts of NASA's launch vehicles have been previously assessed and publicized, the impacts associated with the use of these launch vehicles are not discussed further in this EA. If a launch vehicle is selected that has not been previously analyzed using the NEPA process, NASA may prepare an additional or supplemental environmental analysis that meets the requirements of NEPA and other applicable statutory and regulatory requirements.

2.1.5 Cruise Trajectory

The prime launch window for the Dragonfly mission is in June 2027, with an arrival in the mid-2030s, though these dates are subject to change. The mission trajectory has not been finalized and is dependent on the launch vehicle selected for the Dragonfly mission. The current notional trajectory option includes using one Earth flyby and a Deep Space Maneuver (DSM) to obtain a suitable cruise trajectory to Titan, as shown on Figure 2-5. A gravity assist is the use of the orbit and gravity of a planet to alter the path and speed of a spacecraft and is typically implemented to save propellent or enable distant missions within the limits of available propellent loads. Importantly, the mission would be designed to ensure that during an Earth gravity assist (EGA) maneuver, the spacecraft would maintain an altitude of at least 450 km (280 miles) from the Earth, and the probability of an inadvertent Earth re-entry would be less than 1 in 1,000,000 (APL, 2020c, 2020d).

Figure 2-5. Conceptual Dragonfly Mission Trajectory



2.1.6 Nuclear Components

The rotorcraft lander would use a single MMRTG as the source of heat and electrical power for its systems and instruments. In addition, the rotorcraft lander's thermoelectric environment could be augmented by the heat output of up to 43 RHUs. The use of RHUs is not a component of the current Dragonfly design; however, the RHUs could supplement the MMRTG to keep the rotorcraft lander onboard systems at proper operating temperatures during the trip to Titan and in the extremely cold environment of Titan. An analysis that includes the use of a single MMRTG and up to 43 RHUs is included in this EA because of the potential need for RHUs. In case NASA does not include the RHUs in the Dragonfly design, this EA is still considered satisfactory for compliance with NEPA regulations. The following is a detailed description of each of these systems.

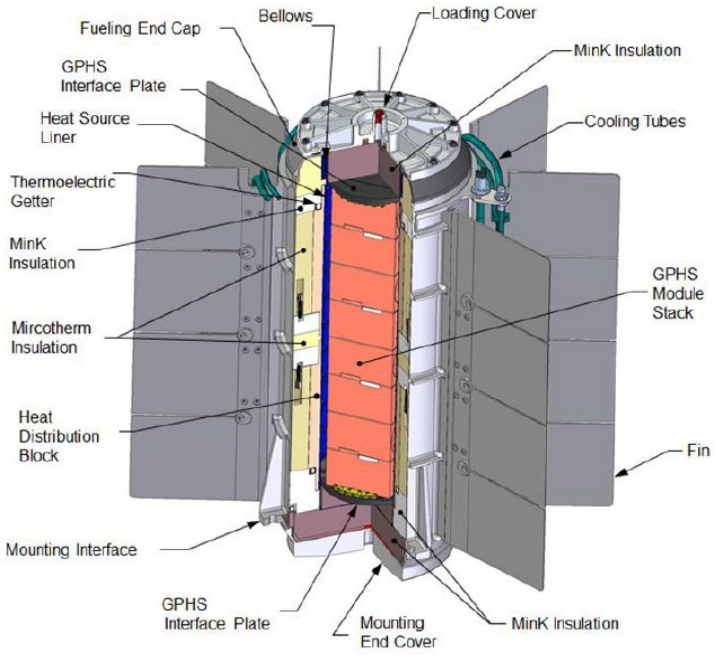
2.1.6.1 Multi-Mission Radioisotope Thermoelectric Generator

An MMRTG is a space nuclear power system that converts heat into electricity without using moving parts; instead, an MMRTG directly converts heat from the natural decay of Plutonium-238 (Pu-238) into electricity. The MMRTG is approximately 64 centimeters (25 inches) in diameter by 66 centimeters (26 inches) long and weighs 45 kilograms (kg) (94 pounds [lb]). The MMRTG contains approximately 4.8 kg (10.6 lb) of plutonium dioxide fuel, which provides approximately 2,000 watts of thermal power and 120 watts of electrical power at the time of fueling the MMRTG.

The MMRTG includes eight General Purpose Heat Source (GPHS) modules, which contain and protect the Pu-238 fuel. The GPHS modules are engineered and constructed with multiple protective design features that substantially mitigate the risk of a release and dispersal of nuclear material in an accident situation. These safety features include the ceramic form of the Pu-238 heat source material, iridium metal alloy cladding, graphite sleeves that protect the fuel, and the rugged carbon-fiber material that forms the shell (Figure 2-6).

Several types of radioisotope thermoelectric generators (RTGs) have been used successfully on 32 previous U.S. missions. Of these, 24 of these were NASA missions, including six Apollo flights and the Pioneer (1972), Viking 1 and 2 (1975), Voyager 1 and 2 (1977), Galileo (1989), Ulysses (1990), Cassini (1977), New Horizons (2006), Mars Science Laboratory (MSL) Curiosity (2011), and Mars 2020 Perseverance (2020) missions. The Dragonfly mission would be the 25th NASA mission with RTGs. The Dragonfly mission would employ an MMRTG similar to that used on the MSL and Mars 2020 missions. The interfaces and spacecraft accommodations, such as the external cooling loops and radiative fins, may be slightly different from those used on previous Mars missions, but the base generator will remain unchanged.

Figure 2-6. MMRTG Configuration



The MMRTG would be a mission-enabling technology for the Dragonfly mission, as it provides a continuous and simultaneous source of electric power and heat to warm the interior of the lander while on Titan, which has an average temperature of -179 °C (94 Kelvin or -290°F). The radiant heat (that is, thermal power) is a

crucial component of maintaining an adequate operating temperature in Titan's cold environment. For power storage, the MMRTG would also be used to charge an 11.7-kilowatt-hour lithium-ion battery used for operations.

2.1.6.2 Radioisotope Heater Units

RHUs are small devices that use the natural decay of Pu-238 to provide thermal energy to heat electronics. This heat is transferred to spacecraft structures, systems, and instruments by direct radiant energy or heat pipes, without moving parts or electronic components. Consequently, RHUs are among the simplest of all space nuclear devices.

By using RHUs in conjunction with an MMRTG, the Dragonfly mission planners can allocate scarce electrical power to operate the spacecraft's systems and instruments instead of heating. RHUs also provide the benefit of reducing electromagnetic interference with instruments or electronics that might be generated by electrical current heating.

The current-generation RHUs are referred to as light weight radioisotope heater units (LWRHUs) and have heated deep space missions since the 1980s, though previous versions of RHUs have been used since the 1960s. An LWRHU contains a fuel pellet, about the size of a pencil eraser, which contains 2.7 grams (0.1 ounce) of plutonium dioxide (the quantity of Pu-238 in the plutonium dioxide is less than 2.7 grams). The entire LWRHU is approximately the size of a C-cell battery (Figure 2-7) and releases about 1 watt of heat (NASA, 2014a). Combined, the MMRTG and 43 LWRHUs would contain 4.9 kg (10.8 lb) of plutonium dioxide in total.

Figure 2-7. Radioisotope Heater Unit

Similar to MMRTGs, LWRHUs were designed to withstand most potential accidents without the release of Pu-238 by including multiple layers of protection. The outermost layer of protection is composed of fine-weave, pierced fabric carbon-carbon composite material that provides the primary protection to the metal capsule against impacts resulting from explosions or accidental reentry. Additionally, the outermost layer contains three layers of pyrolytic graphitic insulators provide thermal protection that limits the heating of the metal capsule containing the fuel pellet in events such as fires and accidental reentry. The innermost level of protection is the platinum-rhodium metal alloy capsule that minimizes the dispersal of the fuel pellet under fires and accidental reentry. Finally, the hot-pressed ceramic fuel pellet itself ensures the Pu-238 is in its most stable form to minimize risk of release in the event of an accident. The fuel pellet has the highest melting point of all the materials used in the LWRHU. It is resistant to fracture and tends to break into pieces to minimize the generation of fine dust during extreme impacts, thereby limiting the potential airborne release of Pu-238 (Tate, 1982).

2.2 No Action Alternative

Under the No Action Alternative, NASA would discontinue preparations for the Dragonfly mission, and the spacecraft would not be launched. The No Action Alternative would then necessitate that NASA satisfy the objective of the congressionally mandated New Frontiers Program in another way.

2.3 Alternatives Eliminated from Further Analysis

The following sections provide descriptions of the power and launch location alternatives that were analyzed for the Dragonfly mission but were determined to be infeasible and, therefore, eliminated from further analysis.

2.3.1 Power Alternatives

2.3.1.1 Exclusive Use of Solar Arrays

Titan's distance from the Sun and its dense atmosphere prevent sufficient solar radiation energy from reaching the surface to adequately power the spacecraft's scientific instruments and flight systems. A solar array on Titan would operate at extremely low intensity, in very low temperature conditions, and would consequently produce very low power output. The limited power output from the exclusive use of solar arrays would not meet the needs of the Dragonfly mission. Furthermore, the mass of the solar arrays would be incompatible with atmospheric flight in the Titan environment (NASA, 2020b).

2.3.1.2 Exclusive Use of Batteries

The requirements to conduct scientific measurements at different regions of Titan's surface and the time required to move to these locations result in a core mission duration of 3.3 years. The exclusive use of batteries would not provide sufficient energy needed for operating on Titan for the entire mission duration. A single day of operation on Titan would require approximately 2 tons of batteries. Furthermore, current launch vehicles cannot propel a spacecraft with such batteries for a suitable duration and trajectory. Therefore, the mission trajectory and duration prevents the exclusive use of batteries for surface operations (NASA, 2020b).

2.3.2 Launch Location Alternatives

Historically, KSC and CCSFS have successfully handled and integrated radioisotope materials and technology into spacecraft. Furthermore, KSC and CCSFS have the trained personnel and the contingency requirements in place to appropriately approve, conduct, and respond to missions using nuclear power systems. Currently, other NASA and USSF facilities do not have the capability to conduct a nuclear-enabled mission. Therefore, no other launch facilities were considered in the analysis.

2.4 Resources Analyzed

For the purpose of this analysis, resources have been divided into two groups: (1) resources studied in detail and (2) resources eliminated from further analysis.

2.4.1 Resources Studied in Detail

The only relevant resource concern related to the Proposed Action is the potential for radiation exposure during a mission mishap scenario. All other non-nuclear-related resource concerns, such as exposure to noise during a launch, have been previously addressed in the *NASA Routine Payload EA* (NASA, 2011) and other launch vehicle-specific NEPA documents (SpaceX, 2013; FAA, 2008, 2015, 2017, 2019, 2020; NASA, 2013, 2016; USAF, 2000). Although the specific launch vehicle is currently unknown, only launch vehicles that have undergone the NEPA process will be considered for the Dragonfly mission. This EA evaluates the potential impacts associated with radiation to the following environmental resources in Section 3, *Affected Environment and Environmental Consequences*:

- Nuclear Radiation
- Land Use
- Water Resources
- Biological Resources

- Hazardous Materials
- Cultural Resources

2.4.2 Resource Areas Eliminated from Further Analysis

In accordance with the CEQ directives to focus NEPA analyses on environmental resource areas where there is a potential for significant impact and where the analyses are expected to provide useful information to the decision maker (40 CFR Subpart 1502.2), some common resource areas have been eliminated from detailed study in this EA. The rationale for their elimination is summarized as follows:

- **Visual Resources**: The Dragonfly mission would be within the typical visual characteristics of CCSFS and KSC.
- **Noise and Noise-Compatible Land Use**: The noise associated with launches has been analyzed in NEPA documentation for the individual launch vehicles (NASA, 2011; SpaceX, 2013; FAA, 2008, 2015, 2017, 2019, 2020; NASA, 2013, 2016; USAF, 2000).
- **Utilities and Infrastructure**: There would be no substantial changes to existing utilities, building infrastructure, or energy supply under the Proposed Action. The Dragonfly mission would not result in additional resource or utility demands.
- **Environmental Justice**: Executive Order (EO) 12898, "Federal Actions to Address Environmental Justice in Minority and Low-income Populations," requires federal agencies to consider disproportionate risk to minority and low-income communities. Using the U.S. Environmental Protection Agency's (EPA's) Environmental Justice Screening and Mapping Tool, a 16-km (10-mile) buffer area surrounding the CCSFS boundary did not contain a disproportionate percentage of minority and low-income populations (EPA, 2020). Although minority and low-income individuals reside within the buffer area, the Proposed Action would not disproportionately impact these individuals; consequently, there is no likelihood for a disproportionately high and adverse effect to minority and low-income populations resulting from the Proposed Action. The potential environmental effects associated with the production of MMRTGs and RHUs have been addressed in existing DOE NEPA documentation (DOE, 2008, 2013).
- **Children's Environmental Health and Safety Risks**: EO 13045, "Protection of Children from Environmental Health Risks and Safety Risks," directs federal agencies to identify and assess environmental health risks and safety risks that may disproportionately affect children. Although children reside within the buffer area, the Proposed Action would not disproportionately expose children (EPA, 2020). The potential for health effects to children from exposure to nuclear material is considered in Section 3.1, *Nuclear Radiation*.
- **Ambient Air Quality and Climate**: CCSFS is in full attainment of National Ambient Air Quality Standards for criteria pollutants under the Clean Air Act. Previous NEPA documents have analyzed the impacts of launches on air quality and climate. The Dragonfly mission would not result in noticeable changes to the current Clean Air Act criteria pollutants at KSC or CCSFS and would not result in a noticeable increase in greenhouse gas emissions. Furthermore, the Proposed Action would also be in full compliance with KSC and CCSFS's Title V Operating Permits (KSC, 2021; CCAFS, 2014). Therefore, no new impacts to air quality or climate are expected from the Proposed Action. Impacts associated with an airborne release of Pu-238 are discussed in detail in Section 3.1, *Nuclear Radiation*.
- **Socioeconomics**: Missions that attract significant public interest often result in socioeconomic benefits both locally (in Brevard County) and regionally because of increased economic activity (hotel room occupancy, restaurants, merchandising, and similar activities). No additional onsite personnel would be hired to implement the Proposed Action, and no population growth resulting from the Proposed Action is expected. Similar to other launches, there would be only beneficial socioeconomics effects under the Proposed Action. Potential impacts to land use, including nearby seaports, farmland, and recreational areas, are discussed in Section 3.2, *Land Use*.

- **Transportation**: The potential environmental effects associated with the transportation of RHUs and MMRTGs have been addressed in existing DOE NEPA documentation (DOE 2000, 2008, 2013), and no changes to transportation infrastructure are expected from the Proposed Action.
- **Geology and Soils**: In the extremely unlikely event of a release of Pu-238 during a launch accident, the depth of potential soil cleanup outside immediate impact sites would be approximately 2 inches (NASA, 2020c), which would be too shallow to affect geology. Regional soils should be only negligibly affected; potential effects to cropland are discussed in Section 3.2*, Land Use*.
- **Coastal Zones**: The Coastal Zone Management Act (CZMA) establishes a national policy to preserve, protect, develop, restore, and enhance the resources of the nation's coastal zones. Federal agencies are responsible for making consistency determinations within coastal zone areas. The Proposed Action area is located within Florida's coastal zone area. However, the Proposed Action would have no effect on coastal zone resources in Florida and would be consistent with the Florida Coastal Management Program (Appendix 2.6A).

SECTION 3

Affected Environment and Environmental Consequences

This section provides an explanation of the affected environment for each of the potentially impacted resources, along with an explanation of the potential environmental consequences associated with the Dragonfly mission.

Affected Environment

The following Affected Environment sections provide an overview of the existing natural and cultural conditions within the Proposed Action area. In compliance with NEPA, the description of the affected environment focuses on those resources and conditions potentially impacted by the Proposed Action.

The Affected Environment sections are organized by resource type and include a description of the existing environment and the region of influence for each resource. The region of influence is defined as the area in which project-related environmental impacts could occur. For most resources, the region of influence is limited to the KSC and CCSFS installation boundaries, as shown on Figure 2-4. However, for some resources, the potential effects of the project must be considered within the context of the surrounding vicinity. For example, the evaluation of land use also includes the surrounding areas. Resources that occur across a broader area were considered on a regional scale.

Environmental Consequences

The purpose of NEPA is to inform decision makers and the public of the likely environmental consequences of the Proposed Action. Consistent with these requirements, the Environmental Consequences section identifies the anticipated effects of the Proposed Action on each resource. The analysis of resource impacts focuses on environmental issues in proportion to the degree of impact within the region of influence. Under NEPA (40 CFR Subpart 1508.27), a determination of significance requires consideration of context and intensity. Accordingly, impacts described in this EA are evaluated in terms of type (beneficial or adverse), context (local or regional), intensity (none, negligible, minor, moderate, or significant), and duration (temporary or permanent). These terms are further defined in the introductory tables in each of the following resource sections.

Mitigation measures or best management practices that would be implemented to avoid or minimize potential impacts are identified, where relevant. As required under NEPA, the environmental effects of the No Action Alternative are also evaluated.

3.1 Nuclear Radiation

3.1.1 Affected Environment

The following sections provide an overview of nuclear radiation, an explanation of the health concerns associated with radiation exposure, and a description of the current radiological conditions at CCSFS and KSC.

3.1.1.1 Radiation and Plutonium-238

Nuclear radiation is defined as energy in the form of particles or electromagnetic waves that are emitted when the nucleus of a radioisotope decays. The particles or waves are considered ionizing radiation if they contain enough energy to separate electrons from their atoms. The process of an unstable isotope undergoing spontaneous change is called radioactive decay. Radioactive decay generates heat through the interaction of emitted particles or waves with nearby atoms. MMRTGs and RHUs function through the

release of heat from the radioactive decay of Pu-238 (an isotope of the element plutonium). In an MMRTG, a portion of the released heat is converted to electrical power.

3.1.1.2 Health Effects from Radiation Exposure

Humans are constantly exposed to ionizing radiation from both natural and artificial sources, including cosmic radiation (for example, the Sun) and terrestrial radiation (for example, certain rocks and soils). These types of radiation are commonly referred to as background radiation. Common artificial sources of radiation also exist; for example, smoke detectors, cigarette smoke, and certain coatings on camera lenses emit small amounts of radiation. Because living cells are constantly exposed to ionizing radiation, they have developed biochemical mechanisms to repair damage from this exposure. However, when delivered in enough quantity, ionizing radiation can overwhelm repair mechanisms and cause significant health effects, such as cancer. External exposure to alpha radiation is not harmful because the outer dead layer of skin serves as a natural barrier and prevents penetration to more sensitive cells. However, if alpha-emitting radionuclides such as Pu-238 are introduced into the body by breathing, they can deposit in internal organs and deliver a radiation dose to tissues (Nuclear Regulatory Commission, 1991).

The International Commission on Radiological Protection has studied the movement of Pu-238 within the human body. The inhalation of small particles, less than 5 microns in diameter, poses the greatest potential health effect. Breathing (or inhalation) is approximately 1,000 times more effective than eating (or ingesting) for transporting plutonium to the sensitive tissues in the human body. Ingested Pu-238 particles would quickly pass through the digestive system and be excreted, with only a minute fraction being absorbed into the bloodstream. Inhaled Pu-238 particles could be transported to the deep portions of the lungs, depending on the particle size. Generally, particles larger than 5 microns in diameter would be intercepted in the nose or throat, swallowed, and passed through the digestive tract and excreted. Particles smaller than 5 microns in diameter could accumulate in the deep lung regions. Most health effects would result from Pu-238 accumulating in the deep lungs and then migrating into the bloodstream. Once Pu-238 has entered the bloodstream, it would be deposited primarily in the liver and bone marrow tissues, creating a potential for cancer if the radiation dose were sufficiently large (ICRP, 1986; National Research Council, 2006). Therefore, most of the radiological impacts associated with mission mishaps are attributed to the potential release of Pu-238 particles in a respirable form. Mishap scenarios that do not result in a release of Pu-238 or that result in a release of Pu-238 in coarse fragments (large particle sizes) are a relatively minor component of potential effects.

The unit of radiation dose measurement to humans is called a Roentgen Equivalent Man (rem). Radiation dose is a measurement of the amount and type of ionizing radiation energy adsorbed per unit mass of body tissue and the relative biological effect of that absorbed radiation. An average person in the U.S. is exposed to approximately 0.62 rem per year from a combination of natural background and artificial sources of radiation. The single largest source of radiation exposure to the average resident of the U.S. is medical radiation, which amounts to approximately 0.30 rem per year. Cosmic radiation and radon exposure amount to approximately 0.26 rem per year to an average person in the U.S. This yearly dose of 0.62 rem has not been shown to cause harm to humans, including children and other sensitive populations (Nuclear Regulatory Commission, 2021).

3.1.1.3 Existing Conditions

Florida receives less exposure from cosmic radiation than most parts of the country because of its low elevation, resulting in a thicker atmosphere that absorbs more cosmic radiation. Assessments performed by the U.S. Geological Survey and EPA indicate that KSC, CCSFS, and adjacent areas have a low potential for geological radon (terrestrial radiation). With respect to medical radiation exposure and other categories of background radiation exposure, Florida is consistent with the national average (NASA, 2014b).

3.1.1.4 Established Nuclear Safety Procedures

Regional Safety Procedures

CCSFS, KSC, the City of Cape Canaveral, and Brevard County have a mutual-aid agreement in the event of emergencies. During launch activities, CCSFS remains in communication with KSC, Brevard County Emergency Management, the Florida Marine Patrol, the U.S. Coast Guard, and the Florida Division of Emergency Management. The CCSFS Range Safety Program monitors launch areas to ensure that risks to people, aircraft, and surface vessels are within acceptable limits. Control areas and airspace are closed to the public during launches (USAF, 1998; NASA, 2014b).

Prior to the Dragonfly launch approval, a comprehensive set of plans will be developed by NASA to ensure that any launch accident would be met with a well-developed and tested response. NASA's plans are developed in accordance with the National Response Framework (DHS, 2019) and the National Response Framework Nuclear/Radiological Incident Annex (DHS, 2016) in coordination with DOE, USSF, other federal agencies, the State of Florida, Brevard County, and other local governmental organizations. These organizations and agencies could be involved in response to a radiological emergency, as needed (Scott et al., 2012).

Onsite Safety Procedures

The Radiological Control Center (RADCC) at KSC coordinates all radiological contingency planning and initial response activities. The RADCC is equipped with extensive communication and computing systems. The main functions of the RADCC are field data monitoring, data assessment, formulation of recommendations (onsite or offsite), coordination with response organizations, and delivery of information to the public (Scott et al., 2012).

The RADCC uses ground monitoring teams, dispersion modeling, and a network of Environmental Continuous Air Monitors to collect data during launches. The Environmental Continuous Air Monitors provide near real-time radiological air concentration measurements and correlations with wind speed and directions. Prior to each NASA launch, a joint NASA/USSF contingency response group is formed and prepared to coordinate an emergency response in the event of a mission mishap (Scott et al., 2012).

International Response Procedures

For incidents that occur post-launch and outside the jurisdiction of the U.S., NASA and DOE would assist the U.S. Department of State in coordinating the U.S. response via diplomatic channels and deploying federal resources as requested. If an impact occurs in the ocean following an accident, NASA and DOE coordinate with the U.S. Department of Homeland Security (DHS), the U.S. Coast Guard, and the U.S. Navy to initiate security measures and assess the feasibility of search and retrieval operations. Efforts to recover MMRTGs and RHUs are based on an assessment of technical feasibility, potential risks to recovery personnel, and potential environmental impacts.

3.1.2 Environmental Consequences

The following analysis considers potential radiation exposure after a mission mishap involving a release of Pu-238 during the Dragonfly mission. The concept of a maximally exposed individual[3] (MEI) is used to evaluate potential effects. MEI analysis is a standard method for calculating doses to members of the general public and can be compared to U.S. standards and regulations for exposure limits. The threshold for evaluating the intensity of potential impacts from radiation exposure is based on known exposure limits and established radiation exposure standards, including:

[3] The MEI is a hypothetical individual who–because of realistically assumed proximity, activities, and living habitats–would receive the highest radiation dose, considering all pathways, from a given event, process, or facility (DOE Order 458.1).

- National Security Presidential Memorandum-20 (NSPM-20), *Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems* (White House, 2019)
- Nuclear Regulatory Commission: 10 CFR Subpart 20.1301, *Dose Limits for Individual Members of the Public* (Nuclear Regulatory Commission, 1991)
- EPA: 40 CFR Part 190, *Environmental Radiation Protection Standards for Nuclear Power Operations* (EPA, 1997)

Table 3.1-1 identifies and defines the thresholds for nuclear radiation impacts. Table 3.1-2 depicts the gradient scale of impacts for radiation exposure, as described in Table 3.1-1. The grades are established based on the probability of release and the MEI exposure to a member of the general public.

TABLE 3.1-1
Impact Thresholds for Nuclear Radiation
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Impact	Description
No Impact	No potential for radiation exposure.
Negligible	Impacts from radiation exposure would be very small (less than 0.025 rem MEI exposure) or beyond extremely unlikely (less than a 1-in-1,000,000 probability).
Minor	Impacts from radiation exposure would be small (0.025 to 5 rem MEI exposure) and unlikely (1-in-100 to 1-in-10,000 probability) or large (5 to 25 rem MEI exposure) and extremely unlikely (1-in-10,000 to 1-in-1,000,000 probability).
Moderate	Impacts from radiation exposure would be small (0.025 to 5 rem MEI exposure) and likely (greater than 1-in-100 probability); large (5 to 25 rem MEI exposure) and unlikely (1-in-100 to 1-in-10,000 probability); or very large (greater than 25 rem MEI exposure) and extremely unlikely (1-in-10,000 to 1-in-1,000,000 probability).
Significant	Impacts from radiation exposure would be very large (greater than 25 rem MEI exposure) and unlikely (1-in-100 to 1-in-10,000 probability) to likely (greater than a 1-in-100 probability).
Quality:	Beneficial–would have a beneficial effect Adverse–would have an adverse effect
Duration:	Temporary–would occur only during the launch Permanent–would continue beyond the launch

MEI = maximally exposed individual
rem = Roentgen Equivalent Man

TABLE 3.1-2
NEPA Impact Thresholds for Radiation Exposure
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

	Probability of Airborne Release[a]			
MEI Exposure (Member of the Public)[b]	**Beyond Extremely Unlikely (less than 1 in 1,000,000[c])**	**Extremely Unlikely (1 in 10,000 to 1 in 1,000,000)**	**Unlikely (1 in 100 to 1 in 10,000)**	**Likely (greater than 1 in 100)**
Greater than 25 rem	Negligible	Moderate	Significant	Significant
5 rem to 25 rem	Negligible	Minor	Moderate	Moderate
0.025 rem to 5 rem	Negligible	Minor	Minor	Moderate
Less than 0.025 rem	Negligible	Negligible	Negligible	Negligible

[a] Probability thresholds (likely, unlikely, extremely unlikely, and beyond extremely unlikely) are based on definitions provided in DOE-STD-3009-2014.

[b] A member of the public is defined as an individual who is outside the restricted area around a launch site. The rem exposures thresholds are derived from guidance provided in NSPM-20 (White House, 2019)

[c] 1:1,000,000 or 1E-6 is defined as an acceptable probability level for a severe consequence by EPA (1991), the Federal Aviation Administration (FAA, 2000), and the U.S. Air Force (USAF, 2019).

MEI = maximally exposed individual
rem = Roentgen Equivalent Man

3.1.2.1 Proposed Action

The most likely outcome of implementing the Proposed Action is the successful launch of the Dragonfly mission; this scenario represents the normal operating conditions and would result in no release of Pu-238. In the unlikely event of an accident, the most probable outcome is still an accident with no release of Pu-238, as MMRTGs and RHUs are designed to withstand most energetic accident conditions associated with launch mishaps without compromising the Pu-238. Nonetheless, certain low-probability accident scenarios could involve a sequence of thermal and mechanical insults to the MMRTG GPHS modules or RHUs that may result in the release of Pu-238. The following sections discuss the potential for this scenario along with the associated environmental consequences.

Low Probability Release Scenarios

For an accident to result in a release of Pu-238, a sequence of thermal conditions and multiple mechanical system failures within the MMRTG GPHS modules or RHUs would need to occur for the Pu-238 pellets to vaporize into a respirable form; refer to Section 3.1.1.2, *Health Effects from Radiation Exposure*, for further information on the importance of respirable form. In the history of using GPHS modules and RHUs in spacecraft, there have been no such releases of Pu-238. However, such failure scenarios have been postulated and the following credible scenarios could result in a respirable release of Pu-238:

- The GPHS modules and RHUs both have safety features designed to withstand most accident scenarios throughout the launch phases, but a sustained exposure to burning solid fuel or a liquid propellant fire could result in the release of a measurable amount of respirable Pu-238. Prolonged proximity to burning fuel represents the upward bounds of potential release scenarios; therefore, accidents of this type include the highest bounding case for a potential release. However, the likelihood of this occurrence is extremely unlikely, as it would require burning fuel to land on, or very close to, the GPHS modules or RHUs after a mishap.
- A suborbital (below Earth's orbit), orbital, or supraorbital (above Earth's orbit) re-entry accident, in which the space vehicle unintentionally returns to Earth outside of the launch area, could occur and result in a release of Pu-238. However, GPHS modules and RHUs are designed to withstand most re-entry accident scenarios, and missions are planned such that the potential for unintentional re-entry with a release of plutonium is extremely unlikely. Furthermore, rocket boosters, which contain the rocket fuel, are jettisoned relatively early in the flight sequence, which greatly reduces the potential and respirable quantity of released Pu-238. Other less likely scenarios, such as striking a hard surface, could result in a release of Pu-238 after a re-entry; however, these scenarios require a series of unlikely events to occur that culminate in an extremely unlikely occurrence. The aiming of the Dragonfly spacecraft and minimum altitude during EGA maneuvers set the potential for a mishap to beyond extremely unlikely. Despite its extremely low probability of occurrence, all re-entry scenarios would be closely monitored, with support given to the USSF and DOE to attempt to recover the Pu-238, as applicable.

The probability of a potential release of Pu-238 during the Dragonfly mission was assessed by reviewing analyses performed for previous NASA missions involving MMRTGs and RHUs (NASA, 1997, 2020c). Table 3.1-3 provides the estimated probability of a release of Pu-238 through the various mission phases of the Dragonfly mission. These probabilities are based on numerous variables specific to the previous missions, including launch vehicle type and payload configurations. Currently, the specific vehicle type and payload configuration for the Dragonfly mission is unknown; however, it is expected that the release probabilities would be in keeping with previously calculated release probabilities. If an adverse probability deviation is discovered (i.e., a probability in the next level category definition [Table 3.1-3]), a supplemental NEPA document may be developed for the mission.

TABLE 3.1-3
Probability of a Radiological Release
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Mission Phase	Scenario	Probability of a Release of Pu-238	Definition[a]
Phase 0 Pre-launch	Accident before launch sequence initiation.	1 in 10,000 to 1 in 1,000,000	Extremely Unlikely
Phase 1 Early Launch			
On-pad Explosion	Accident involving an outward explosion on the launch pad.	1 in 10,000 to 1 in 1,000,000	Extremely Unlikely
Full-stack Impact	Accident in which the entire launch vehicle impacts the ground. This scenario represents the upper bounds of a respirable Pu-238 potential release.	Less than 1 in 1,000,000	Beyond Extremely Unlikely
Intact Stage 2 and Space Vehicle Impact	Accident in which the intact Stage 2 component and launch vehicle impact the ground.	1 in 10,000 to 1 in 1,000,000	Extremely Unlikely
Space Vehicle Intact Impact	Accident in which only the space vehicle impacts the ground.	Less than 1 in 1,000,000	Beyond Extremely Unlikely
Low-Altitude Flight Termination System	Accident in which the launch vehicle is destroyed at low altitude and debris impacts the ground. While this scenario represents the highest probability, the MMRTG or RHU would be separated from the fuel source, and the release of respirable Pu-238 would be much lower than other scenarios.	1 in 100 to 1 in 10,000	Unlikely
Phase 2 Late Launch	Accident occurs shortly after launch. Would affect the Atlantic Ocean.	1 in 10,000 to 1 in 1,000,000	Extremely Unlikely
Phase 3 Suborbital	Accident occurs prior to orbit. Would affect the Atlantic Ocean or African Continent.	1 in 10,000 to 1 in 1,000,000	Extremely Unlikely
Phase 4 Orbital	Accident occurs during orbit. Latitudes between 35° North and 35° South would be most likely affected.	1 in 10,000 to 1 in 1,000,000	Extremely Unlikely
Phase 5 Long Term	Accident post orbit. Would affect any latitude.	1 in 10,000 to 1 in 1,000,000	Extremely Unlikely
Earth Gravity Assist Maneuver	Accident during an Earth gravity assist of the spacecraft. Would affect any latitude.	Less than 1 in 1,000,000	Beyond Extremely Unlikely

Sources: NASA, 1997, 2020c.
[a] Probability thresholds (likely, unlikely, extremely unlikely, and beyond extremely unlikely) are based on definitions provided in DOE-STD-3009-2014
Pu-238 = Plutonium-238

Dose Consequences Associated with a Release of Pu-238

DOE's Idaho National Laboratory (INL) performed a comprehensive review of nuclear risk assessments and NEPA documents from previous NASA missions using MMRTGs and RHUs to assess the potential effects associated with a launch mishap during the Dragonfly mission (INL, 2021). Specifically, the consequence calculations for the Mars 2020 mission were used to assess the potential effects for the Dragonfly mission, because the Dragonfly mission would employ a nearly identical MMRTG as the Mars 2020 mission. Furthermore, the Mars 2020 analysis involved more advanced modeling and provided more accurate dose consequence analysis than prior mission assessments (INL, 2021). Although the interfaces and spacecraft accommodations, such as the external cooling loops and radiative fins, may be slightly different from the Mars 2020 mission, the base MMRTG design, which is the most important component for the release

probability, would remain unchanged for the Dragonfly mission. The deterministic analysis[4] performed by INL was also independent of a launch vehicle, launch location, and time of year, due to the overall conservatism employed in the assumption of the accident scenarios and meteorological conditions. Various release types were calculated to determine the worst-case accident scenario, including a 1-, 5-, 10-, 20-, 100-, 1,000-, and 10,000-megawatt fire; and a 100-, 500-, 1,000-, 5,000-, 10,000-, and 82,500-lb TNT-Equivalent explosion under low and high wind speed meteorological conditions[5] (Figure 3-1).

Based on INL's analysis and applying the probabilities in Table 3.1-3, a conservative estimate of the highest radiation dose to the MEI would be between 2.98 and 21.4 rem resulting from an extremely unlikely event in Phase 0, 1, or 2 (probability less than 1 in 10,000)[6]. This range is based on the upper level of exposure under the low and high wind speed meteorological conditions. For the highest level of exposure (21.4 rem) to occur, a launch mishap would have to occur during low wind speeds; however, higher wind speeds are more typical along the Florida coastline, making this event even more unlikely and placing the potential consequence closer to the 2.98 rem estimate associated with higher winds. Applying the 2.98 to 21.4 rem consequence to the probability of occurrence (less than 1 in 10,000) to the Table 3.1-2 results in a **negligible to minor, adverse, and permanent** impact to the MEI from potential radiation exposure after a launch mishap. The impacts associated with other launch mishap scenarios or to other potentially exposed members of the general public would be of less consequence.

3.1.2.2 No Action Alternative

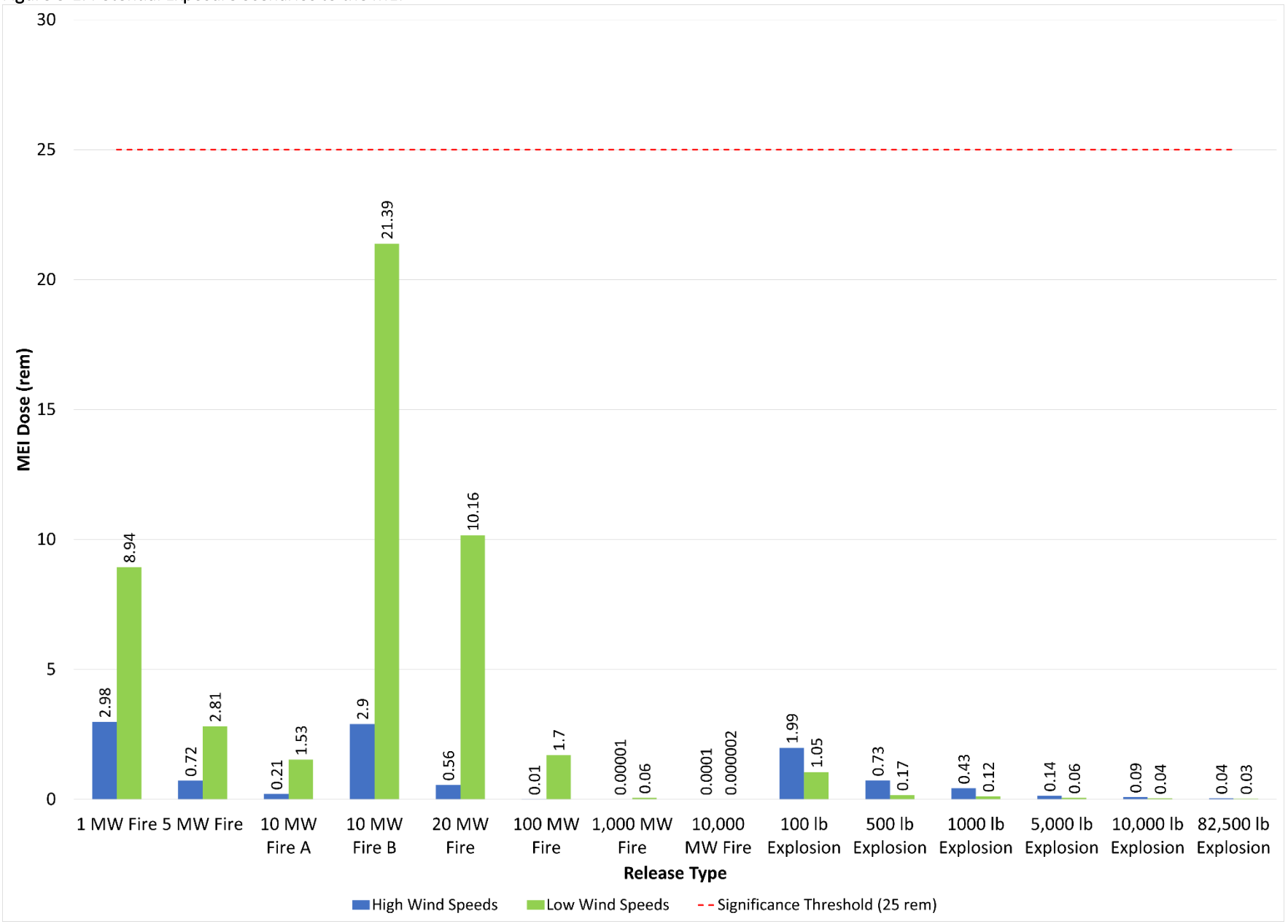
Under the No Action Alternative, the Dragonfly mission would not be launched; therefore, there would be **no potential effect** to health and safety from the mission. However, MMRTGs and RHUs could continue to be used in future missions at KSC and CCSFS and environmental impacts evaluated through separate NEPA documentation, as applicable.

[4] A deterministic analysis relies solely on parameter values for outputs, whereas probabilistic analysis incorporates the probability of an event into the output along with the parameter values. Consequently, the same set of parameter values and initial conditions will lead to a group of different outputs between these types of analysis.

[5] The Pasquill stability classes categorize the stability of the atmosphere. For the purposes of the DOE INL analysis, the Pasquill stability class F (1 m/s) represents low wind speeds and class D (4.5 m/s) represents high wind speeds.

[6] Low-Altitude Flight Termination System mishap would result in a higher probability release (1:100 to 10,000); however, while this scenario represents the highest probability, the MMRTG or RHU would be separated from the fuel source, and the release of respirable Pu-238 would be much lower than other scenarios.

Figure 3-1. Potential Exposure Scenarios to the MEI



3.2 Land Use

3.2.1 Affected Environment

The following sections describe land resources at CCSFS and KSC, including administrative and natural areas. The region of influence for land use includes KSC, CCSFS, and the surrounding areas, as shown on Figure 3-2.

3.2.1.1 Kennedy Space Center

Land use at KSC is planned and managed to support space missions and to maximize protection of the environment. Essential safety zones, clearance areas, lines-of-sight, and similar elements are incorporated into land use planning (NASA, 2014c).

KSC is located on the northern part of Merritt Island adjacent to CCSFS and consists of 565 km^2 (139,490 acres) of land and lagoon waters (Figure 3-2). The majority (95%) of KSC is identified as undeveloped area, which includes uplands, wetlands, mosquito control impoundments, and open water areas. Nearly 40% of this undeveloped area is open water areas of the Indian River Lagoon system, which includes portions of the Indian River, Banana River, Mosquito Lagoon, and Banana Creek (NASA, 2013). Undeveloped lands within the operational areas are dedicated safety zones or are reserved for planned and future expansion. The remaining 5% (18 km^2 [4,415 acres]) is identified as NASA's operational area and includes both developed and undeveloped areas. The developed operational areas are primarily used for ground processing, launch, and landing activities and include facilities and associated infrastructure such as roads, parking areas, and maintained rights-of-way. Developed operational areas also include LC-39A, LC-39B, and LC-48.

Management of the remaining areas within KSC's boundaries that are not directly used for NASA operations has been delegated to the U.S. Fish and Wildlife Service (USFWS) at the MINWR and the National Park Service (NPS) at the CNS. The NPS administers 27 km^2 (6,644 acres) of the CNS, and the USFWS administers 206 km^2 (50,945 acres) of the CNS and the 305 km^2 (75,383 acres) of the MINWR (NASA, 2013).

MINWR and CNS provide an operational buffer between KSC operations and the surrounding communities. The USFWS and NPS also exercise management control over recreational and environmental programs within MINWR and CNS. All zoning and land use planning at MINWR and CNS are under NASA directive. Therefore, USFWS and NPS management is subject to operational requirements defined by NASA, such as temporary closures for launch and landing-related activities (NASA, 2014c).

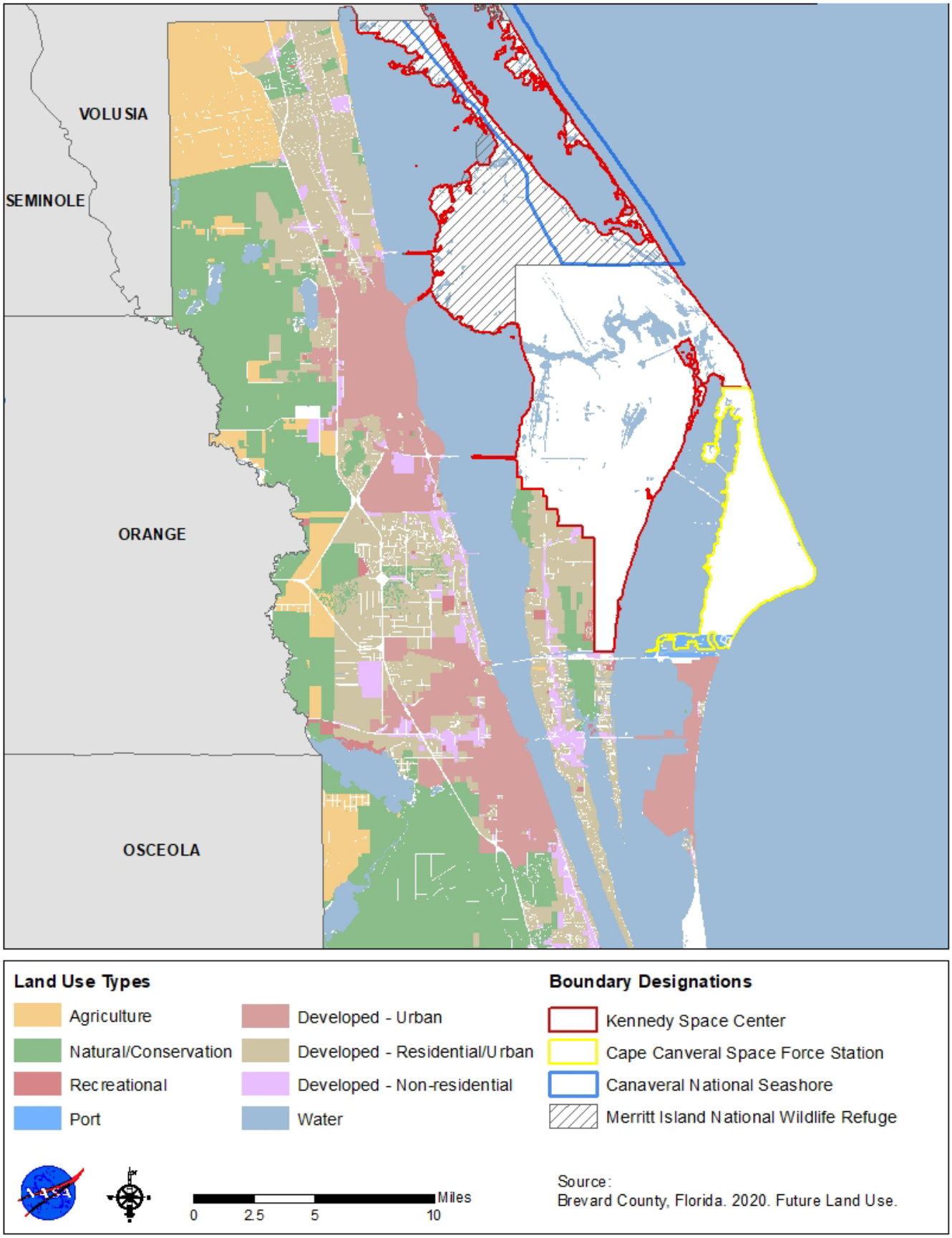
3.2.1.2 Cape Canaveral Space Force Station

CCSFS includes approximately 66 km^2 (16,198 acres) that support multiple land use types (Figure 3-2), including administrative, airfield operations, industrial, munitions and weapons storage, open space, and outdoor recreation. The launch operations land use category is present along the Atlantic Ocean shoreline and includes the active and inactive launch sites and support facilities. Other CCSFS operational land uses are primarily in the central and southern portions of the facility. Open space includes areas managed for natural resources and is the largest land use category at CCSFS. All land uses at CCSFS are under operational control of the USSF SLD 45 at Patrick Space Force Base (NASA, 2013). The beaches along CCSFS are used for launch operations and are restricted from public use (USAF, 2020a).

3.2.1.3 Surrounding Land Use

Land use surrounding KSC and CCSFS includes an active seaport; residential, recreation, and wildlife management areas; and agricultural uses that include citrus, mixed tropical fruits and other crops and pasture (Figure 3-2). Port Canaveral to the south of CCSFS has several cruise ship and commercial port terminals. Security personnel regularly patrol the Port waters to ensure unauthorized personnel do not access CCSFS via the Port. There is an abundance of public recreational opportunities in the area, including beaches, waterways, lakes, open land, and parks. The coastal beaches and supporting facilities that are a part of the CNS or MINWR are classified as operational buffer/public use; these areas are open to the public but are closed during some launch operations at the discretion of USSF (USAF, 2020a).

Figure 3-2. Land Cover Types of Surrounding Area



3.2.2 Environmental Consequences

This section identifies potential impacts to land use that may result from implementing the Proposed Action or the No Action Alternative. The following analysis considers impacts associated with the deposition of radionuclides after a mission mishap involving a release of Pu-238. Table 3.2-1 identifies and defines the thresholds for land use impacts.

TABLE 3.2-1
Impact Thresholds for Land Use
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Impact	Description
No Impact	No potential for impacts to land use.
Negligible	Impacts to land use would be at the lowest levels of detection.
Minor	Impacts to land use would be detectable but would not permanently alter the use of the land as it is currently intended.
Moderate	Impacts to land use would be readily detectable and would permanently alter the use of the land as it is currently intended; however, valued resources such as farmland and residential and recreational areas would likely not be affected.
Significant	Impacts to land use would be readily detectable and would permanently alter the use of the land as it is currently intended. Valued resources such as farmland and residential and recreational areas would likely be affected.
Quality:	Beneficial–would have a beneficial effect Adverse–would have an adverse effect
Duration:	Temporary–would occur only during the launch Permanent–would continue beyond the launch

3.2.2.1 Proposed Action

Under normal operating conditions, there would be no impacts to land use from the Proposed Action. Land uses, including recreation, wildlife areas, and agricultural land, would remain the same. Any impacts from the use of existing facilities are expected to be within the scope of previously approved programs (USAF, 1998, 2000; NASA, 2002, 2011).

Radiological Deposition

There is a potential for Pu-238 to be released into the environment under an unlikely release scenario, as described in Section 3.1, *Nuclear Radiation*. Such a release could result in the deposition of radiological materials on the ground. The U.S. Food and Drug Administration has defined Pu-238 contamination of 7.3 microcuries per square meter ($\mu Ci/m^2$) (NASA, 2020c) as the threshold for intervention of farmland. However, in the highest consequence release event (a launch pad accident), the potential soil contamination would remain at or below 6.41 $\mu Ci/m^2$ and the potentially impacted land would be within the boundaries of KSC and CCSFS (INL, 2021). Consequently, there is little potential for an impact to valued land uses such as the seaport, recreational areas, residential areas, or agricultural/farmland areas outside KSC or CCSFS (Figure 3-2). Impacts within KSC or CCSFS would be mitigated by the federal government.

There is an extremely unlikely potential for radiological materials to be deposited outside KSC or CCSFS during a late-phase accident (Table 3.1-3); however, any depositions would be expected to remain below the 6.41 $\mu Ci/m^2$ contamination threshold. If a launch mishap resulting in a release of Pu-238 were to happen, NASA and DOE would coordinate response activities in accordance with the National Response Framework (DHS, 2019). NASA, with its federal, state, and local partners, would undertake the appropriate

radiological screening and other necessary response actions in accordance with previously developed contingency plans. The area would return to normal use after radiation concerns were addressed.

Land use impacts within or outside of KSC and CCSFS associated with an accidental release of Pu-238 from the Proposed Action would be **minor, adverse, and temporary**. This determination was made based on the highest projected disposition, which is below U.S. Food and Drug Administration contamination thresholds; the high probability of the affected area remaining within KSC and CCSFS boundaries; and the mitigation measures currently in place.

3.2.2.2 No Action Alternative

Under the No Action Alternative, the Dragonfly mission would not be launched; therefore, there would be **no potential effect** to land use from the mission. However, MMRTGs and RHUs could continue to be used in future missions at KSC and CCSFS and environmental impacts evaluated through separate NEPA documentation, as applicable.

3.3 Water Resources

The following sections describe water resources at CCSFS and KSC, including surface water, groundwater, drinking water supply, and wetlands. The region of influence for water resources includes the Upper St. Johns River and Cape Canaveral watersheds (FDEP, 2018) as well as the aquifers beneath the watersheds.

3.3.1 Affected Environment

3.3.1.1 Surface Water

KSC is located on a barrier island. It is bounded by Mosquito Lagoon to the north and the Atlantic Ocean and Banana River to the east, and it is separated from the mainland by the Indian River to the west (Figure 3-3). CCSFS is east of KSC and is bounded by the Banana River on the west and the Atlantic Ocean to the east. Where most of the launch pads are located, surface drainage flows to the west into the Banana River. South of CCSFS is the Port Canaveral channel, which connects the Banana River to the Atlantic Ocean.

The Florida Department of Environmental Protection (FDEP) assigns a classification system to surface waters of Florida based on their potential use and value. The Banana River, Mosquito Lagoon, and Indian River are classified as Class II surface waters that are suitable for shellfish propagation and harvesting under *Florida Administrative Code* 62-302. Waters within the MINWR and CNS have been designated as Outstanding Floridian Water by the FDEP, which supersedes other classifications and has the highest water quality standards under *Florida Administrative Code* 62-302.

3.3.1.2 Groundwater

Three aquifers are located within the region of influence. These aquifer layers are not uniform in thickness, and the depths below the ground surface vary throughout the region. The top layer is the surficial aquifer, which is composed of sand, silt, and clay and ranges from approximately 23 to 53 meters (75 to 175 feet) in thickness and depth. The surficial aquifer begins at the land surface. Underneath the surficial aquifer is the intermediate aquifer, which is composed of clay with thin water-bearing zones of sand, shell, and limestone. The intermediate aquifer ranges from 0 to 152 meters (0 to 500 feet) in thickness and disappears in a small area near the St. Johns River and west of KSC. The intermediate aquifer begins 23 to 53 meters (75 to 175 feet) below land surface. Underneath the intermediate aquifer is the Floridian aquifer, which is composed of limestone and dolomite. The top plane of the Floridian aquifer ranges from 23 to 152 meters (75 to 500 feet) below land surface. These aquifers are recharged primarily through rainfall infiltration (SJRWMD, 1990).

3.3.1.3 Drinking Water Supply

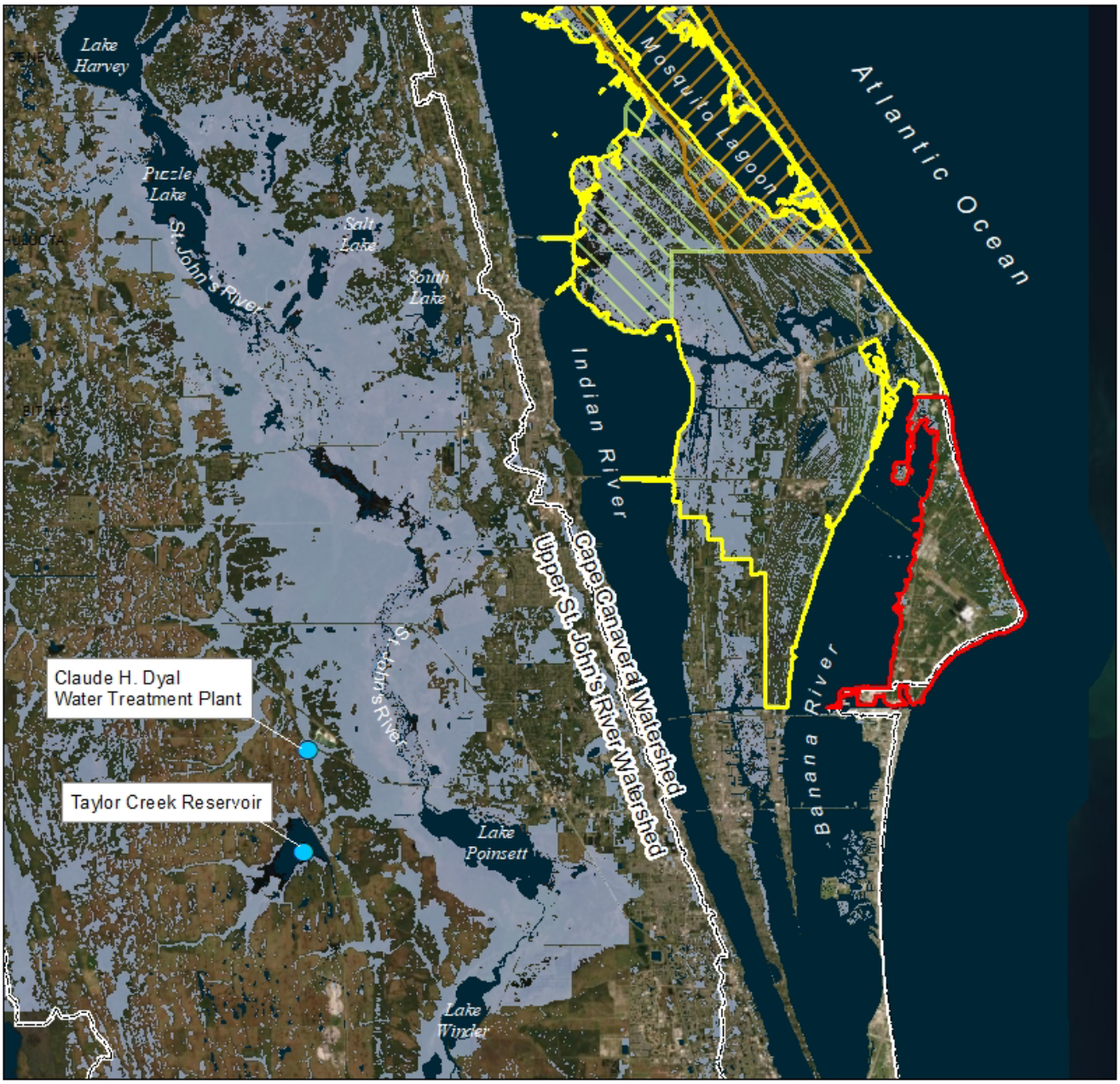
CCSFS, KSC, and much of Brevard County obtain drinking water from the City of Cocoa's Claude H. Dyal Water Treatment Plant, which treats and distributes water obtained from the Taylor Creek Reservoir and 34 Floridian aquifer wells approximately 122 to 183 meters (400 to 600 feet) deep and 14 wells in the

intermediate aquifer (City of Cocoa, 2009). The reservoir and wells are located more than 24 km (15 miles) west of KSC and CCSFS. The tributary streams that drain into the reservoir are even farther west. Water supplies from ground and surface water sources are treated to EPA drinking water standards before distribution. Also, numerous private well owners obtain their potable water from all three aquifers.

3.3.1.4 Wetlands

Wetlands are areas where the frequent and prolonged presence of water at or near the soil surface drives the natural system, including the kinds of soil that form, the plants that grow, and the fish and/or wildlife communities that use the habitat. Wetland locations for the region of influence were obtained from the National Wetlands Inventory database (USFWS, 2020a) and are shown on Figure 3-3.

Figure 3-3. Surface Water Features



3.3.2 Environmental Consequences

This section identifies potential impacts to water resources that may result from implementing the Proposed Action or the No Action Alternative. Table 3.3-1 identifies the NEPA impact thresholds for water resources.

TABLE 3.3-1
Impact Thresholds for Water Resources
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Impact	Description
No Impact	No impacts to water resources would be expected.
Negligible	Impacts to water resources would be barely detectable and would not alter water resources conditions.
Minor	Impacts to water resources would be detectable but would be within historical hydrologic or desired water quality conditions.
Moderate	Impacts to water resources would appreciably alter resource conditions. Historical baseline or desired water quality conditions would be altered temporarily.
Significant	Impacts would permanently alter water resources from the historical hydrologic baseline or desired water quality conditions or water supply.
Quality:	Beneficial–would have a beneficial effect Adverse–would have an adverse effect
Duration:	Temporary–would occur only during the launch Permanent–would continue beyond the launch

3.3.2.1 Proposed Action

Under normal operating conditions of the Proposed Action, there would be no impacts to water resources from the use of MMRTGs and RHUs. The following impacts are evaluated only for the unlikely event that Pu-238 is released during a launch accident as described in Section 3.1, *Nuclear Radiation*.

Surface Water

For surface water to be affected by the Proposed Action, a mission mishap would have to deposit portions of a Pu-238 pellet in a waterway, or a plume of airborne Pu-238 would have to spread over a waterway. In these scenarios, the Pu-238 would be released as an oxide that has low solubility; therefore, in the extremely unlikely event that portions of a Pu-238 pellet came into contact with water, the pellet fragments would sink into the sediment. If an airborne plume extended over a water body, the Pu-238 would condense or attach to particulates, sink to the bottom, and bind with saturated sediments. The relatively insoluble nature of the Pu-238 oxide and its tendency to bind with solid sediments makes ingestion (eating) of the compound the most likely exposure pathway for humans and aquatic species. As explained in Section 3.1.1.2, *Health Effects from Radiation Exposure*, ingestion does not represent a substantial risk, as Pu-238 would most likely be expelled during the digestive process before a health effect could be realized. Given the low solubility of Pu-238 oxide and the limited potential for an adverse health effect for humans and aquatic species, the potential impacts to surface water are considered **negligible**.

Groundwater

Water supply from the three aquifers is extremely unlikely to be impacted by the Proposed Action. Because Pu-238 oxide is relatively insoluble, there is no direct mechanism for transport into groundwater. Soil studies have shown that more than 95% of Pu-238 oxide remains in the top 2 inches of undisturbed surface soil after deposition. The remaining 5% may be pushed beyond the top 2 inches by percolation of rainfall or

animal burrowing activity, or unintentionally by human activities such as plowing (DOE, 1987). However, DOE and NASA would be committed to performing radiological response in accordance with the National Response Framework (DHS, 2019); therefore, the likelihood of groundwater contact is extremely remote, and the impacts are considered **negligible**.

Potable Water

The Taylor Creek Reservoir is more than 15 miles west of KSC and CCSFS and is far removed from the potential affected area (Figure 3-3). In the highly improbable event that debris containing an MMRTG from a suborbital mishap is carried far enough to reach the reservoir or tributary streams, it is possible that suspended Pu-238 oxide particles could be introduced into the treatment plant. However, the Claude H. Dyal Water Treatment Plant process is designed to comply with the EPA drinking water standards (40 CFR Part 141) and monitors for radiation. The treatment process includes sand and anthracite coal filters (City of Cocoa, 2020), which are effective in removing Pu-238 (NASA, 1990). The impact from Pu-238 exposure from drinking water is **negligible** due to the low solubility of Pu-238 oxide, the distance of the Taylor Creek Reservoir from the launch pads, the low probability that ingested Pu-238 would remain in the human body, and existing infrastructure that meets EPA drinking water standards.

Wetlands

In the unlikely event that Pu-238 is released in a launch accident, site response would be conducted in accordance with the National Response Framework (DHS, 2019) (Figure 3-3). Any effects to wetlands would likely require Clean Water Act permitting through the U.S. Army Corps of Engineers (USACE) and state agencies if wetlands or waters of the U.S. or the State of Florida were affected after an accidental release of Pu-238. Impacts to wetlands are expected to be **negligible** because the potential for an impact is unlikely and because NASA would coordinate potential wetland impacts with USACE and obtain necessary permits prior to affecting wetlands.

3.3.2.2 No Action Alternative

Under the No Action Alternative, the Dragonfly mission would not be launched; therefore, there would be **no potential effect** for water resources from the mission. However, MMRTGs and RHUs could continue to be used in future missions at KSC and CCSFS and environmental impacts evaluated through separate NEPA documentation, as applicable.

3.4 Biological Resources

3.4.1 Affected Environment

The following sections describe biological resources at CCSFS and KSC, including the ecological setting, vegetation, fish and wildlife, and protected species. The region of influence for biological resources consists of CCSFS, KSC, the adjacent Atlantic Ocean, and three major inland water bodies, including the Banana River, the Indian River, and Mosquito Lagoon.

3.4.1.1 Ecological Setting

CCSFS and KSC occupy a coastal habitat on a barrier island complex that parallels Florida's mid-Atlantic coast. The MINWR and CNS are located north of KSC and CCSFS. Most of the land adjacent to the KSC/CCSFS barrier island complex is developed.

3.4.1.2 Vegetation

Natural vegetation communities on KSC and CCSFS are dominated by forests and wetlands. This includes upland scrub and pine flatwoods (beach dune, coastal strand, coastal grassland, oak scrub, palmetto scrub, pine flatwoods), upland forest (upland coniferous forest, upland hardwood forest, cabbage palm, hardwood hammock), and wetlands (mangrove wetlands, salt marshes, freshwater wetlands, estuaries, basin marsh, coastal interdunal swale) (NASA, 2016; USAF, 2020a).

3.4.1.3 Fish and Wildlife

The water bodies and natural areas provide for a variety of habitats and resources for aquatic and terrestrial wildlife at KSC and CCSFS. Common animals occurring at KSC and CCSFS include frogs, turtles, lizards, snakes, birds, mammals, fish, alligators, and invertebrates. Adjacent areas of water, including the Atlantic Ocean and three major inland water bodies, support over 140 species of freshwater fish, saltwater fish, and aquatic mammals (USAF, 2020a).

3.4.1.4 Protected Species

Threatened and endangered species are federally protected plants and animals that are in danger of becoming extinct within the foreseeable future throughout all, or a significant portion of, the species' range. The Endangered Species Act (ESA) requires federal agencies to ensure their actions do not jeopardize the continued existence of any federally listed endangered or threatened species or adversely modify any critical habit of such species. CCSFS and KSC contain 25 federally listed wildlife species and 8 federally listed plant species on CCSFS or KSC (Table 3.4-1).

The Marine Mammal Protection Act (MMPA) prohibits, with certain exceptions, the take (harass, hunt, capture, collect or kill) of marine mammals in U.S. waters and by U.S. citizens on the high seas. Marine mammals that populate the coastal and lagoon waters of KSC and CCSFS include the bottlenose dolphin, the spotted dolphin, and the West Indian manatee (USAF, 1998).

The Migratory Bird Treaty Act (MBTA) establishes federal responsibilities to protect migratory birds. Under the MBTA, nearly all species of birds occurring in the U.S. are protected. The MBTA makes it illegal to take (hunt, pursue, wound, kill, possess, or transport by any means) listed bird species or their eggs, feathers, or nests unless otherwise authorized. Resident and migrating bird species at KSC and CCSFS include numerous common land and shore birds. In addition to protection under the ESA, the wood stork, piping plover, roseate tern, and Florida scrub jay receive protection under the MBTA.

TABLE 3.4-1
Federally Threatened and Endangered Species Documented to Occur at CCSFS or KSC
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Species Type	Common Name	Scientific Name	Federal Status
Reptiles and Amphibians	American Alligator	*Alligator mississippiensis*	Threatened
Reptiles and Amphibians	Atlantic (Kemp's) Ridley Sea Turtle	*Lepidochelys kempi*	Endangered
Reptiles and Amphibians	Atlantic Green Sea Turtle	*Chelonia mydas*	Endangered
Reptiles and Amphibians	Atlantic Salt Marsh Snake	*Nerodia clarkia taeniata*	Threatened
Reptiles and Amphibians	Eastern Indigo Snake	*Drymarchon corais couperi*	Threatened
Reptiles and Amphibians	Gopher Tortoise	*Gopherus polyphemus*	Candidate for Federal Listing
Reptiles and Amphibians	Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered
Reptiles and Amphibians	Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered
Reptiles and Amphibians	Atlantic Loggerhead Sea Turtle	*Caretta caretta*	Threatened
Mammals	Northern Atlantic Right Whale	*Eubalaena glacialis*	Endangered
Mammals	Southeastern Beach Mouse	*Peromyscus polionotus niveiventris*	Threatened
Mammals	West Indian Manatee	*Trichechus manatus latirostris*	Endangered
Fishes	Smalltooth Sawfish	*Pristis pectinata*	Endangered

Species Type	Common Name	Scientific Name	Federal Status
Fishes	Nassau grouper	*Epinephalus striatus*	Threatened
Birds	Auburn's Crested Caracara	*Polyborus plancus audubonii*	Threatened
Birds	Crested Caracara	*Caracara cheriway*	Threatened
Birds	Eastern Black Rail	*Laterallus jamaicensis* ssp. *Jamaicensis*	Proposed Threatened
Birds	Everglade Snail Kite	*Rostrhamus sociabilis pumbeus*	Endangered
Birds	Florida Scrub Jay	*Aphelocoma coerulescens*	Threatened
Birds	Piping Plover	*Charadrius melodus*	Threatened
Birds	Red Knot	*Calidris canutus rufa*	Threatened
Birds	Red-cockaded Woodpecker	*Picoides borealis*	Endangered
Birds	Roseate Tern	*Sterna dougallii*	Threatened
Birds	Wood Stork	*Mycteria americana*	Endangered
Birds	Bald Eagle	*Haliaeetus leucocephalus*	Protected under the Bald and Golden Eagle Protection Act
Plants	Carter's Mustard	*Warea carteri*	Endangered
Plants	Four-petal Pawpaw	*Asimina tetramera*	Endangered
Plants	Florida Perforate Lichen	*Cladonia perforafa*	Endangered
Plants	Lakela's mint	*Dicerandra immaculata*	Endangered
Plants	Lewton's Polygala	*Polygala lewtonii*	Endangered
Plants	Johnson's Seagrass	*Halophila johnsonii*	Threatened
Plants	Beach jacquemontia	*Jacquemontia reclinate*	Endangered
Plants	Tiny Polygala	*Polygala smallii*	Endangered

Source: USFWS, 2020b; USAF, 2020a.

3.4.2 Environmental Consequences

This section identifies potential impacts to biological resources that may result from implementing the Proposed Action or the No Action Alternative. Table 3.4-2 identifies the NEPA impact thresholds for biological resources.

TABLE 3.4-2
Impact Thresholds for Biological Resources
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Impact	Description
No Impact	No impacts to biological resources would be expected.
Negligible	Impacts to biological resources would not be detectable and would not alter resource conditions.
Minor	Impacts to biological resources would be detectable but they would result in minimal loss of resource integrity. Impacts would not appreciably alter resource conditions or permanent changes of population use of habitats.

Impact	Description
Moderate	Impacts to biological resources would result in disturbance to a site, loss of integrity, and/or alteration of resource conditions. Impacts would appreciably alter biological resource conditions; however, the scale of the impacts would not be expected to affect resource or species population stability in the region.
Significant	Impacts to biological resources would result in severe disturbance to a site, loss of integrity, and/or alteration of resource conditions. Impact would appreciably alter resource conditions and could affect regional population stability.
Quality:	Beneficial–would have a beneficial effect Adverse–would have an adverse effect
Duration:	Temporary–would occur only during the launch Permanent–would continue beyond the launch

3.4.2.1 Proposed Action

Under normal operating conditions of the Proposed Action, there would be no impacts to biological resources from the use of an MMRTG and RHUs, as there would be no release of plutonium dioxide.

Terrestrial and aquatic wildlife species receive external and internal doses of ionizing radiation from inhalation, ingestion, and immersion, similar to exposure pathways experienced by humans. Ecological protection programs are based on the premise that radiological protection for humans also provides conditions that adequately protect wildlife, including sensitive species. This has been qualitatively demonstrated by the International Atomic Energy Agency (IAEA, 2014). Because the potential effects of radiation exposure after an accidental release of Pu-238 are considered negligible to minor, adverse, and permanent to human populations (Section 3.1, *Nuclear Radiation*), impacts to wildlife from the use of the MMRTGs and RHUs in spacecraft are expected to be **negligible to minor, adverse, and permanent** as well. NASA and/or USSF will coordinate any necessary response activities with the USFWS and the National Marine Fisheries Service (NMFS) as required under the ESA and the MMPA to determine appropriate mitigation for the protection of sensitive species. NASA will informally consult with the USFWS regarding the Proposed Action. In the unlikely event of a launch mishap that results in a release of radiological material into the environment where threatened or endangered species may be affected, NASA would enter into formal ESA Section 7 emergency consultation under 50 CFR Subpart 402.05. The ESA Section 7 consultation documents can be found in Appendix 3.4A.

The deposition of radiological material would be addressed through appropriate screening and other remediation as required, and any disturbed vegetation would be expected to reestablish after the completion of response activities. As discussed in Section 3.3, *Water Resources*, no permanent impacts to freshwater, saltwater, or surface water ecosystems are expected, because Pu-238 would be released as an oxide that has low solubility in aquatic ecosystems. Therefore, the impacts to the surrounding ecosystems from land and water contamination are considered **negligible**.

3.4.2.2 No Action Alternative

Under the No Action Alternative, the Dragonfly mission would not be launched; therefore, there would be **no potential effect** from the use to biological resources from the mission. However, MMRTGs and RHUs could continue to be used in future missions at KSC and CCSFS and environmental impacts evaluated through separate NEPA documentation, as applicable.

3.5 Cultural Resources

The following sections describe cultural resources at CCSFS and KSC, including archeological and historical sites. The region of influence for cultural resources is KSC and CCSFS. Federal agencies are required to

ensure that cultural resources are considered in all of their undertakings and that significant resources are protected to the extent possible.

3.5.1 Affected Environment

The most relevant federal laws pertaining to cultural resources for the Proposed Action are the National Historic Preservation Act (NHPA) and the Archaeological Resources Protection Act (ARPA). The NHPA is generally considered the foundation for the preservation of cultural resources in the U.S. The NHPA defines historic properties as any prehistoric or historic district, site, building, structure, or object included in, or eligible for, the National Register of Historic Places (NRHP). The NRHP is a federally maintained list of historic properties significant in American history, prehistory, architecture, archeology, engineering, and culture. To be listed in the NRHP, a property must have historic significance and integrity and generally be at least 50 years old. Certain properties less than 50 years old can be eligible if they possess exceptional importance. Numerous NRHP-listed and eligible sites are located within the region of influence, due to their roles in current and previous space programs.

The ARPA forbids anyone from excavating or removing archaeological resources from federal or Indian land without a permit from a land managing agency. ARPA also forbids any sale, purchase, exchange, transport, or receipt of archaeological resources. An archeological resource is generally an item that is at least 100 years old and represents the remains of past human life or activities. Typical archaeological resources include pottery, basketry, weapons, tools, and graves.

3.5.1.1 Kennedy Space Center

NASA has a stewardship responsibility for managing the cultural resources on NASA-owned or NASA-administered lands and facilities and has developed an Integrated Cultural Resource Management Plan (ICRMP) that reflects its commitments to the protection of significant cultural resources at KSC. KSC has a designated Cultural Resource Manager (CRM) under NASA's Environmental Management Division to manage the ICRMP. It is a goal at KSC to balance historic preservation considerations with NASA's missions and avoid conflict with ongoing operational requirements (NASA, 2016).

3.5.1.2 Cape Canaveral Space Force Station

USSF has a stewardship responsibility for managing the cultural resources on USSF-owned lands and facilities and has developed an ICRMP (USAF, 2020b) that reflects its commitments to the protection of significant cultural resources at CCSFS. A designated CRM at CCSFS manages the ICRMP. It is also a goal at CCSFS to balance historic preservation considerations with USSF's missions and avoid conflict with ongoing operational requirements.

3.5.2 Environmental Consequences

This section identifies potential impacts to cultural resources that may result from implementing the Proposed Action and the No Action Alternative. Table 3.5-1 identifies and defines the NEPA impact thresholds for cultural resources.

TABLE 3.5-1
Impact Thresholds for Cultural Resources
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Impact	Description
No Impact	No impacts to cultural resources would be expected.
Negligible	Impacts to cultural resources would be barely detectable and would not alter cultural resources conditions, such as site preservation, or the relationship between the resource and the affiliated group's body of practice or beliefs.

Minor	Impacts on cultural resources would result in little, if any, loss of integrity and would be slight but noticeable. Impacts would not appreciably alter resource conditions or the relationship between the resource and the affiliated group's body of practices or beliefs.
Moderate	Impacts on cultural resources would result in readily noticeable disturbance to a site, loss of integrity, and/or alteration of resource conditions. Impacts would appreciably alter resource conditions and/or the relationship between the resource and the affiliated group's body of practices or beliefs.
Significant	Impacts on cultural resources would result in severe and permanent disturbance to a site, loss of integrity, and/or alteration of resource conditions. Impacts would appreciably alter resource conditions and/or the relationship between the resource and the affiliated group's body of practices or beliefs.
Quality:	Beneficial–would have a beneficial effect Adverse–would have an adverse effect
Duration:	Temporary–would occur only during the launch Permanent–would continue beyond the launch

3.5.2.1 Proposed Action

Under normal operating conditions, there would be no impacts to cultural resources from the use of an MMRTG and RHUs. However, there is a potential for Pu-238 to be released into the environment under an unlikely release scenario, as described in Section 3.1, *Nuclear Radiation*. Such a release could theoretically result in a deposition of radiological material on a cultural resource. Consequently, potential cultural resource impacts were evaluated against the potential response requirements following a release of Pu-238 as defined in Section 3.2, *Land Use*. NASA will informally consult with the Florida State Historic Preservation Office (SHPO) regarding the Proposed Action. The NHPA Section 106 consultation documents can be found in Appendix 3.5A.

Archeological Sites

Pu-238 is relatively insoluble and typically remains on the top 2 inches of surface soil after a release (NASA, 2014b). Consequently, the potential for impacting a known or unknown archeological site present in a contaminated area is limited. In the extremely unlikely event that cleanup activities require the excavation of soil on a NRHP-listed or eligible archeological resource, the Florida SHPO will be notified prior to any non-emergency response activities at the site, and appropriate mitigation measures will be developed in accordance with the NHPA. If a new (inadvertent) archeological site is identified during cleanup activities, the respective KSC or CCSFS Historic Preservation Officer (HPO) will be notified immediately. The HPO will determine if the site is eligible for listing on the NRHP; if it is deemed eligible, the SHPO will be notified before any other response activities are conducted at that site to determine appropriate mitigation measures. Impacts to archeological sites are considered **negligible**, given the remote probability of a site being affected and NASA's and USSF's commitment to work with the SHPO in the event an archeological site requires cleanup.

Historic Sites

Numerous NRHP-listed and eligible historic sites, as well as National Historic Landmarks, are located on KSC and CCSFS. These significant historic resources include the LCs where the Dragonfly spacecraft could be launched. Potential effects to cultural resources after a launch mishap have been studied in detail in previous EAs and environmental impact statements (EISs) for KSC and CCSFS (NASA 1994, 1997, 2002, 2005, 2014b, 2020c). Radioisotope-specific impacts could involve potential cleanup activities, primarily on the exterior of structures. If a historic structure were identified as part of a response activity, the Florida SHPO would be notified beforehand, and appropriate mitigation measures would be developed in accordance with the NHPA. Impacts to historic sites are considered **negligible**, given the remote probability of a site being

affected and NASA's and USSF's commitment to work with the Florida SHPO in the event a historic site requires cleanup.

3.5.2.2 No Action Alternative

Under the No Action Alternative, the Dragonfly mission would not be launched; therefore, there would be **no potential effect** to cultural resources from the mission. However, MMRTGs and RHUs could continue to be used in future missions at KSC and CCSFS and environmental impacts evaluated through separate NEPA documentation, as applicable.

3.6 Hazardous Materials

Hazardous materials are substances defined by the Comprehensive Environmental Response, Compensation, and Liability Act as substances that, because of their quantity, concentration, or physical, chemical, or infectious characteristics, may present substantial danger to public health or the environment. Numerous types of hazardous materials are used to support missions and conduct general maintenance operations at KSC and CCSFS; however, previous EAs and EISs analyzed the impacts associated with the use of these hazardous materials and resulting wastes for launches (NASA 1994, 1997, 2002, 2005, 2014b, 2020c); therefore, they are not considered in further detail in this EA. The only hazardous material unique to the Proposed Action is Pu-238; consequently, this analysis focuses only on Pu-238. The region of influence for hazardous material is the LCs at KSC and SLCs at CCSFS. Environmental impacts associated with production and transport of Pu-238 have been analyzed in previous DOE NEPA documents (DOE, 2000, 2002, 2008, 2013).

3.6.1 Affected Environment

3.6.1.1 Kennedy Space Center

The Radiation Protection Program at KSC manages the use of radioactive materials and ionizing radiation devices to ensure safe practices and operations. This includes the approval, procurement, use, transfer/shipment, and disposal of ionizing radiation sources. The goal of the KSC Radiation Protection Program is to ensure safe practices and operations to prevent unnecessary exposure to personnel and to limit exposure to levels as low as are reasonably achievable (KSC, 2009, 2016).

NASA is responsible for providing adequate infrastructure (that is, facilities and personnel) in conjunction with prelaunch and launch operations that meet criteria mutually acceptable to DOE and NASA for the storage, assembly, checkout, servicing, and repair of RPS. The criteria include safeguards and security protection (NASA and DOE, 2016) such as ensuring all personnel using sources of ionizing radiation are properly trained in safe practices for the possession and use of the materials and are familiar with the applicable regulatory and program requirements.

3.6.1.2 Cape Canaveral Space Force Station

The Radiation Protection Program for the SLD 45 manages radioactive materials at CCSFS. Controlled ionizing radiation devices transferred to, or stored or used on, CCSFS by NASA must be approved by the SLD 45 Radiation Protection Officer. Radioactive sources are handled under the supervision of the Range User or Radiation Protection Officer named on the Nuclear Regulatory Commission license, state license, or USSF permit (USAF, 2019).

The SLD 45 Range Safety requirements establish radioactive source design standards and requirements for radioactive sources carried on launch vehicles and payloads, including general design requirements, test requirements, launch approval requirements, and data requirements; RPS are compatible with these regulatory specifications (USAF, 2017a, 2017b, 2019).

3.6.2 Environmental Consequences

This section identifies potential impacts from hazardous materials that may result from implementing the Proposed Action or the No Action Alternative. Table 3.6-1 identifies and defines the NEPA impact thresholds for hazardous materials.

TABLE 3.6-1
Impact Thresholds for Hazardous Materials
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Impact	Description
No Impact	No potential for impact from hazardous materials.
Negligible	Impacts from the use of hazardous materials would be barely detectable. No new infrastructure, safety controls, or policies would be necessary.
Minor	Impacts from the use of hazardous materials would be measurable. Any release of hazardous materials or solid waste could be remediated by onsite personnel.
Moderate	Impacts from the use of hazardous materials would be measurable.
Significant	Impacts from the use of hazardous materials would be measurable. The resulting impacts could be severe and permanent.
Quality:	Beneficial–would have a beneficial effect Adverse–would have an adverse effect
Duration:	Temporary–would occur only during the launch. Permanent–would continue beyond the launch.

3.6.2.1 Proposed Action

KSC and CCSFS have extensive infrastructure, safety controls, and policies in place for the handling and safeguarding of nuclear material; these infrastructure and measures help prevent the release of nuclear material, including Pu-238. No new infrastructure, safety controls, or policies would be needed for the use of the MMRTG or RHUs in the Dragonfly mission. All established radiological safety controls and precautions relating to the receipt, storage, handling, and installation of radioactive materials would be followed for the mission. Therefore, under normal operating conditions, there would be **no hazardous materials impacts** from the use of Pu-238 in the MMRTG or RHUs for the Dragonfly mission.

In the unlikely event a mission mishap resulted in a release of Pu-238, the impacts would reflect those described in Section 3.1, *Nuclear Radiation*, and Section 3.2, *Land Use*.

3.6.2.2 No Action Alternative

Under the No Action Alternative, the Dragonfly mission would not be launched; therefore, there would be **no potential effect** from the use of hazardous materials from the mission. However, MMRTGs and RHUs could continue to be used in future missions at KSC and CCSFS and environmental impacts evaluated through separate NEPA documentation, as applicable.

3.7 Cumulative Impacts

Cumulative impacts are defined by the CEQ in 40 CFR Subpart 1508.7 as “impacts on the environment which result from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions.” Cumulative impacts must occur to the same resources, in the same geographic area, and within the same period for the Proposed Action and other projects.

At a local scale, other sources of radioactivity are present from the St. Lucie Nuclear Power Plant in South Hutchinson Island near Port St. Lucie, Florida, approximately 160 km (100 miles) directly south of CCSFS. The Nuclear Regulatory Commission has defined two emergency planning zones around the St. Lucie Nuclear Power Plant. The first zone is a plume exposure pathway with a radius of 16 km (10 miles), which is concerned primarily with exposure resulting from releases of airborne radioactive material. The second zone is an ingestion exposure pathway with a radius of 80 km (50 miles) and is concerned primarily with exposure via ingestion of food and liquid that may be contaminated by radioactivity. CCSFS and KSC are outside these two zones; therefore, there would be no cumulative impacts at the local scale (Nuclear Regulatory Commission, 2020).

Because there is a minimal chance of environmental impacts associated with the Proposed Action, the potential for the Proposed Action to cause collectively significant cumulative environmental impacts is unlikely. NASA and USSF may conduct other missions containing nuclear devices such as RHUs or MMRTGs; however, the chance of one of these missions resulting in a mishap with a release of nuclear material in the same timeframe as a mishap from the Dragonfly mission, resulting in a release of Pu-238, is remote.

SECTION 4

Summary of Impacts

The potential impacts associated with the Proposed Action and No Action Alternative and the measures that would be implemented to avoid or minimize those impacts are summarized in Table 4-1. The normal operating conditions as shown in the second column of Table 4-1 represent the most likely outcome of implementing the Proposed Action and includes the successful launch of the Dragonfly mission. In the unlikely event of an accident, the most probable outcome is still an accident without the release of airborne Pu-238, as the MMRTG and RHUs have been designed to withstand the majority of launch mishaps and Earth re-entry. Multiple failures would have to occur and the MMRTG or RHUs would have to be exposed to an extreme condition for the Pu-238 to be released; this scenario is referred to as the "Unlikely Release Scenario" in Table 4-1.

TABLE 4-1
Summary of Potential Impacts and Proposed Mitigation Measures
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Resource Category	Proposed Action: Normal Operating Conditions	Proposed Action: Unlikely Release Scenario	No Action Alternative	Measures to Minimize Impact
Nuclear Radiation	No impact	Negligible to minor, adverse, and permanent impacts to the public.	No impact	Implement standard mitigation measures such as sheltering, evacuation, and cleanup. Follow established radiation procedures, as described in Section 3.1.1.4, *Established Nuclear Safety Procedures*.
Land Use	No impact	Minor, adverse, and temporary impacts to land use.	No impact	Coordinate any cleanup efforts in accordance with the National Response Framework. Undertake the appropriate radiological screening and other necessary response actions in accordance with a mission-specific contingency plan.
Water Resources	No impact	Negligible impacts to water resources.	No impact	Coordinate with USACE and state agencies if wetlands or waters of the U.S. or the State of Florida could be affected after a potential release of Pu-238.
Biological Resources	No impact	Negligible to minor, adverse, and permanent impacts to wildlife species, including protected species. Negligible impacts to ecosystems.	No impact	Coordinate with the USFWS and NMFS if protected species could be affected after an accidental release of Pu-238.
Cultural Resources	No impact	Negligible impacts to cultural sites.	No impact	Coordinate with Florida SHPO if a NRHP-eligible or listed cultural site would be affected during response activities. Follow an established inadvertent discovery plan in the event a new archeological site is discovered during cleanup activities.

Resource Category	Proposed Action: Normal Operating Conditions	Proposed Action: Unlikely Release Scenario	No Action Alternative	Measures to Minimize Impact
Hazardous Materials	No impact	Minor, adverse, and temporary impacts from hazardous materials.	No impact	Follow all hazardous material regulations and procedures, including training.
Cumulative Impacts	No impact	Minimal chance for a cumulative effect.	No impact	None

SECTION 5

Distribution

Although NASA was the lead federal agency for this EA, DOE and USSF served as cooperating agencies. Numerous subject matter experts, including a wide range of NEPA planners, scientists, engineers, nuclear experts, and attorneys from these agencies reviewed and provided input on this EA.

The EA was distributed to the following NASA centers, DOE laboratories, government agencies, and public libraries:

- NASA Headquarters
- NASA SMD
- NASA Office of International and Interagency Relations
- NASA KSC
- NASA Glenn Research Center
- NASA Office of General Counsel
- Johns Hopkins University APL
- DOE Headquarters
- DOE INL
- USSF CCSFS
- USSF Space Force Space Command
- USFWS
- FDEP Clearinghouse
- Florida SHPO
- Central Brevard Library
- Cocoa Beach Public Library
- Melbourne Library
- Merritt Island Public Library
- Port St. John Public Library
- Titusville Public Library
- Satellite Beach Public Library

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SECTION 6

List of Preparers

The NASA NEPA contractors responsible for preparing this report are listed in Table 6-1.

TABLE 6-1
List of Preparers
Environmental Assessment for the Dragonfly Mission, NASA SMD, Washington, DC

Name	Role	Experience
Michelle Rau, PMP	Project Manager and NEPA Lead	M.S., Business Administration; B.S., Ecology and Evolutionary Biology; 24 years of experience
Arthur Desrosiers, CHP	Senior Health Physicist	Sc.D., Radiation Protection; M.S., Nuclear Engineering; B.S. Physics; 43 years of experience
Christina McDonough, PE	Senior Reviewer	M.S., Environmental Engineering; B.S., Civil Engineering; 26 years of experience
Emily Gulick, CEP-IT	NEPA Support	B.A., Environmental Studies; B.A., Geography; 4 years of experience
Michael Witmer, EIT	Radiation Engineer	M.S., Environmental Engineering; B.S., Civil Engineering; 5 years of experience
Molly Turner	Technical Editor	B.A., English; 13 years of experience
Karen Sanders	Technical Editor	J.D., Law; B.A. Anthropology; 25 years of experience

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SECTION 7

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Appendix 2.6A
Coastal Zone Management Act (CZMA) Consultation Documents

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April 22, 2022

Donald Dankert
KSC NEPA Manager
321.861.1196
donald.j.dankert@nasa.gov

Chris Stahl
Clearinghouse Coordinator
Florida State Clearinghouse
Florida Department of Environmental Protection
3900 Commonwealth Boulevard, M.S. 47
Tallahassee, Florida 32399-3000

Subject: Federal Agency Coastal Zone Management Act (CZMA) Negative Determination

Dear Mr. Stahl:

This letter provides the State of Florida with the National Aeronautics and Space Administration's (NASA's) Negative Determination under Section 307 of the CZMA, Title 16 *United States Code* Section 1456, and Title 15 *Code of Federal Regulations* (CFR) Section 930.35. The information in this Negative Determination is also provided pursuant to 15 CFR Section 930.35.

Overview

NASA has prepared an Environmental Assessment (EA) to analyze the environmental effects of launching the Dragonfly mission, which would use a single multi-mission radioisotope thermoelectric generator (MMRTG) and up to 43 radioisotope heater units (RHUs). The Dragonfly mission would employ a multi-rotor vehicle to explore and investigate Saturn's largest moon, Titan. The launch would take place at Cape Canaveral Space Force Station (CCSFS) or Kennedy Space Center (KSC) in Brevard County, Florida, during 2027; however, the launch schedule is subject to change.

Purpose and Need

NASA needs to fulfill the congressional mandate to carry out the New Frontiers Program objective. The proposed Dragonfly mission would satisfy this mandate by exploring Titan in partnership with the Johns Hopkins University Applied Physics Laboratory. Additionally, the National Research Council's 2013-2022 Decadal Survey, *Vision and Voyages for Planetary Science in the Decade*, identified Titan as a high priority of the planetary science community because it is an ocean world and the only moon in our solar system with a dense atmosphere. It is potentially the most Earth-like world in our solar system, which makes it an ideal location for studying prebiotic chemistry and the potential for extraterrestrial life. Therefore, the Decadal Survey advises NASA to conduct two New Frontiers missions per decade.

Radioisotope Power Systems

Some of the most significant challenges in deep space exploration are efficiently keeping spacecraft warm and providing sustained power in deep space environments where the use of solar or batteries is ineffective. For these reasons, alternative sources are necessary for operating the spacecraft under these harsh conditions. NASA proposes to use a single MMRTG and up to 43 RHUs for providing electrical power and heat to the spacecraft for the duration of the Dragonfly mission. Due to the extended length of the mission, the distance from the Sun, and the density of the atmosphere, the Dragonfly mission is unable to implement solar or batteries into the spacecraft design.

The process of harnessing the heat from the natural decay of radioisotopes is established technology that has been refined based on decades of experience and demonstrated success; recent nuclear-enabled space missions include the 2006 launch of the New Horizons spacecraft, the 2011 launch of the Mars Science Laboratory, and most recently the Mars 2020 Perseverance Rover. Radioisotope power systems (RPS) can produce heat for decades under the harsh conditions of deep space without refueling or needing sunlight. Consequently, NASA needs to be able to use RPS for a successful Dragonfly mission.

Federal Review

After review of the Florida Coastal Management Program and its enforceable policies, NASA decided that this activity would not affect the state of Florida coastal zone or its resources.

Thank you for your attention to this matter. Our contractor for the environmental components of this project is Jacobs Engineering Group Inc., which will serve as our designated representative on this matter. Michelle Rau, Project Manager, can be reached by telephone at 719-331-5699 or via e-mail at michelle.rau@jacobs.com. Please feel free to contact either Michelle Rau or me (contact information above), if you have any questions or concerns.

Sincerely,

Donald Dankert
NEPA Manager
NASA KSC

Enclosures: Florida Coastal Management Program Consistency Review

TABLE 2.6A-1
Florida Coastal Management Program Consistency Review

Statute	Consistency	Scope
Chapter 161 Beach and Shore Preservation	The Proposed Action would not affect beach or shore management in Florida. All land activities would occur on existing federal facilities.	Authorizes the Bureau of Beaches and Coastal Systems within DEP to regulate construction on, or seaward of, the state's beaches.
Chapter 163, Part II Growth Policy; County and Municipal Planning; Land Development Regulation	The Proposed Action would not affect local government comprehensive plans.	Requires local governments to prepare, adopt, and implement comprehensive plans that encourage the most appropriate use of land and natural resources in a manner consistent with the public interest.
Chapter 186 State and Regional Planning	The Proposed Action would not affect Florida's plans for water use, land development, or transportation.	Details state-level planning efforts. Requires the development of special statewide plans governing water use, land development, and transportation.
Chapter 252 Emergency Management	The Proposed Action would not affect Florida's vulnerability to natural disasters. The Proposed Action would not affect emergency response or evacuation procedures.	Provides for planning and implementation of the state's response to, efforts to recover from, and the mitigation of natural and man-made disasters.
Chapter 253 State Lands	All activities would occur on federal property; therefore, the Proposed Action would not affect state public lands.	Addresses the state's administration of public lands and property of this state, and provides direction regarding the acquisition, disposal, and management of all state lands.
Chapter 258 State Parks and Preserves	The Proposed Action would not affect state parks, recreational areas, and aquatic preserves.	Addresses administration and management of state parks and preserves.
Chapter 259 Land Acquisition for Conservation or Recreation	The Proposed Action is not likely to affect tourism and/or outdoor recreation. If on the remote chance a recreational resource is affected by the Proposed Action, NASA and/or the USSF would coordinate with the U.S. Fish and Wildlife Service and National Park Service.	Authorizes acquisition of environmentally endangered lands and outdoor recreation lands.
Chapter 260 Recreational Trails System	The Proposed Action would not include the acquisition of land and would not affect the Greenways and Trails Program.	Authorizes acquisition of land to create a recreational trails system and to facilitate management of the system.
Chapter 267 Historical Resources	The Proposed Action is not likely to affect cultural resources of Florida. If on the remote chance a historic resource is affected by the Proposed Action, NASA and/or the USSF would coordinate with the Florida State Historic Preservation Office, per the National Historic Preservation Act.	Addresses management and preservation of the state's archaeological and historical resources.
Chapter 288 Commercial Development and Capital Improvements	The Proposed Action would not affect future business opportunities on state lands, or the promotion of tourism in the region.	Provides the framework for promoting and developing the general business, trade, and tourism components of the state economy.
Chapter 334 Transportation Administration	The Proposed Action would not affect transportation.	Addresses the state's policy concerning transportation administration.
Chapter 339 Transportation Finance and Planning	The Proposed Action would not affect the finance and planning needs of the state's transportation system.	Addresses the finance and planning needs of the state's transportation system.
Chapter 373 Water Resources	The Proposed Action does not include construction and would not affect Florida's water resources.	Addresses the state's policy concerning water resources.

TABLE 2.6A-1
Florida Coastal Management Program Consistency Review

Statute	Consistency	Scope
Chapter 375 Multipurpose Outdoor Recreation; Land Acquisition, Management and Conservation	The Proposed Action is not likely to affect tourism and/or outdoor recreation. If on the remote chance a recreational resource is affected by the Proposed Action, NASA and/or the USSF would coordinate with the U.S. Fish and Wildlife Service and National Park Service.	Develops comprehensive multipurpose outdoor recreation plan to document recreational supply and demand, describe current recreational opportunities, estimate the need for additional recreational opportunities, and propose means to meet the identified needs.
Chapter 376 Pollutant Discharge Prevention and Removal	The Proposed Action would be consistent with Florida's statutes and regulations regarding the transfer, storage, or transportation of pollutants.	Regulates transfer, storage, and transportation of pollutants and cleanup of pollutant discharges.
Chapter 377 Energy Resources	The Proposed Action would not affect energy resource production, including oil and gas, and/or the transportation of oil and gas.	Addresses regulation, planning, and development of oil and gas resources of the state.
Chapter 379 Fish and Wildlife Conservation	The Proposed Action is not likely to affect wildlife. The Proposed Action should not affect marine fisheries. NASA and the USSF will work with the U.S. Fish and Wildlife Service if there is any potential to affect threatened or endangered species. NASA and the USSF will work with the U.S. National Marine Fisheries Service if there is any potential to affect fisheries.	Establishes public policy concerning marine fisheries resources and the hunting, fishing, and taking of game.
Chapter 380 Land and Water Management	The Proposed Action would not result in growth-inducing effects.	Establishes land and water management policies to guide and coordinate local decisions relating to growth and development.
Chapter 381 Public Health, General Provisions	The Proposed Action would not affect Florida's policy concerning the public health system.	Establishes public policy concerning the state's public health system.
Chapter 388 Mosquito Control	The Proposed Action would not affect mosquito control efforts.	Addresses mosquito control effort in the state.
Chapter 403 Environmental Control	The Proposed Action would not affect water quality, air quality, pollution control, solid waste management, or other environmental control efforts in Florida.	Establishes public policy concerning environmental control in the state.
Chapter 553 Building Construction Standards	The Proposed Action would not involve constructing new buildings.	Establishes policy concerning building and construction in coastal zone areas.
Chapter 582 Soil and Water Conservation	The Proposed Action does not involve any construction in Florida. Therefore, the Proposed Action would not affect State of Florida soil and water conservation efforts.	Provides for the control and prevention of soil erosion.
Chapter 597 Aquaculture	The Proposed Action would not affect aquaculture production efforts.	Provides for the coordination, prioritization, and conservation of aquaculture production efforts.

Appendix 3.4A
Endangered Species Act Consultation Documents

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April 22, 2022

MEMORANDUM FOR: U.S. Fish and Wildlife Service

FROM: NASA Kennedy Space Center
Donald Dankert
NEPA Manager

SUBJECT: Endangered Species Act Section 7 Consultation for the Dragonfly Mission from Cape Canaveral Space Force Station (CCSFS) and Kennedy Space Center (KSC), Florida.

1. The National Aeronautics and Space Administration (NASA) requests your concurrence on a "not likely to adversely affect" determination for federally listed species from the launching of the Dragonfly mission from CCSFS or KSC.

2. NASA is preparing an environmental assessment (EA) per the National Environmental Policy Act (NEPA) regulations at Title 40 *Code of Federal Regulations* (CFR) for NASA's upcoming Dragonfly mission. As part of this EA, NASA is analyzing the environmental impacts of launching the Dragonfly mission, which would use a single multi-mission radioisotope thermoelectric generator (MMRTG) and up to 43 radioisotope heater units (RHUs). Please refer to Attachment 1 for a more detailed explanation of MMRTGs and RHUs and their associated radiological profile.

3. Through the environmental review process, NASA has determined that there would be no impacts to federally listed species or designated critical habitat from using a single MMRTG and up to 43 RHUs under normal operating conditions (successful launch). For potential impacts to occur, there would have to be a launch mishap that results in the release of some of the Plutonium-238 (Pu-238) fuel from the MMRTG and/or RHUs, which is extremely unlikely (1 in 10,000 to 1 in 1,000,000), given the safety features designed into the MMRTG and RHUs. Additionally, due to the limited exposure pathways and the relatively insoluble composition of Pu-238, there would only be discountable impacts to federally listed or designated critical habitat. Please refer to Attachment 2 for the U.S. Fish and Wildlife Service's Information for Planning and Consultation report for the federally listed species in Brevard County, Florida.

4. We appreciate your review and concurrence of this proposed action. Please contact Mr. Donald Dankert, KSC NEPA Manager, at (321) 861-1196 for additional information regarding the Dragonfly mission. Please address any written comments to donald.j.dankert@nasa.gov.

Donald Dankert

KSC NEPA Manager

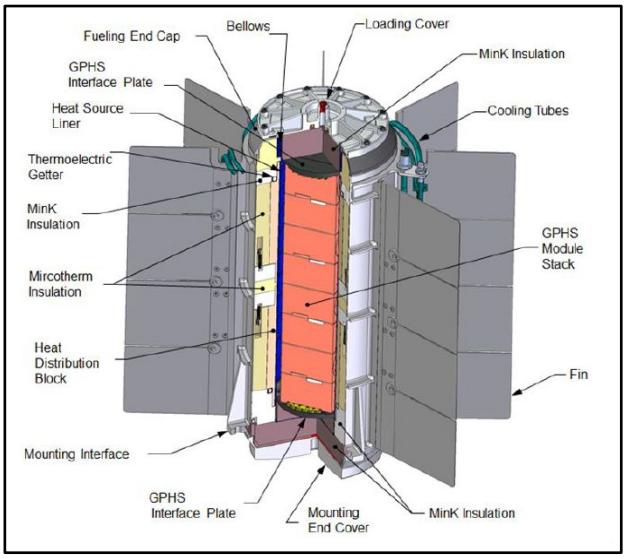
Attachment 1: MMRTG and RHU Descriptions and Radiological Risk Profile

Attachment 2: Federally Listed Species

Attachment 1: MMRTG and RHU Descriptions and Radiological Risk Profile

MMRTG Description

- MMRTGs, a type of Radioisotope Thermoelectric Generator (RTG), are space nuclear power systems that convert heat into electricity without using moving parts; instead, MMRTGs directly convert heat from the natural decay of Pu-238 into electricity. A single MMRTG would be used for the Dragonfly mission as the source of heat and electrical power for its systems and instruments.
- MMRTGs have been successfully used on 32 space missions since the 1960s and have been analyzed in previous NEPA documents including the Mars 2020 Perseverance Rover launch most recently. There have been no radiological incidents in the history of using RTGs in spacecraft.



- The integrity and durability of MMRTGs have been well documented by the Department of Energy (DOE). MMRTGs are designed with safety features to withstand potential accidents from a wide-range of space missions without the release of Pu-238.
- A MMRTG includes eight General Purpose Heat Source (GPHS) modules, which are considered the essential building block of an MMRTG, as they contain and protect the Pu-238 fuel. The GPHS module is engineered and constructed with multiple protective design features that substantially mitigate the risk of a release and dispersal of nuclear material in an accident situation. These safety features include the ceramic form of the Pu-238 heat source material, iridium metal alloy cladding, graphite sleeves that protect the fuel, and the rugged carbon-fiber material that forms the shell (refer to the figure).
- The majority of any release would remain on the launch pad.
- For more information on MMRTGs, please visit: https://rps.nasa.gov/resources/86/multi-mission-radioisotope-thermoelectric-generator-mmrtg/?category=fact_sheets

RHU Description

- RHUs are small devices that use the natural decay of Pu-238 to provide thermal energy to heat electronics for a mission.
- RHUs have flown on nine NASA missions since the 1960s and have been analyzed in approximately eight Environmental Impact Statements since 1988. There have been no radiological incidents in the history of using RHUs in spacecraft.
- The integrity and durability of RHUs have been well documented by the DOE; RHUs are designed to withstand the potential accidents of a wide range of space missions without the release of Pu-238.

- RHUs include multiple layers of protection. The outermost layer of protection is composed of fine-weave, pierced fabric carbon-carbon composite material. The innermost level of protection is the platinum-rhodium metal alloy. Finally, the hot-pressed ceramic fuel pellet itself ensures the Pu-238 is in its most stable form to minimize risk of release in the event of an accident. The fuel pellet has the highest melting point of all the materials used in the RHU. It is resistant to fracture and, in the extremely unlikely event of a launch mishap, the ceramic form could break into pieces rather than fine dust, thereby limiting the potential airborne release of Pu-238. Additionally, NASA designs their missions to avoid this potential.
- For more information on RHUs, please visit: https://rps.nasa.gov/power-and-thermal-systems/thermal-systems/light-weight-radioisotope-heater-unit/

Associated Risks from MMRTG and RHU systems

- There are no inherent environmental effects associated with MMRTGs or RHUs operating in a normal environment (successful launch). Consequently, the only potential risks to the Endangered Species Act or Marine Mammal Protection Act relates to the potential inhalation of radioactive material after a launch mishap and the resulting impact from the cleanup of any contaminated land. For this to occur, there would have to be a launch accident that results in the release of some of the Pu-238 fuel from the MMRTG and/or RHUs, which is extremely unlikely (1 in 10,000 to 1 in 1,000,000), given the safety features designed into the MMRTG and RHUs.
- The calculated radiation dose to a member of the public after a launch incident that results in release from a single MMRTG and up to 43 RHUs ranges from 2.98 to 21.4 rem, depending on distance from the incident and meteorological conditions. However, these dose consequences represent a conservative estimate of release, which is beyond extremely unlikely. Therefore, it is doubtful that the potential radiation exposure after an event would result in a health effect to a protected species, as the radiation exposure would be within the range of what species are typically subjected and adapted to.

Attachment 2: Federally Listed Species List

Federally Threatened and Endangered Species Documented to Occur at CCSFS or KSC

Species Type	Common Name	Scientific Name	Federal Status
Reptiles and Amphibians	American Alligator	*Alligator mississippiensis*	Threatened
Reptiles and Amphibians	Atlantic (Kemp's) Ridley Sea Turtle	*Lepidochelys kempi*	Endangered
Reptiles and Amphibians	Atlantic Green Sea Turtle	*Chelonia mydas*	Endangered
Reptiles and Amphibians	Atlantic Salt Marsh Snake	*Nerodia clarkia taeniata*	Threatened
Reptiles and Amphibians	Eastern Indigo Snake	*Drymarchon corais couperi*	Threatened
Reptiles and Amphibians	Gopher Tortoise	*Gopherus polyphemus*	Candidate for Federal Listing
Reptiles and Amphibians	Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered
Reptiles and Amphibians	Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered
Reptiles and Amphibians	Atlantic Loggerhead Sea Turtle	*Caretta caretta*	Threatened
Mammals	Northern Atlantic Right Whale	*Eubalaena glacialis*	Endangered
Mammals	Southeastern Beach Mouse	*Peromyscus polionotus niveiventris*	Threatened
Mammals	West Indian Manatee	*Trichechus manatus latirostris*	Endangered
Fishes	Smalltooth Sawfish	*Pristis pectinata*	Endangered
Fishes	Nassau grouper	*Epinephalus striatus*	Threatened
Birds	Auburn's Crested Caracara	*Polyborus plancus audubonii*	Threatened
Birds	Crested Caracara	*Caracara cheriway*	Threatened
Birds	Eastern Black Rail	*Laterallus jamaicensis* ssp. *Jamaicensis*	Proposed Threatened
Birds	Everglade Snail Kite	*Rostrhamus sociabilis pumbeus*	Endangered
Birds	Florida Scrub Jay	*Aphelocoma coerulescens*	Threatened
Birds	Piping Plover	*Charadrius melodus*	Threatened
Birds	Red Knot	*Calidris canutus rufa*	Threatened
Birds	Red-cockaded Woodpecker	*Picoides borealis*	Endangered
Birds	Roseate Tern	*Sterna dougallii*	Threatened
Birds	Wood Stork	*Mycteria americana*	Endangered
Birds	Bald Eagle	*Haliaeetus leucocephalus*	Protected under the Bald and Golden Eagle Protection Act
Plants	Carter's Mustard	*Warea carteri*	Endangered
Plants	Four-petal Pawpaw	*Asimina tetramera*	Endangered
Plants	Florida Perforate Lichen	*Cladonia perforafa*	Endangered
Plants	Lakela's Mint	*Dicerandra immaculata*	Endangered
Plants	Lewton's Polygala	*Polygala lewtonii*	Endangered

Species Type	Common Name	Scientific Name	Federal Status
Plants	Johnson's Seagrass	*Halophila johnsonii*	Threatened
Plants	Beach jacquemontia	*Jacquemontia reclinate*	Endangered
Plants	Tiny Polygala	*Polygala smallii*	Endangered

Source:
U.S. Fish and Wildlife Service (USFWS). 2020. "Information for Planning and Consultation" (IPac), Version 1.4. Brevard County.
U.S. Air Force (USAF). 2020. *Integrated Cultural Resources Management Plan for the 45th Space Wing*. Final. July.

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Appendix 3.5A
National Historic Preservation Act Consultation Documents

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April 22, 2022

MEMORANDUM FOR: Florida State Historic Preservation Office (SHPO)

FROM: NASA Kennedy Space Center
Donald Dankert
NEPA Manager

SUBJECT: National Historic Preservation Act Section 106 Consultation for the Dragonfly Mission from Cape Canaveral Space Force Station (CCSFS) and Kennedy Space Center (KSC), Florida.

1. The National Aeronautics and Space Administration (NASA) requests your concurrence on a "no adverse effect" determination for National Register of Historic Places (NRHP)-listed and eligible sites at CCSFS and KSC from the launch of the Dragonfly mission.

2. NASA is preparing an environmental assessment (EA) per the National Environmental Policy Act (NEPA) regulations at Title 40 *Code of Federal Regulations* (CFR) for NASA's upcoming Dragonfly mission. As part of this EA, NASA is analyzing the environmental impacts of launching the Dragonfly mission, which would use a single multi-mission radioisotope thermoelectric generator (MMRTG) and up to 43 radioisotope heater units (RHUs).

3. Through the environmental review process, NASA has determined that there would be no impacts to NRHP-listed or eligible sites at CCSFS or KSC from using a single MMRTG and up to 43 RHUs under normal operating conditions (successful launch). The only potential risks to NRHP-listed and eligible sites relate to the potential cleanup activities that would occur after a launch mishap. However, for this to occur, there would have to be a launch mishap that results in the release of some of the Pu-238 fuel from the MMRTG and/or RHUs, which is extremely unlikely (1 in 10,000 to 1 in 1,000,000), given the safety features designed into the MMRTG and RHUs.

4. Pu-238 is relatively insoluble and will typically remain on the top 2 inches of surface soil after a release. Consequently, the potential for impacting a known or unknown archeological site present in a contaminated area is limited. In the extremely unlikely event that cleanup activities require the excavation of soil on or near a NRHP-listed or eligible archeological resource, the Florida State Historic Preservation Officer will be notified prior to any non-emergency response activities at the site, and appropriate mitigation measures will be developed in accordance with the National Historic Preservation Act (NHPA). If a new archeological site is identified during decontamination activities, the respective KSC or CCSFS Historic Preservation Officer will be notified immediately. The Historic Preservation Officer will determine if the site is eligible for listing on the NRHP; if it is deemed eligible, the Florida State Historic Preservation Officer will be notified before any other response activities are conducted at that site to determine appropriate mitigation measures.

5. Numerous NRHP-listed and eligible historic sites, as well as National Historic Landmarks, are located on CCSFS and KSC. These significant historic resources include the launch complexes where the Dragonfly spacecraft could be launched. MMRTG- and RHU-specific impacts could involve potential cleanup activities, primarily on the exterior of structures. If a historic structure were identified as part of a response activity, the Florida State Historic Preservation Officer would be notified beforehand, and appropriate mitigations measures would be developed in accordance with the NHPA.

6. We appreciate your review of this proposed action. Please contact Mr. Donald Dankert, KSC NEPA Manager, at (321) 861-1196 for additional information regarding the Dragonfly mission. Please address any written comments to donald.j.dankert@nasa.gov.

Donald Dankert
KSC NEPA Manager