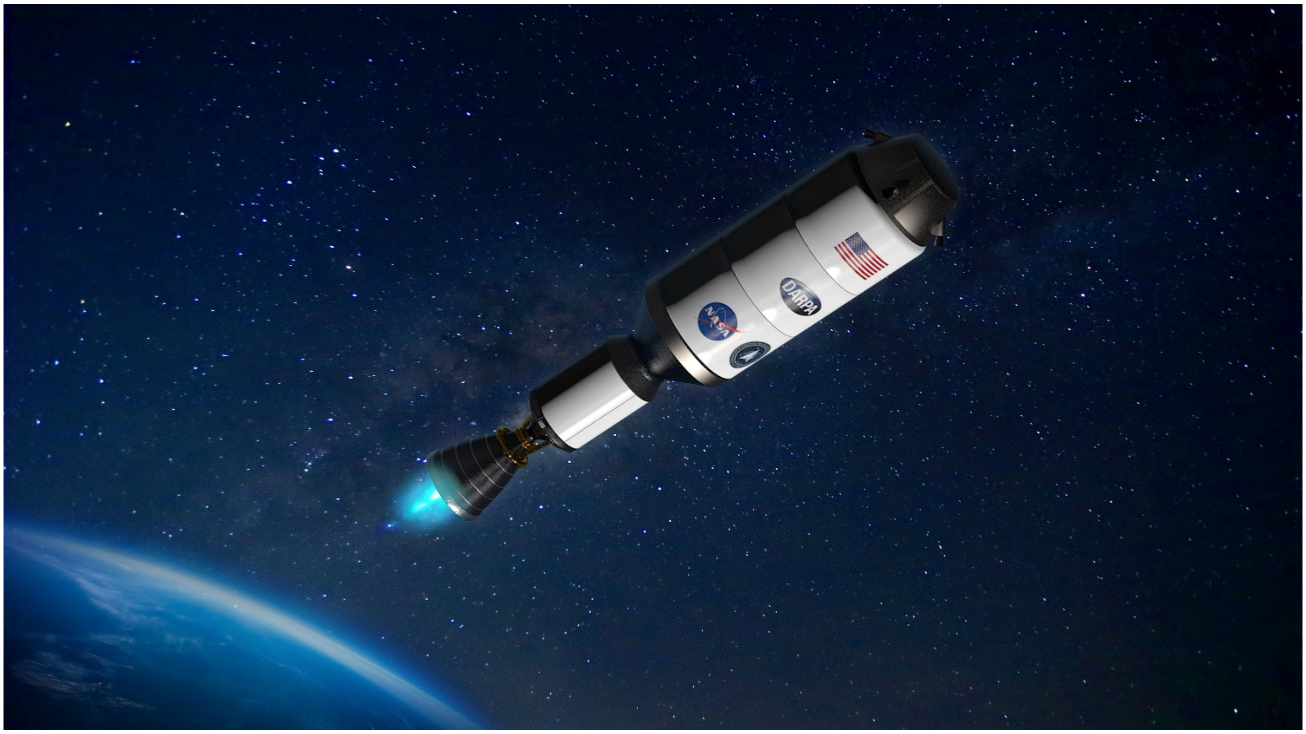
Defense Advanced Research Projects Agency



Final

Environmental Assessment for the Demonstration Rocket for Agile Cislunar Operations (DRACO) Mission

23 October 2023

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Privacy Advisory

This Environmental Assessment (EA) was provided for public comment in accordance with the National Environmental Policy Act (NEPA), the President's 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 the U.S. Air Force's (USAF's) NEPA implementing regulations (32 CFR Part 989) and policy.

The NEPA process provides an opportunity for the public to comment on U.S. Space Force (USSF), National Aeronautics and Space Administration (NASA), and Defense Advanced Research Projects Agency (DARPA) decision-making, offer input on alternative ways for the agencies to accomplish what is proposed, and comment on the agencies' analysis of environmental effects.

Public comments allow USSF, NASA, and DARPA to make better, informed decisions. Letters or other written or oral comments provided may be published in the EA. As required by law, comments provided will be addressed in the EA and made available to the public. Providing personal information is voluntary. Private addresses will be compiled to develop a mailing list for those requesting copies of the EA. However, only the names of the individuals making comments and their specific comments will be disclosed. Personal home addresses and phone numbers will not be published in the Final EA.

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Acronyms and Abbreviations

Acronym	**Definition**
$\mu g/m^3$	microgram(s) per cubic meter
$\mu Ci/m^2$	microcurie(s) per square meter
AEC	U.S. Atomic Energy Commission
ARPA	Archaeological Resources Protection Act
CCSFS	Cape Canaveral Space Force Station
CEQ	Council on Environmental Quality
CFR	*Code of Federal Regulations*
cm^2	square centimeter(s)
CNS	Canaveral National Seashore
CRM	cultural resource manager
DARPA	Defense Advanced Research Projects Agency
DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
dpm	disintegration(s) per minute
DRACO	Demonstration Rocket for Agile Cislunar Operations
EA	environmental assessment
EIS	environmental impact statement
EO	Executive Order
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FAA	Federal Aviation Administration
FDA	U.S. Food and Drug Administration
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
HALEU	high assay low-enriched uranium
IAEA	International Atomic Energy Agency
ICRMP	Integrated Cultural Resources Management Plan
ICRP	International Commission on Radiological Protection
km	kilometer(s)
km^2	square kilometer(s)
KSC	Kennedy Space Center

Acronym	Definition
LC	launch complex
LEO	low Earth orbit
MBTA	Migratory Bird Treaty Act
MEI	maximally exposed individual
mg	milligram(s)
mg/week	milligram(s) per week
MINWR	Merritt Island National Wildlife Refuge
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site
NOA	Notice of Availability
NPS	National Park Service
NRC	U.S. Nuclear Regulatory Commission
NRHP	National Register of Historic Places
NSPM-20	National Security Presidential Memorandum-20
NTP	Nuclear Thermal Propulsion
NTR	Nuclear Thermal Rocket
Pu-238	Plutonium-238
RADCC	Radiological Control Center
rem	Roentgen Equivalent Man
RPS	radioisotope power systems
SHPO	State Historic Preservation Office
SJRWMD	St. Johns River Water Management District
SLC	space launch complex
SLD 45	Space Launch Delta 45
STEL	short-term exposure limit
U.S.	United States
U.S.C.	*United States Code*
UN	United Nations
USAF	U.S. Air Force
USFWS	U.S. Fish and Wildlife Service
USSC	U.S. Space Command
USSF	U.S. Space Force

SECTION 1

Purpose and Need for the Proposed Action

1.1 Introduction

The Defense Advanced Research Projects Agency (DARPA) has prepared this Environmental Assessment (EA) to analyze the environmental effects of launching the Demonstration Rocket for Agile Cislunar[1] Operations (DRACO) spacecraft. The goal of the DRACO program is to demonstrate an operable nuclear thermal propulsion (NTP) system. NTP uses a nuclear reactor to heat propellant to temperatures in the range of 3,600 to 5,400 degrees Fahrenheit before expelling the hot propellant through a nozzle, thereby producing thrust. Compared to chemical space propulsion technologies, NTP offers two-to-three times greater efficiency at comparable thrust. The assembly would likely occur at an industry-owned facility licensed by the Nuclear Regulatory Commission (NRC). The launch would take place at the U.S. Space Force's (USSF's) Cape Canaveral Space Force Station[2] (CCSFS) or National Aeronautics and Space Administration's (NASA's) Kennedy Space Center (KSC) in Brevard County, Florida, in 2027; however, the launch schedule is subject to change.

DARPA is the lead federal agency for this Proposed Action. NASA, USSF, and National Nuclear Security Administration (NNSA) are cooperating agencies. NASA is a cooperating agency because of its jurisdiction by law over activities which occur, or may occur, at KSC. NASA also has special expertise with respect to rocket launches from KSC, including missions with integrated space nuclear systems. USSF is a cooperating agency because it manages the launch facilities at CCSFS, the launch processes for the U.S. Department of Defense (DOD) and has special expertise in the launch of space nuclear systems. NNSA's cooperating agency role stems from providing guidance and peer review to DARPA in the use of nuclear materials.

This EA has been prepared in accordance with the Council on Environmental Quality's (CEQ's) National Environmental Policy Act (NEPA), as amended (*United States Code* [U.S.C.] Title 42, Section 4321, et seq.); the CEQ regulations for Implementing the Procedural Provisions of NEPA (*Code of Federal Regulations* [CFR] Title 40, Parts 1500 through 1508); and the U.S. Air Force's (USAF's) NEPA implementing regulations (32 CFR Part 989) and policy. This EA was underway prior to the issuance of the National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions and Climate Change, issued 9 January 2023, and therefore, the new guidance is not implemented in this analysis.

1.2 Background

Nuclear technology has been used in U.S. space missions since 1961. All launches involving the use of space nuclear systems undergo rigorous analysis and review prior to launch approval. The main types of space nuclear systems are radioisotope systems and fission systems. Radioisotope Power Systems (RPS), represent nearly all the space nuclear system deployed to date. RPS convert the natural decay products of plutonium-238 (Pu-238) to heat; this heat can then be converted to electricity using a thermoelectric generator, depending on the type of system. The DRACO nuclear thermal rocket (NTR) is a fission system that contains a nuclear reactor utilizing fissionable High Assay Low-Enriched Uranium (HALEU[3]) fuel. The only previous fission reactor launched by the United States (U.S.) was the Systems for Nuclear Auxiliary Power 10A (SNAP-10A), which was launched in 1965 as an experimental nuclear-powered satellite 4 years prior to the

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[1] Cislunar space is the volume of space influenced by the gravitational pull of the Earth and Moon.

[2] On December 9, 2020, the Cape Canaveral Air Force Station and Patrick Air Force Base were renamed as Space Force installations.

[3] HALEU is a type of nuclear reactor fuel that is enriched to between 5% and 20% uranium-235. Additional details are provided in Section 3.1, *Nuclear Radiation*.

enactment of NEPA. Numerous other space fission reactor development programs have progressed since 1965, although none have resulted in a launch. Since 1965, new approaches in the development of NTP systems engineering, with associated improvements in predicted safety, reliability, and economy of scale, have made this technology feasible for launch and operational testing in space. The new approaches include the type of fuel used in the systems and the use of computers in the development of reactor designs. The DOD and NASA have a renewed interest in NTP given the increased maneuverability it could provide to future missions.

The reactor would be held in a subcritical state during payload handling, shipment, integration, and launch. Radiation-producing power operation would not occur until DRACO had achieved a predefined safe orbit, which is when the reactor would be turned on and the propulsion for the spacecraft would be demonstrated. A nuclear fission reactor only presents a substantial radiological hazard if it achieves criticality. Criticality is the normal operating condition of a reactor in which a fission chain reaction[4] is sustained by nuclear fuel. Prior to criticality, the radioactivity level of the material would be close to levels typically found in nature; this is an important difference from RPS technologies. A RPS generates energy from the natural atomic decay of a radioisotope (Pu-238), such that the radioactivity level would be highest at the start of the mission. As fission systems do not have appreciable radioactivity until they achieve criticality; safety for DRACO's fission reactor focuses on precluding mishaps that could result in inadvertent criticality during assembly, testing, and launching. Further explanation regarding the definition of a safe orbit is provided in Section 2.1.2.3, *Demonstration*.

1.3 Purpose and Need for the Proposed Action

In a presentation to the U.S. Senate Committee on Armed Services in April 2021, General James H. Dickinson, Commander, U.S. Space Command (USSC) described the intent of the U.S.'s major international adversaries in space (USSC, 2021):

> Over the past two decades, an increasingly assertive China and a resurgent Russia worked to develop advanced technologies to erode core U.S. military advantages, such as power projection and rapid, global, space-enabled precision fires. Their militaries actively integrate advanced space and counterspace technologies into multi-domain warfighting strategies to challenge U.S. regional superiority, position themselves as space powers, and create improved balance of power dynamics in their near abroad. Both countries reorganized their militaries to develop deeper competency in technical military fields such as electronic warfare, cyberspace and space operations.

The project is needed for the DOD to provide space-based assets to deter strategic attack by adversaries and execute U.S. national strategy. While movement and maneuver are core tenets of modern operations on land, at sea, and in the air, rapid maneuver in the space domain has traditionally been challenging because electric and chemical space propulsion systems have drawbacks in thrust-to-weight and propellent efficiency, respectively.

As the commercial space economy grows, NTP could be a linchpin technology that would provide a variety of benefits. The unique combination of impulse and propellent efficiency of nuclear propulsion provides an elevated dimension to space transportation and spacecraft maneuverability over conventional chemical rockets. From its high impulse and propellent efficiency, NTP capability would enable spacecraft to more rapidly traverse and maneuver through space, including enhancing cis-lunar space mobility. Demonstrating NTP in cis-lunar space and evolving its performance capability into an operational system could establish a reliable transportation system for a growing lunar economy. NTP could reduce mission staging, duration, and risk for an eventual moon-to-Mars human exploration mission. NTP would facilitate the development of the nascent, but rapidly developing, international commercial space economy; there is interest in advancing

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[4] A fission chain reaction occurs when enough neutrons are released to sustain an ongoing series of reactions.

this technology for satellite placement and servicing, as well as in NASA's Artemis program. Beyond being a key capability that could allow increased space mobility, sustainable lunar settlements, and a commercial lunar economy, NTP would significantly reduce the transit time between the Moon and Mars, thereby reducing an astronaut's exposure to solar radiation. Therefore, NTP would bolster other deep space exploration missions through gains in power, efficiency, and endurance.

The purpose of the project is to demonstrate a system that has the potential to achieve high thrust-to-weight ratios similar to in-space chemical propulsion with two to three times greater efficiency. This combination, which would be provided by NTP, would give spacecraft a greater ability to rapidly transit and maneuver in space and maintain the U.S.'s position as the global leader for development of a secure and robust space-based economy.

1.4 Organization of the Environmental Assessment

DARPA has prepared this EA to provide an efficient and comprehensive analysis of the potential environmental effects associated with the implementation of the proposed DRACO program. 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.
- **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 these 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 September 10, 2023. The Draft EA and associated NOA are also posted on the Patrick Space Force Base website (https://www.patrick.spaceforce.mil/Resources/Environmental). Public comments were accepted through October 10, 2023. Copies of the Draft EA were also 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 North Brevard Ave., Cocoa Beach, FL 32931
- Melbourne Public Library, 540 E. Fee Ave., Melbourne, FL 32901
- Merritt Island Public Library, 1195 North Courtenay Parkway, 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

One comment was received during the 30-day review period for the Draft EA. The comment was from the U.S. Environmental Protection Agency (EPA). The comment and response are included in Appendix 1.5A. The Final EA is posted on the Patrick Space Force Base website (https://www.patrick.spaceforce.mil/Resources/Environmental).

1.6 Agency and Government to Government Coordination and Consultation

Compliance with Section 7 of the Endangered Species Act (ESA) and implementing regulations requires communication with the U.S. Fish and Wildlife Service (USFWS) in cases where a federal action could affect threatened or endangered species. After discussions with Space Launch Delta 45 (SLD 45) and USFWS, it was determined that a Section 7 consultation for the Proposed Action would not be necessary, given the remote possibility of effects on endangered species. For further explanation, refer to Section 3.4, *Biological Resources*. In compliance with Section 106 of the National Historic Preservation Act (NHPA), DOD is consulting with the Florida State Historic Preservation Office (SHPO) regarding the Proposed Action. DOD requested concurrence on a “no adverse effect” determination for the Proposed Action (refer to Appendix 1.6A). Tribes were notified of this project during the public review process, and any comments received will be included and addressed in the Final EA.

SECTION 2

Description of the Proposed Action and Alternatives

This section identifies and describes the Proposed Action, the No Action Alternative, the alternatives eliminated from further analysis, and the resources analyzed.

2.1 Proposed Action

Under the Proposed Action, the DOD would launch a DRACO spacecraft into orbit. The following subsections provide a detailed explanation of the DRACO spacecraft components.

2.1.1 Nuclear Thermal Propulsion

NTP works by pumping a liquid propellant, such as hydrogen, through a central chamber that contains the reactor core[5]. The liquid propellent is heated by the reactor, which causes the liquid to expand into a gas that accelerates out of a nozzle to generate a high amount of thrust. This process is different from a traditional chemical rocket that generates heat with the combustion of two liquid propellants consisting of an oxidizer and a fuel. With NTP, the reactor's heat is generated by a process called nuclear fission, in which uranium atoms are split by neutrons present in the reactor core. The power and temperature are controlled through the rate of fission and flow of hydrogen coolant through the core (DOE, 2020a). A notional drawing of the NTR components is shown as Figure 2-1. NTP would not be initiated until the spacecraft achieves a safe orbit as described in Section 2.1.2.3, *Demonstration*.

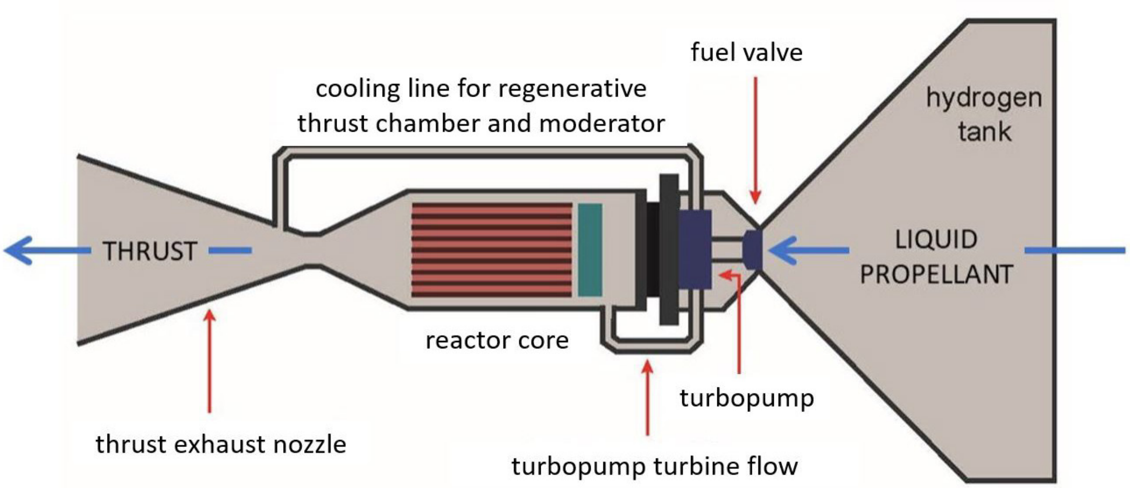

Figure 2-1. Nuclear Thermal Propulsion Schematic

2.1.2 DRACO Program Phases

The demonstration mission of the DRACO spacecraft consists of four distinct phases:

1. Pre-launch assembly and transport
2. Launch

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[5] In the case of DRACO, the reactor core is the central portion of a nuclear reactor, which contains the fuel assemblies, moderator, and support structures. The reactor core is where fission takes place (NRC, 2021). For the DRACO reactor, neutron poisons and control drums are located outside of the reactor core.

3. Demonstration of the NTR engine at an altitude at or above low Earth orbit (LEO)
4. In-space shutdown and decommissioning[6]

2.1.2.1 Pre-Launch

The pre-launch phase consists of the assembly, testing, and delivery of the DRACO spacecraft to the launch site. The location of the reactor assembly site has not yet been determined; however, it would be a location where the assembly activities have been evaluated previously under NEPA. Testing and analysis of the spacecraft and reactor would confirm the reactor could not achieve criticality under credible[7] mishap conditions. The spacecraft components would be delivered to the CCSFS/KSC launch complex in Brevard County, Florida, via highway or rail transport. The transport of the DRACO reactor is consistent with U.S. Department of Transportation (DOT) regulations governing the transport of nuclear material (Hazardous Materials Transportation Act, 49 U.S.C. Section 5101 et seq.; 49 CFR Parts 171 through 180). While the transportation of fuel would be DOD's responsibility, DOE has previously evaluated the transportation of HALEU fuel by truck and rail under NEPA and found no significant impacts to any resources and that EIS and Record of Decision (DOE/NNSA, 2013, 2014) is incorporated here by reference. HALEU fuel development has also been previously evaluated under NEPA and was found to have no significant impacts to any resources (DOE, 1996, 2011, 2018); those documents are also incorporated here by reference.

Once the reactor is received at KSC or CCSFS, it would be secured within a building engineered to meet fire safety standards to mitigate the risk of potentially releasing radioactive material in the case of a fire. Small fires would be mitigated with fire suppression systems. Accidents that could release radioactive material to the environment during receipt of the reactor, combining the NRT engine with the non-nuclear engine hardware, or integration into the spacecraft are not credible, given that the reactor would not be critical and would have a relatively low amount of radioactivity during this phase.

2.1.2.2 Launch

The DRACO launch is expected to occur no earlier than 2027 at either CCSFS or KSC in Brevard County, Florida; however, the launch timing is subject to change and may be delayed. Launching at a later date would not affect the objectives or the potential environmental effects of the DRACO program.

The DRACO spacecraft, including the NTP engine, would be launched into space by a 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 DRACO has not been formally chosen; however, DARPA intends to select a launch vehicle whose potential environmental effects from a launch at CCSFS or KSC have already been analyzed and are understood. It is reasonably foreseeable that environmental effects associated with launch vehicles flown from CCSFS or KSC would be in keeping with the impacts disclosed in the environmental documents for these launch sites and in compliance with the launch vehicle certification process. Because DARPA intends to select a launch vehicle whose potential environmental impacts have been assessed and publicized previously (45th Space Wing, 2019, 2020; FAA, 2008, 2015, 2017, 2019, 2020; NASA, 2011, 2013, 2016, 2019; Space Florida, 2020; SpaceX, 2013, 2019; USAF, 2000), the environmental effects associated with the use of the 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 or that otherwise falls outside the scope of the previous environmental effect analysis for the launch vehicle, DARPA would prepare an additional or supplemental environmental analysis that meets the requirements of NEPA and other applicable statutory and regulatory requirements.

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[6] Decommissioning is safely removing the system from service in accordance with Chapter I of Title 10, "Energy" of the CFR, Part 20, Subpart E.

[7] Credible is defined in this document to mean a probability of greater than 1 in 1,000,000.

Additional details regarding the launch facilities are provided in Section 2.1.3, *Launch Locations.*

2.1.2.3 Demonstration

The demonstration phase would occur at or above LEO (2,000-kilometer [km]) and in an orbit at or above the “sufficiently high orbit” as defined by United Nations (UN) Resolution 47/68, *Principles Relevant to the Use of Nuclear Power Sources in Outer Space* (UN, 1992). Using a sufficiently high orbit would remove the possibility of the reactor’s reentering Earth’s atmosphere for hundreds of years and before the fission products adequately decay to levels similar to the low levels of radioactivity that were in the reactor core at the time of the launch. Once the spacecraft reaches a sufficiently high orbit, the reactor would be properly oriented, turned on, and used for demonstration of the spacecraft propulsion. The demonstration orbit would be chosen to mitigate the potential of colliding with another spacecraft or space debris.

2.1.2.4 Decommissioning

The final project phase, referred to as in-space decommissioning, would occur after the demonstration phase and would be conducted in accordance with Presidential Memorandum on the National Strategy for Space Nuclear Power and Propulsion Space Policy Directive – 6 (DOE, 2020b). In-space decommissioning would ensure the reactor is left in the sufficiently high orbit chosen for the demonstration phase or a higher orbit.

2.1.3 Launch Location

The DRACO spacecraft would be launched from either CCSFS or KSC, both of which are located on the east coast of Florida in Brevard County. Previous DOD and NASA missions using nuclear systems have launched from these locations, and CCSFS and KSC have trained personnel and contingency plans already coordinated with federal, State, and local emergency response agencies that describe the unique response and recovery aspect of a nuclear/radiological incident (DHS, 2016).

2.1.3.1 Description of CCSFS

CCSFS is operated by the SLD 45 at Patrick Space Force Base, which is located 24 km (15 miles) south of CCSFS (Figure 2-2). SLD 45 operates the U.S. Eastern Range, which provides launch facilities and services to support NASA, DOD, and commercial launch service providers, and is responsible for overseeing the preparation and launching of U.S. Government and commercial spacecraft from CCSFS. 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. Most east coast launch operations use the Eastern Range.

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).

CCSFS has seven active space launch complexes (SLCs): SLC-16, SLC-20, SLC-36, SLC-37, SLC-40, SLC-41, and SLC-46, and an additional landing site, referred to as SLC-13 (Landing Zone-1 and Landing Zone-2) (FDOT, 2021).

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 primary space launch location and is home to NASA's Launch Service Program (Figure 2-2). Its core competencies are rooted in its 50-year history in space flight and include the following:

- Acquiring and managing launch services.
- Processing, launching, landing and recovering, operating, and sustaining launch vehicle and spacecraft.
- 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.

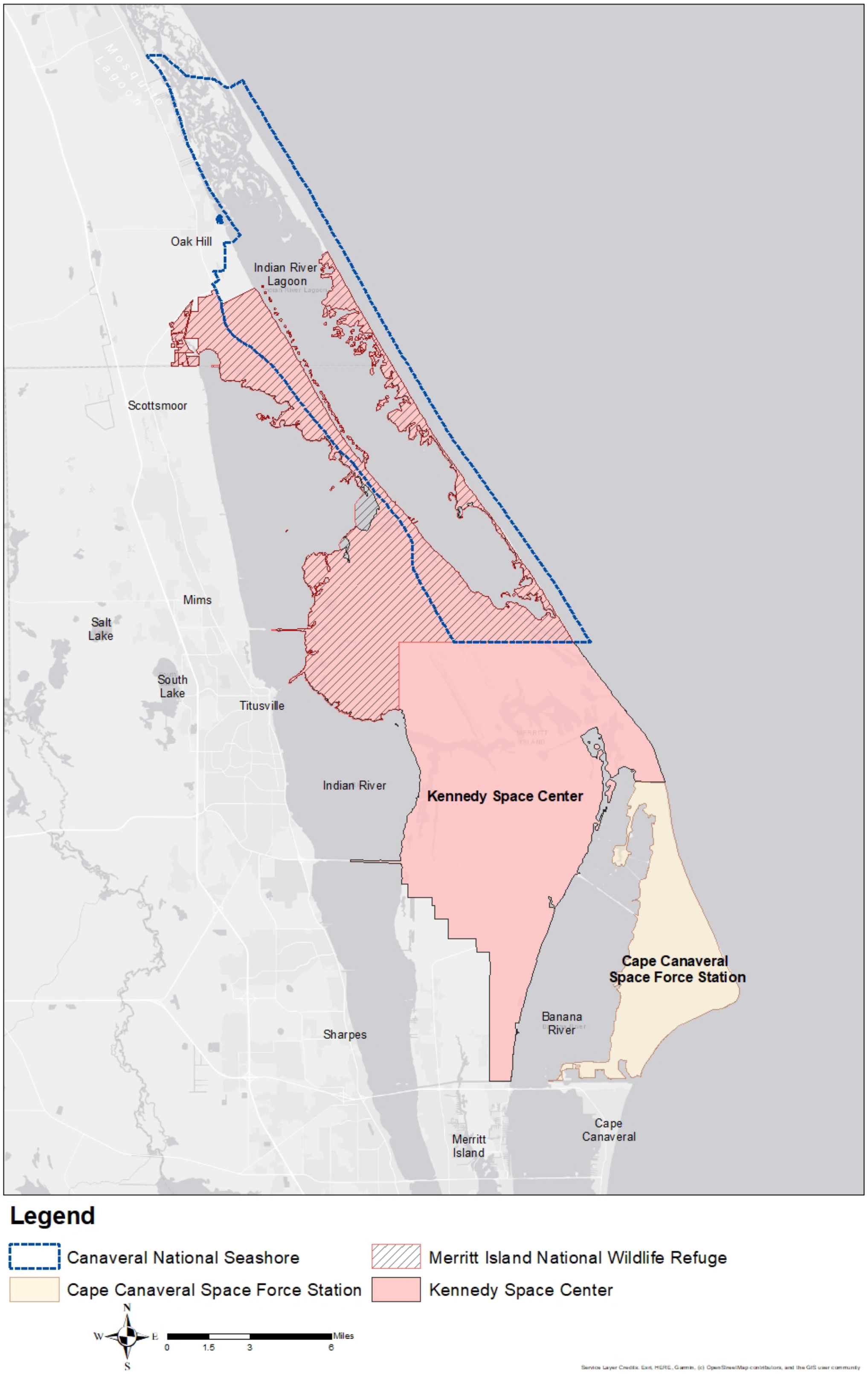
KSC has four active launch complex (LC) sites: LC-39A, LC-39B, LC-39C, and most recently, LC-48. The remaining LCs are either deactivated or inactive (FDOT, 2021). As of 2013, the former Shuttle Landing Facility, now the Launch and Landing Facility, has been transferred over to Space Florida for non-government 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 approximately 74 km (46 miles) 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).

2.1.4 Onsite Construction

There is no anticipated need for construction or other activities that may require surface disturbance of the otherwise undisturbed land associated with the Proposed Action at either the CCSFS or KSC complex.



Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 2-2. KSC and CCSFS Launch Infrastructure

2.2 No Action Alternative

Under the No Action Alternative, DARPA would discontinue preparations for DRACO, and the spacecraft would not be launched. DOD and NASA would not benefit from the demonstration of the performance capability of NTP to be an operational system in cis-lunar space. In accordance with 32 CFR Subpart 989.8(d), the No Action Alternative is analyzed to describe the anticipated future condition if the Proposed Action is not implemented.

2.3 Alternatives Eliminated from Further Analysis

The following alternative was analyzed for DRACO and determined to be infeasible; therefore, the alternative was eliminated from further analysis.

Alternative Launch Location

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. Nuclear Safety Procedures at KSC and CCSFS are discussed in Section 3.1.1.5, *Established Nuclear Safety Procedures*. Except for Vandenberg Space Force Base, other NASA and USSF facilities do not have the infrastructure to support nuclear-enabled payloads. However, the launch would need to be targeted toward the east, which makes Vandenberg Space Force Base infeasible. Therefore, no other launch facilities were considered.

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

Potential radiation exposure resulting from a mission mishap has been identified as the primary environmental concern associated with DRACO. Unique, non-radiological exposure to potentially hazardous materials following a mission mishap is also considered in the analysis. Other related resource concerns, such as exposure to noise during a launch, have been addressed previously in separate NEPA documents (45th Space Wing, 2019, 2020; FAA, 2008, 2015, 2017, 2019, 2020; NASA, 2011, 2013, 2016, 2019; Space X, 2013, 2019; Space Florida, 2020; USAF, 2000). Although the specific launch vehicle that would be used is currently unknown, only launch vehicles that have undergone the NEPA process would be considered for the DRACO mission. This EA evaluates the potential impacts of a release of nuclear material into the environment associated with all phases of the DRACO program. The potential impacts to the following environmental resources are discussed in Section 3, *Affected Environment and Environmental Consequences*:

- Nuclear Radiation Exposure
- Land Use
- Water Resources
- Biological Resources
- Hazardous Materials and Waste
- Cultural Resources

2.4.2 Resource Areas Eliminated from Further Analysis

In accordance with the CEQ's directives to briefly provide sufficient evidence and analysis for determining whether to prepare an environmental impact statement (EIS) or a finding of no significant impact (40 CFR Subpart 1501.5), 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 activities associated with DRACO would be within the typical visual characteristics of KSC and CCSFS.
- **Noise and Noise-compatible Land Use**: The noise associated with launches has been analyzed in NEPA documentation for individual launch vehicles, and in each case, no significant impacts from noise were found (NASA, 2011, 2013, 2016; Space X, 2013; FAA, 2008, 2015, 2017, 2019, 2020; USAF, 2000). If a new launch vehicle is chosen for the DRACO mission, that launch vehicle must have the NEPA process completed prior to use. Any noise affects associated with the new launch vehicle would be analyzed in the launch vehicle specific NEPA document.
- **Utilities, Buildings and Transportation Infrastructure**: There would be no changes to existing utilities, buildings, or transportation infrastructure under the Proposed Action. DRACO would not result in additional resource or utility demands or affect energy supply. The potential environmental effects associated with the transportation of the DRACO system have been addressed in existing NEPA documentation, which found no significant impacts to transporation infrastructure (DOE/NNSA, 2013). The emergency evacuation protocols to be implementated if a mission launch mishap were to occur would the same as the protocols for a non-nuclear mission; therefore, there would be no unique impacts to transportation for the Proposed Action.
- **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. Additionally EO 14008, "Tackling the Climate Crisis at Home and Abroad," directs agencies to consider disproportional impacts of climate change on minority and low-income populations. Using the EPA's Environmental Justice Screening and Mapping Tool, a 16-km (10-mile) buffer area surrounding the CCSFS and KSC boundaries did not contain a disproportionate percentage of minority and low-income populations (EPA, 2023). 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 disproportionate adverse effect to minority and low-income populations resulting from the Proposed Action.
- **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 under 5 years of age reside in the vicinity of KSC and CCSFS, the Proposed Action would not disproportionately impact these individuals (EPA, 2021). The potential for health effects to children from exposure to nuclear material is considered in Section 3.1, *Nuclear Radiation*.
- **Geology and Soils:** In the unlikely event of a release of radiological materials during a potential accident, the depth of potential soil cleanup outside immediate impact sites 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*.
- **Air Quality and Climate**: KSC and CCSFS are 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 and found no significant impacts (NASA, 2011, 2013, 2016; Space X, 2013; FAA, 2008, 2015, 2017, 2019, 2020; USAF, 2000). DRACO 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 be in full compliance with KSC's Title V Operating Permits (KSC, 2021). CCSFS no longer operates under a Title V permit; however, CCSFS tracks air emissions to verify operation under pollutant limits set by the Florida Department of Environmental Protection's Division of Air Resource Management's Air General Permit. Therefore, no new impacts to air quality or climate are expected from the Proposed Action. Impacts associated with an airborne release of HALEU are discussed in detail in Section 3.1, *Nuclear Radiation Exposure*.

- **Socioeconomics**: No additional onsite personnel would be hired to implement the Proposed Action, and no population growth resulting from the Proposed Action is expected. Only positive socioeconomic effects would occur under the Proposed Action, similar to other launches. Potential impacts to land use, including farmland and recreational areas, are discussed in Section 3.2, *Land Use*.
- **Coastal Zones**: The Coastal Zone Management Act 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.
- **Floodplains**: EO 11988, Floodplain Management, requires federal agencies to take actions to reduce the risk of flood loss and avoid environmental impacts in floodplains. The Proposed Action consists of a launch that can be easily scheduled around weather events and does not involve the construction of permanent infrastructure that could effect a floodplain.

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 DRACO project.

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. During pre-launch and launch and for most resources, the region of influence is limited to the KSC and CCSFS installation boundaries, as shown on Figure 2-2. However, for some resources, the potential effects of the project must be considered within the context of the resource. For example, the evaluation of land use also includes the surrounding areas, and during demonstration and decommissioning, the region of influence may be anywhere in the world.

Environmental Consequences

The purpose of NEPA is to inform agency 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 1501.3(b)(1)), 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 also identified, where relevant. As required under NEPA, the environmental effects of the No Action Alternative are also evaluated.

3.1 Nuclear Radiation Exposure

3.1.1 Affected Environment

The following sections provide a definition 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 Uranium

Nuclear radiation is defined as energy in the form of particles or electromagnetic waves emitted during the decay of a radioisotope. The particles or waves are considered ionizing radiation if they contain enough energy to separate electrons from their atoms.

Uranium is found naturally in the environment in three isotope forms. More than 99% of naturally found uranium is in the form of U-238, which has the lowest radioactivity concentration among the three isotopes. U-234 and U-235 have higher levels of radioactivity and together by mass total less than 1% of the natural occurrence. Uranium emits radiation in the form alpha particles[8] and gamma rays[9].

Nuclear reactors use manufactured blends of uranium isotopes for fuel in the fission process to create heat. The processing of natural uranium for reactor fuel separates out some of the U-238 to create higher residual concentrations of U-234 and U-235 to create "enriched" uranium. Existing power and research reactors commonly operate on low-enriched uranium, which typically contains up to 5% U-235. HALEU fuel is enriched to between 5% and 20% U-235. HALEU fuel offers improved reactor economics, greater fuel efficiency, enhanced safety, proliferation resistance, lower volumes of waste, and other advantages (World Nuclear News, 2020). HALEU also allows developers to optimize their systems for longer life cores, increased efficiencies, and better fuel utilization (DOE, 2020c).

The higher the enrichment of U-238 to U-235, the lower the engine mass. Fuel can be used for longer time periods in the reactor before having to be replaced and more energy can be obtained from a specific mass of fuel. The increased efficiency is critical for driving costs down and reducing the amount of fuel needed to be launched into space.

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, from 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 dead outer layer of skin serves as a natural barrier and prevents penetration to more sensitive cells. However, if alpha-emitting radionuclides are introduced into the body by inhalation, they can deposit in internal organs and deliver a radiation dose to tissues (EPA, 2023). Gamma radiation can penetrate barriers such as skin and can be harmful to the entire body; however, gamma-emitting particles cause 20 times less damage to living tissue compared to alpha particles when inhaled or ingested (EPA, 2014a).

Because uranium occurs naturally in the environment, small amounts of uranium are ingested (about 1 microgram [µg]) and inhaled (about 0.6 µg) by everyone each day. When inhaled, coarse particles of uranium are caught in the upper part of the respiratory system and swallowed. Fine particles of uranium can reach the lower part of the lungs and be trapped or exhaled. Insoluble forms of uranium remain in the lungs, while soluble forms are transferred into the blood stream. About 10% of the uranium uptake in the lungs are initially concentrated in the kidneys. Most of the ingested uranium passes through the body. The primary target of uranium is the kidneys, with a small fraction remaining in the bones, and other soft tissue (EPA, 2014b). In high enough concentrations, uranium has more health effects than radiological effects due to chemical toxicity and it can cause kidney failure (IAEA, 2022). In humans, there is evidence that kidney damage caused by occupational uranium overexposure can eventually heal after the excessive exposure ends (Hursh and Spoor, 1973). In cases of acute exposure, both the chemical and radiological consequences should be evaluated.

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

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[8] Alpha particles consist of two protons and two neutrons.

[9] Gamma Radiation are waves of pure energy.

tissue and the relative biological effect of that absorbed radiation. Radiation dose takes into account the variety of biological effects induced by different types of radiation. Organs in the body have different levels of susceptibility to radiation damage and different isotopes tend to concentrate in different organs. All of these effects are taken into account when setting dose limits for radiological workers and members of the public. An average person in the U.S. is exposed to approximately 0.62 rem per year from 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 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. A dose of 0.62 rem per year has not been shown to cause harm to humans, including children and other sensitive populations (NRC, 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 allows more cosmic radiation to be absorbed. 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, 2014a).

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, 2014a) and the facilities where the DRACO spacecraft would be assembled and stored are controlled-access buildings and secure installations.

Prior to DRACO launch approval, the DOD would develop a comprehensive set of plans to ensure that any mission mishap would be met with a well-developed and tested response. These plans would be 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 would 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 direction. Prior to each 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., the DOD 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 a mission mishap, DOD coordinates with the U.S. Department of Homeland Security, 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 the DRACO reactor components would be 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 HALEU or reactor fission products during the DRACO mission. Additional details are located in the DRACO NEPA Consequence Analysis (Appendix 3.1A). The concept of a maximally exposed individual[10] (MEI) is used to evaluate the 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 set by the EPA, OSHA, and the White House (regulations listed below). The threshold for evaluating the intensity of potential impacts from radiation exposure is based on known exposure limits and established radiation exposure standards, including:

- National Security Presidential Memorandum-20 (NSPM-20), *Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems* (White House, 2019)
- 10 CFR Subpart 20.1301, “Dose Limits for Individual Members of the Public”
- 40 CFR Part 190, “Environmental Radiation Protection Standards for Nuclear Power Operation*s”*
- 29 CFR Subpart 1910.1096, “Ionizing radiation”

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 DRACO Mission, Defense Advanced Research Projects Agency

Impact	Description
No Impact	No potential for radiation exposure.
Negligible	Impacts from radiation exposure would be very small (less 0.025 rem MEI exposure) or beyond extremely unlikely (less than a 1-in-1,000,000 probability of occurrence).
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 or for a short time after the launch Permanent–would continue beyond the launch

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[10] 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).

TABLE 3.1-2

NEPA Impact Thresholds for Radiation Exposure

Environmental Assessment for DRACO Mission, Defense Advanced Research Projects Agency

MEI Exposure (Member of the Public) [b]	**Probability of Airborne Release [a]**			
	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 threshold (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), FAA (2000), and USAF (2019).

3.1.2.1 Proposed Action

A range of possible mission mishap scenarios for each phase of the launch process were evaluated for the DRACO NTR in the DRACO NEPA Consequence Analysis (Appendix 3.1A). These scenarios included prelaunch operations through the end of life and Earth reentry (after centuries in orbit). Many of the mission parameters and the system design have not yet been finalized; therefore, a conservative range of estimates was used to encompass the possible mission mishaps and the reactor response. None of the mission options include the reactor achieving criticality prior to operations in space. As a result, none of the mishap scenarios include the potential for exposure to high levels of radiation or release of radioactive fission products. If the decision is made to proceed with the proposed action, the mission would be further refined, and the design would be finalized. The range of mishaps would be reevaluated as part of the Safety Analysis Report required by NSPM-20 and compared to the estimates provided in this EA. If the updated values result in a higher level of impact threshold (Table 3.1-2), then additional NEPA review would be conducted as necessary.

The most likely outcome of implementing the Proposed Action would be the successful launch of the DRACO spacecraft; this scenario represents the normal operating conditions and would result in **no impact** from the release of HALEU or reactor fission products. To prevent adverse radiological consequences from a launch or system mishap, the reactor would be designed with many engineered safety features as described in Appendix 3.1A, Section 4.

The credible mishap scenarios evaluated in the DRACO NEPA Consequence Analysis (Appendix 3.1 A) result in a maximum dose to the MEI of 0.002 during an early phase launch mishap or 2.4 rem during a late phase mishap or long-term re-entry at the end of mission. There is a potential for a high dose associated with an inadvertent criticality event; however, the DRACO system would be designed to avoid such an event and the probability of its occurrence would be less than 1 in 1,000,000 (Table 3.1-3). Given these combinations of probability and consequence, the effects from radiation exposure after a mission mishap are expected to be **negligible to moderate.** The DOD and NASA would comply with all the established nuclear safety procedures described in Section 3.1.1.4.

TABLE 3.1-3
Summary of Potential DRACO Scenarios
Environmental Assessment for DRACO Mission, Defense Advanced Research Projects Agency

Potential Release Scenario	Conservative Probability of Release	Maximum MEI Dose (rem)	Impact Threshold
Launch mishap	1-in-16	0.002	negligible
Suborbital Flight mishap	1-in-31	2.4	moderate
Inadvertent Criticality	Less than 1-in-1,000,000	0.22 to 460	negligible
Intentional Long-term Reentry (end of life)	15-in-16	2.4	moderate

Notes:

Probability of release conservatively assumes a release of material from any mishap.

Refer to Appendix 3.1A.

3.1.2.2 No Action Alternative

Under the No Action Alternative, the DRACO spacecraft would not be launched; therefore, there would be **no potential effect** from radiation exposure from the mission. However, radiological materials would continue to be used in future missions at KSC and CCSFS; environmental impacts would be evaluated through separate NEPA documentation, as applicable.

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 during pre-launch and launch includes KSC, CCSFS, and the surrounding areas, as shown on Figure 3-1.

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, 2014b).

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 3-1). 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 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.

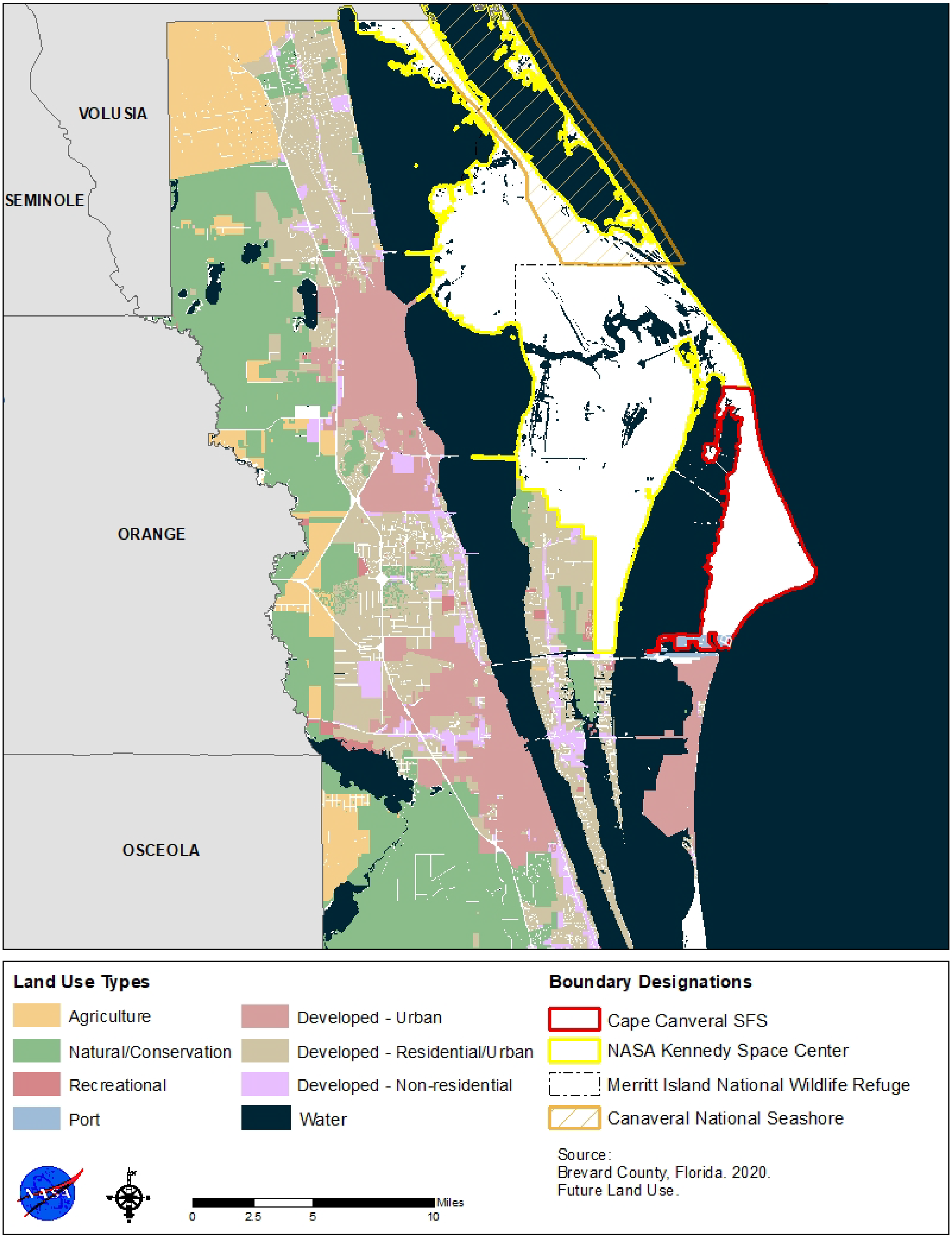
Therefore, USFWS and NPS management is subject to operational requirements defined by NASA, such as temporary closures for launch and landing-related activities (NASA, 2014b).

3.2.1.2 Cape Canaveral Space Force Station

CCSFS includes 66 km^2 (16,198 acres) that support multiple land use types (Figure 3-1), including administrative, airfield operations, industrial, ordnance operations, 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 3-1). 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).



Source:
Brevard County, Florida. 2020.
Future Land Use.

Figure 3-1. Land Cover Types of Surrounding Area

3.2.2 Environmental Consequences

This section identifies potential impacts to land use that may result from implementing either 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 radiological material. 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 DRACO Mission, Defense Advanced Research Projects Agency

Impact	Description
No Impact	No potential for impacts to land use.
Negligible	Impacts to land use would be at the lowest detectable levels.
Minor	Impacts to land use would be detectable, yet temporary, and would not permanently change 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 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, residential areas, and recreational areas would be affected.
Quality:	Beneficial–would have a beneficial effect Adverse–would have an adverse effect
Duration:	Temporary–would occur only during or for a short time after 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 the previously established programs (USAF, 1998, 2000; NASA, 2002, 2011).

A detailed explanation of potential land contamination is provided in Appendix 3.1A. There would be a potential for uranium or fission products to be released into the environment under the combinations of probability and consequence release scenarios (Table 3.2-2). Such releases could result in the deposition of radiological materials on the ground and effect existing land use. The regulatory standard for control of uranium surface contamination on property is 5,000 disintegrations per minute (dpm)/100 cm^2, which is approximately 0.227 microcuries per square meter ($\mu Ci/m^2$) (AEC, 1974; NRC, 1983, 1993), this standard was used as the threshold of concern for this analysis.

The level of surface deposition of uranium resulting from a uranium release (i.e., after a launch mishap or after intentional long-term reentry) is 0.0002 to 0.22 $\mu Ci/m^2$ (refer to Appendix 3.1A). This is below the regulatory limit for contamination of soil or property; therefore, no mitigations related to contamination of soil or property would be required. Land use effects from a non-critical launch mishap or after long-term reentry are expected to be **negligible.**

The probability of an inadvertent criticality event with substantial consequences, or inadvertent reentry after the initiation of criticality is extremely unlikely (Table 3.2-2), though it is difficult to predict where on Earth this may occur. Assuming normal weather conditions during a mishap, the maximum contamination level would be 160 μCi/m^2 (refer to Appendix 3.1A), and the associated emitted gamma radiation would be 0.0044 rem/hour at a distance of approximately 1.5 km. The weather scenario assumes the radioactive material is carried by the wind in a relatively narrow plume and is not deposited evenly throughout the area surrounding of the impact location; therefore, some areas within the plume path would receive much lower than the 160 μCi/m^2 estimate. If the contaminated area was populated, temporary evacuations may be required, to reduce the duration of external exposure or ingestions of deposited material. While the 160 μCi/m^2 is higher than the regulatory standard of 0.227 μCi/m^2, assuming prompt relocation of individuals within the plume path, the potential exposure rates would comply with MEI dose levels shown in Table 3.1-3 (Section 3.1, *Radiation Exposure*). A mission-specific contingency plan would be created for DRACO and appropriate radiological screening and other necessary response actions would be conducted in accordance with the National Response Framework (DHS, 2019).

The fission products produced by the criticality excursion have short half-lives and 99.997% of the deposited radioactivity would decay within a 30-day period. The maximum contamination level would naturally reduce from 160 μCi/m^2 to approximately 0.0051 μCi/m^2, and the emitted gamma radiation would be less than 0.0044 rem/hour. After 30 days, the likely residual radioactivity would be less than 0.02 μCi/m^2, which is below regulatory standards for control of soil or property (AEC, 1974; NRC, 1983, 1993). The emitted gamma radiation level would also be reduced to levels consistent with natural background radiation. This scenario could result in requiring some downwind locations to quarantine up to 30 days or until the radioactive contamination has decayed to background levels.

For the long-term reentry scenario, the surface deposition of the radionuclide mixture would be reduced below regulatory limits at a distance of about 4 km. Ground surface deposition of Pu-239 would be measurable, although very low, and ground surface deposition is assumed to be identical to the uranium fire or explosion scenario for a late mission phase impact.

For agricultural land, specific U.S. Food and Drug Administration (FDA)-derived action levels are applicable to potential contamination of food crops. The potential dose levels from a DRACO accident scenario are below the FDA's criteria for interdiction of foods (FDA, 1998), which are 0.5 rem total effective dose or 5 rem to any organ of the body (refer to Appendix 3.1A for further detail).

The potential for evacuations after an accident scenario must be taken seriously and all partners would be required to follow appropriate regulations and established protocols, in accordance with the mission-specific contingency plan. However, given the combinations of probability and consequences (Table 3.2-2) and the temporary nature of the potential contamination, the land use effects from land contamination are expected to be **minor, temporary, and adverse** both on and off KSC and CCSFS. The DOD would comply with all the established nuclear safety procedures described in Section 3.1.1.4 and would work with local authorities if relocations were required.

TABLE 3.2-2
Summary of Potential DRACO Scenarios–Land Contamination
Environmental Assessment for DRACO Mission, Defense Advanced Research Projects Agency

Potential Release Scenario	Probability of Release	Land Contamination	Impact Threshold
Uranium Release from a launch mishap	1-in-16	0.0002 to 0.22 μCi/m^2	negligible
Inadvertent Criticality	1-in-1,000,000	160 μCi/m^2 (immediate) 0.0051 μCi/m^2 (after 30 days)	minor
Intentional Long-term Reentry (end of life)	15-in-16	0.0002 to 0.22 μCi/m^2	negligible

Note:
Refer to Appendix 3.1A.

3.2.2.2 No Action Alternative

Under the No Action Alternative, the DRACO spacecraft would not be launched; therefore, there would be **no potential effect** to land use from the mission. However, radiological materials 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 during pre-launch and launch include the Atlantic Ocean, the Upper St. Johns River, and the 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 3-2). East of KSC is CCSFS, which 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

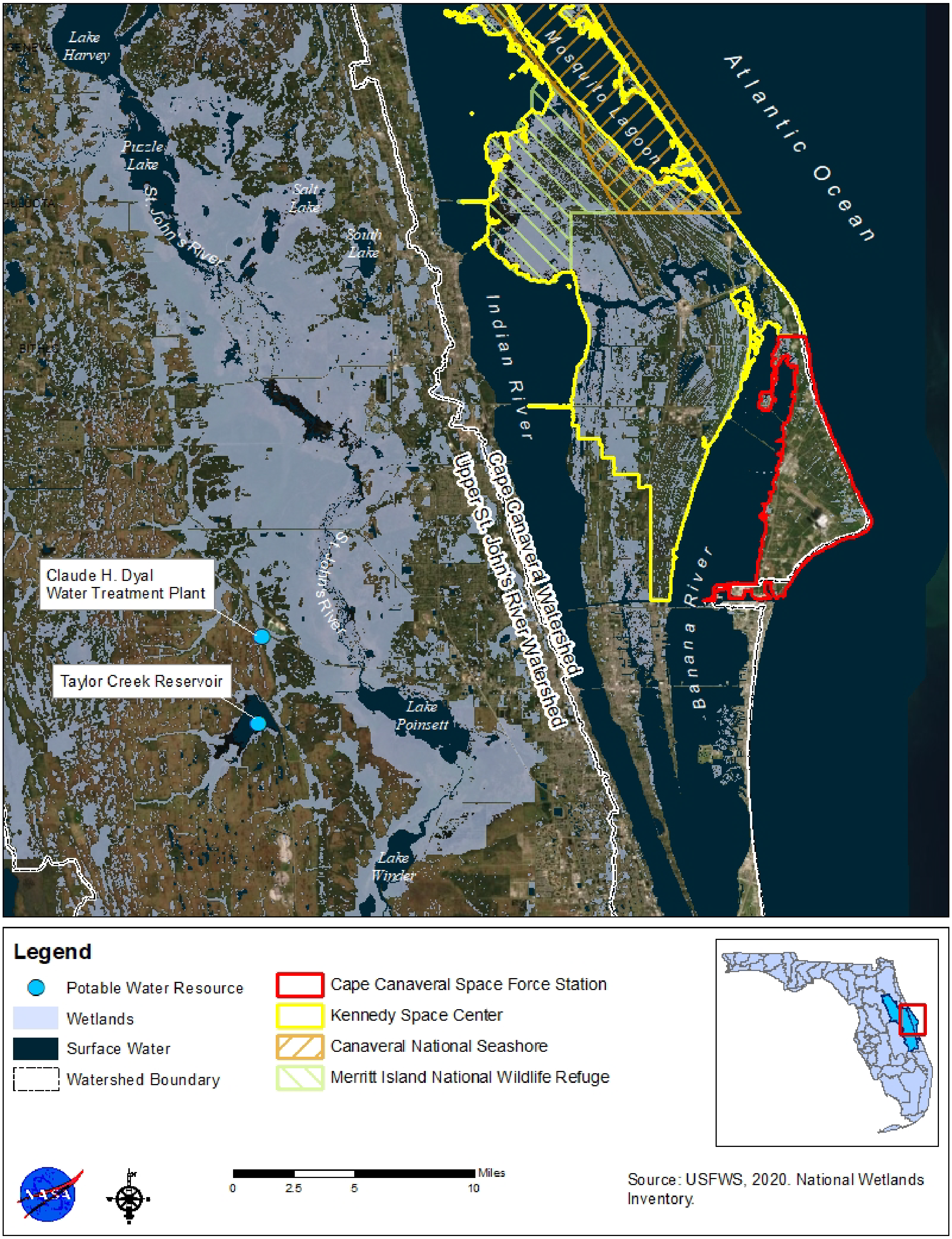
Three aquifers are located within the region of influence. These aquifer layers are not uniform in thickness, and the depths below the ground surface vary throughout the region. The top layer is the surficial aquifer, which is composed of sand, silt, and clay and ranges from approximately 75 to 175 feet (23 to 53 meters) 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 500 feet (0 to 152 meters) in thickness and disappears in a small area near the St. Johns River and west of KSC. The intermediate aquifer begins 75 to 175 feet (23 to 53 meters) 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 75 to 500 feet (23 to 152 meters) 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 400 to 600 feet (122 to 183 meters) 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 drinking 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 3-2.



Source: USFWS, 2020. National Wetlands Inventory.

Figure 3-2. 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 DRACO Mission, Defense Advanced Research Projects Agency

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 resource conditions.
Minor	Impacts to water resources would be detectable but would be within historical hydrologic or acceptable water quality conditions. Historical baseline or desired water quality conditions would be altered temporarily.
Moderate	Impacts to water resources would permanently alter resource conditions but remain within acceptable levels.
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 or for a short time after 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 DRACO mission. The following impacts are evaluated only for the scenarios where radiological material is released during a mission mishap as described in Section 3.1, *Nuclear Radiation*.

Surface Water

For the Proposed Action, a mission mishap that results in the NTR landing in a water body could affect surface water. A major criticality safety design feature, the reactor self-destruct system, is designed to prevent criticality if the reactor accidentally lands in water. Therefore, the consequences of a criticality excursion in water are less severe than a criticality excursion on land (refer to Section 3.2, *Land Use*). As a result, there is limited potential for an adverse health effect for humans and aquatic species, and the potential impacts to surface water are considered **negligible**.

Groundwater

Impacts to the water supply from the three aquifers was evaluated for the Proposed Action. In an accident release scenario, a series of events would have to occur for groundwater contamination. HALEU or fission products would have to be transported to the aquifer via rainfall that mixes with the products, and then percolates into the soil. The surface deposition of HALEU and the fission products would be below regulatory limits after 30 days; levels would become even lower with dilution. The impacts to groundwater are considered **minor, temporary, and adverse**.

Drinking Water

The Taylor Creek Reservoir, operated by the City of Cocoa, and its tributary streams are more than 15 miles west of KSC and CCSFS. In the highly improbable event that HALEU or fission products from a suborbital mishap are carried far enough to reach the reservoir or tributary streams, the Claude H. Dyal Water Treatment Plant process is designed to comply with the EPA drinking water standards (40 CFR Part 141), including the maximum contaminant level of 30 microgram(s) per liter for uranium (EPA, 2022), and monitors for radiation. As a result, the impact from HALEU and fission product exposure to drinking water is **negligible.**

Wetlands

The Proposed Action would have no impacts on wetlands. There would be no cleanup of the wetlands required after surface deposition of HALEU, as the fission products would be below regulatory limits after 30 days. The potential effects to biological organisms within wetlands during the 30-day period is discussed in Section 3.4 Biological Resources.

3.3.2.2 No Action Alternative

Under the No Action Alternative, the DRACO spacecraft would not be launched; therefore, there would be **no potential effect** for water resources from the mission. However, radiological materials 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 during pre-launch and launch 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. These communities include 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 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 designated critical habitat of such species. Species occurring at CCSFS or KSC include 25 federally listed wildlife species and 8 federally listed plant species (Table 3.4-1). Designated critical habitat for two species occurs in the marine environment around CCSF and KSC; however, there is no terrestrial critical habitat on either installation.

The Marine Mammal Protection Act 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 Audubon's crested caracara, eastern black rail, everglade snail kit, Florida scrub jay, piping plover, red knot, red-cockaded woodpecker, roseate tern, and wood stork receive protection under the MBTA.

TABLE 3.4-1

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

Environmental Assessment for DRACO Mission, Defense Advanced Research Projects Agency

Species Type	Common Name	Scientific Name	Federal Status
Reptiles and Amphibians	American Alligator	*Alligator mississippiensis*	Threatened (due to similarity in appearance to the American Crocodile)
Reptiles and Amphibians	Atlantic (Kemp's) Ridley Sea Turtle	*Lepidochelys kempii*	Endangered
Reptiles and Amphibians	Atlantic Green Sea Turtle	*Chelonia mydas*	Endangered
Reptiles and Amphibians	Atlantic Loggerhead Sea Turtle	*Caretta caretta*	Threatened
Reptiles and Amphibians	Atlantic Salt Marsh Snake	*Nerodia clarkii taeniata*	Threatened
Reptiles and Amphibians	Eastern Indigo Snake	*Drymarchon couperi*	Threatened
Reptiles and Amphibians	Hawksbill Sea Turtle	*Eretmochelys imbricata*	Endangered
Reptiles and Amphibians	Leatherback Sea Turtle	*Dermochelys coriacea*	Endangered
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	Atlantic Sturgeon	*Acipenser oxyrinchus*	Endangered
Fishes	Giant Manta Ray	*Manta birostris*	Threatened
Fishes	Nassau grouper	*Epinephelus striatus*	Threatened
Fishes	Oceanic Whitetip Shark	*Carcharhinus longimanus*	Threatened
Fishes	Smalltooth Sawfish	*Pristis pectinata*	Endangered
Birds	Audubon's Crested Caracara	*Polyborus plancus audubonii*	Threatened
Birds	Bald Eagle	*Haliaeetus leucocephalus*	Protected under the Bald and Golden Eagle Protection Act

Species Type	Common Name	Scientific Name	Federal Status
Birds	Eastern Black Rail	*Laterallus jamaicensis*	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
Plants	Carter’s Mustard	*Warea carteri*	Endangered
Plants	Beach Jacquemontia	*Jacquemontia reclinata*	Endangered
Plants	Four-petal Pawpaw	*Asimina tetramera*	Endangered
Plants	Florida Perforate Lichen	*Cladonia perforata*	Endangered
Plants	Lakela’s Mint	*Dicerandra immaculata*	Endangered
Plants	Lewton’s Polygala	*Polygala lewtonii*	Endangered
Plants	Tiny Polygala	*Polygala smallii*	Endangered
Insects	Monarch Butterfly	*Danaus plexippus*	Candidate for listing

Source: USFWS, 2023; 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 DRACO Mission, Defense Advanced Research Projects Agency

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 result in permanent changes to habitats.
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 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. Impacts would appreciably alter resource conditions and could affect regional population stability.

Impact	Description
Quality:	Beneficial–would have a beneficial effect Adverse–would have an adverse effect
Duration:	Temporary–would occur only during or for a short time after 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 DRACO mission as there would be no release of radiological material.

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 HALEU or fission products are considered minor to general human populations (Section 3.1, *Nuclear Radiation*), impacts to wildlife from the DRACO mission are also expected to be **negligible to moderate**.

As discussed in Section 3.2, *Land Use,* and Section 3.3, *Water Resources*, no permanent impacts to aquatic or terrestrial ecosystems would be expected, because the surface deposition of HALEU and fission products would naturally degrade to acceptable levels within 30 days after a mishap. Therefore, the impacts to the surrounding habitats from land and water contamination are considered **negligible**.

3.4.2.2 No Action Alternative

Under the No Action Alternative, the DRACO spacecraft would not be launched; therefore, there would be **no potential effect** to biological resources from the mission. However, radiological materials 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 during pre-launch and launch is KSC and CCSFS. Federal agencies are required to ensure that cultural resources are considered in all of their undertakings and that historic properties 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 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 site, district, building, structure, or object listed in, or eligible for listing in, 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 because of their roles in current and previous space programs.

The ARPA forbids anyone from excavating or removing archeological 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 archeological 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 archeological resources include pottery, basketry, weapons, and tools.

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 DRACO Mission, Defense Advanced Research Projects Agency

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.
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 any 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 any 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 any 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 or for a short time after 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 DRACO mission. However, there is a potential for radiological material to be released into the environment under a mishap 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 radiological material as defined in Section 3.2, *Land Use*. DARPA will informally consult with the Florida SHPO regarding the Proposed Action. The NHPA Section 106 consultation documents can be found in Appendix 1.6A.

Archeological Sites

The potential of impacting a known or unknown archeological site present in a contaminated area is limited. As explained in Section 3.2, *Land Use*, the surface deposition of HALEU and fission products (after 30 days) is below regulatory limits, and cleanup activities would not require the excavation of soil on a NRHP-listed or eligible archeological resource. **No impacts** to archeological sites are expected.

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 DRACO spacecraft could be launched. Potential effects to cultural resources after a mission mishap have been studied in detail in previous EAs and EISs for KSC and CCSFS (NASA, 1994, 1997, 2002, 2005, 2014b, 2020a). As explained in Section 3.2, *Land Use*, the surface deposition of HALEU and fission products (after 30 days) is below regulatory limits and there would be no potential cleanup activities on the exterior of structures. **No impacts** to historic sites are expected.

3.5.2.2 No Action Alternative

Under the No Action Alternative, the DRACO spacecraft would not be launched; therefore, there would be **no potential effect** to cultural resources from the mission. However, radiological materials 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 and Waste

Hazardous materials and hazardous waste are regulated pursuant to a number of environmental statutes, including the Comprehensive Environmental Response, Compensation, and Liability Act, the Resource Conservation and Recovery Act, the Clean Water Act, the Clean Air Act, and the Toxic Substances Control Act. Hazardous materials and hazardous wastes are substances that, because of their quantity, concentration, or physical, chemical, or infectious characteristics, may present substantial danger to human health or the environment when discharged into the environment or when improperly treated, stored, transported, or disposed of. Numerous types of hazardous materials are used to support missions and conduct general maintenance operations at KSC and CCSFS; however, previous EAs and EISs have analyzed the impacts associated with the use of these hazardous materials and resulting wastes for launches and found no significant impacts (NASA, 1994, 1997, 2002, 2005, 2011, 2014b, 2020a). Therefore, they are not considered in further detail in this EA. The hazardous materials unique to the Proposed Action may include uranium as a chemical hazard, beryllium, and lithium hydride. The regions of influence for hazardous materials during pre-launch and launch are the LCs at KSC and the SLCs at CCSFS.

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. Management 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, preclude unnecessary exposure to personnel, and limit exposure to levels as low as reasonably achievable (KSC, 2009, 2016).

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 NRC 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. DRACO's reactor would be compatible with these range safety requirements (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 DRACO Mission, Defense Advanced Research Projects Agency

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 releases of hazardous materials or solid waste could be remediated by onsite personnel.
Moderate	Impacts from the use of hazardous materials would be measurable. Onsite personnel would not be able to remediate releases of hazardous materials or solid waste and offsite personnel would assist with remediation.
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 or for a short time after 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 handling and safeguarding hazardous materials, including nuclear material. Nuclear material that is proposed for use as part of a space nuclear system is managed in accordance with all applicable safety requirements of the DOE and NRC. As noted in Sections 3.6.1.1 and 3.6.1.2, both KSC and CCSFS have robust radiation protection programs that ensure effective and protective storage, transportation, and handling safeguards are in place to minimize any risk of nuclear material being released into the environment throughout a launch evolution. 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 potential effect** from the use of hazardous materials from the DRACO mission.

A detailed explanation of potential non-nuclear hazardous materials is provided in Appendix 3.1A. There would be a potential for up to 297 kg of uranium, which may be toxic as a chemical hazard, to be released into the environment under the combinations of probability and consequence release scenarios (Table 3.6-2). The atmospheric dispersion parameters used to model uranium radiation doses were used to calculate conservative estimates of potential intake and concentrations of chemical uranium in air. Occupational dose limits in 10 CFR Subpart 20.1201 also include a limit for the intake of soluble chemical uranium of 10 milligrams (mg) per week. The modeled intake for a uranium fire accident in the early and late phases of the mission ranges from 0.01 to 7 mg of uranium. These values are less than the 10 mg limit for intakes of uranium, which is the standard used as the threshold of concern for this analysis.

Although the quantity of beryllium is not known at this time, it was assumed to be equal to the quantity of uranium (approximately 297 kg) and evaluated under the combinations of probability and consequence release scenarios (Table 3.6-2). The exposure standards in 29 CFR Subpart 1910.1024 include a short-term exposure limit (STEL) for beryllium of 2 micrograms per cubic meter (µg/m^3) based on a 15-minute exposure period. The calculated air concentration for beryllium in a uranium fire during the early mission phases was 0.025 µg/m^3; this concentration is equivalent to a 15-minute time-weighted average of 0.02 µg/m^3, which is below the STEL. The corresponding equivalent time-weighted average for a uranium fire accident in the late stages of the launch is 20 µg/m^3, which is above the STEL for a brief time period.

Although the quantity of lithium hydride is not known at this time, it was assumed to be equal to the quantity of uranium (approximately 297 kg) and evaluated under the combinations of probability and consequence release scenarios (Table 3.6-2). For lithium hydride, the regulatory basis in 29 CFR Subpart 1910.1000 includes an occupational PEL of 25 µg/m^3 based on a time-weighted average over an 8-hour period. The calculated air concentration for lithium hydride in a uranium fire during the early mission phases was 0.17 µg/m^3; this concentration is equivalent to an 8-hour time-weighted average of 0.004 µg/m^3, which is below the PEL. The corresponding equivalent time-weighted average for a uranium fire accident in the late stages of the launch is 4 µg/m^3, which is below the PEL.

The potential for evacuations after an accident scenario must be taken seriously and all partners would be required to follow appropriate regulations and established protocols in accordance with the mission-specific contingency plan. However, given these combinations of probability and consequences (Table 3.6-2) and the temporary nature of the exposure, the non-radiological effects from hazardous materials are expected to be **negligible to moderate, temporary, and adverse** both on and off KSC and CCSFS. The DOD would comply with all established safety procedures described in Section 3.1.1.4 and would work with local authorities, if required.

TABLE 3.6-2
Summary of Potential DRACO Scenarios–Hazardous Materials
Environmental Assessment for DRACO Mission, Defense Advanced Research Projects Agency

Potential Release Scenario	Probability of Release	Exposure	Impact Threshold
Uranium Release from a Launch Mishap	1 in 16	0.01 to 7 mg/week	negligible
Uranium Release after Long-term Reentry (end of life)	15 in 16	7 mg/week	negligible
Beryllium Release from a Launch Mishap	1 in 16	0.02 to 20 µg/m^3 (15-minute)	moderate
Beryllium Release after Long-term Reentry (end of life)	15 in 16	20 µg/m^3 (15-minute)	moderate
Lithium Hydride Release from a Launch Mishap	1 in 16	0.17 to 4 µg/m^3 (8-hour time-weighted average)	negligible
Lithium Hydride Release after Long-term Reentry (end of life)	15 in 16	4 µg/m^3 (8-hour time-weighted average)	negligible

Note:
Refer to Appendix 3.1A.

3.6.2.2 No Action Alternative

Under the No Action Alternative, the DRACO spacecraft would not be launched; therefore, there would be **no potential effect** from the use of hazardous materials from the mission. However, radiological materials 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 1508.1(g)(3) 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 can result from individually minor, but collectively significant, actions taking place over a period of time.

At a local scale, other sources of radioactivity are present from the St. Lucie Nuclear Power Plant on South Hutchinson Island near Port St. Lucie, Florida, approximately 160 km (100 miles) directly south of CCSFS. The NRC 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 (NRC, 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 also minimal. It is reasonably foreseeable that NASA and USSF may propose to conduct other missions containing space nuclear systems such as radioisotope heater units or multi-mission radioisotope thermoelectric generators. However, in the highly unlikely event that one of these future missions results in a mishap that releases nuclear material into the environment, the DRACO mission, given its extremely low risk of adverse environmental impacts, would not add to the overall cumulative effects in the region of influence. These launches would not be scheduled to occur at the same time or after a mission mishap.

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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 include the successful launch of DRACO. For radiological material to be released, multiple failures would have to occur and DRACO's reactor would have to be exposed to an extreme condition; this scenario is referred to as the "Mission Mishap Scenario" in Table 4-1.

TABLE 4-1
Summary of Potential Impacts and Proposed Mitigation Measures
Environmental Assessment for DRACO Mission, Defense Advanced Research Projects Agency

Resource Category	Proposed Action: Normal Operating Conditions	Proposed Action: Mission Mishap Scenario	No Action Alternative	Measures to Minimize Impact
Nuclear Radiation	No impact	Negligible to moderate impacts to the public.	No impact	Follow established radiation procedures, as described in Section 3.1.1.4, *Established Nuclear Safety Procedure*s. Avoid initiating the DRACO reactor until a safe orbit has been reached.
Land Use	No impact	Negligible to minor impacts to land use.	No impact	Coordinate any relocation 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. Avoid initiating the DRACO reactor until a safe orbit has been reached.
Water Resources	No impact	Minor impacts to groundwater. Negligible impacts to surface and portable water. No impacts to wetlands.	No impact	Undertake the appropriate radiological screening and other necessary response actions, in accordance with a mission-specific contingency plan. Avoid initiating the DRACO reactor until a safe orbit has been reached.
Biological Resources	No impact	Negligible to moderate impacts to wildlife species, including protected species. Negligible impacts to habitat.	No impact	Not applicable.
Cultural Resources	No impact	No impacts to cultural sites.	No impact	Not applicable.
Hazardous Materials	No impact	Negligible to moderate 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	Not applicable.

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SECTION 5

Distribution

Although DRACO was the lead federal agency for this EA, NASA, DOE/NNSA 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 Kennedy Space Center
- NASA Marshal Space Flight Center
- DOE/NNSA
- US Department of Air Force Headquarters
- USSF SLD 45 – CCSFS
- USSF Space Systems Command
- USFWS
- Florida Department of Environmental Protection 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
- NASA Headquarters Library

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SECTION 6

List of Preparers

The primary persons responsible for preparing and reviewing this report are listed in Table 6-1.

TABLE 6-1
List of Preparers
Environmental Assessment for DRACO, Defense Advanced Research Projects Agency

Name	Role	Experience
Michelle Rau, PMP	NEPA Project Manager	M.S., Business Administration; B.S., Ecology and Evolutionary Biology; 25 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	NEPA Lead	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; 5 years of experience
Michael Witmer, EIT	Radiation Engineer	M.S., Environmental Engineering; B.S., Civil Engineering; 5 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 1.5A

Comments Received on the Draft EA and Response to Comments

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
SAM NUNN ATLANTA FEDERAL CENTER
61 FORSYTH STREET, SW
ATLANTA, GEORGIA 30303-8960

October 10, 2023

Dr. Tabitha Dodson
Program Manager, DARPA
675 North Randolph Street
Arlington, VA 22203-2114

Re: EPA Comments on the Draft Environmental Assessment for the Demonstration Rocket for Agile Cislunar Operations Mission at Cape Canaveral Space Force Station and Kennedy Space Center, Brevard County, Florida

Dear Dr. Dodson:

The U.S. Environmental Protection Agency (EPA) reviewed the Defense Advanced Research Projects Agency's (DARPA) Draft Environmental Assessment (EA) for the Demonstration Rocket for Agile Cislunar Operations (DRACO) Mission, in accordance with Section 309 of the Clean Air Act and Section 102(2)(C) of the National Environmental Policy Act (NEPA). The CAA Section 309 role is unique to the EPA. It requires the EPA to review and comment publicly on any proposed federal action subject to NEPA's environmental impact statement requirement and make its comments public.

The purpose of this program is to demonstrate an operable Nuclear Thermal Propulsion (NTP) spacecraft by providing a system that has the potential to achieve high thrust-to-weight ratios similar to in-space chemical propulsion with two-to-three times greater efficiency. DARPA is the lead federal agency for the preparation of the EA. The National Aeronautics and Space Administration, the United States Space Force, and the National Nuclear Security Administration are participating with DARPA as cooperating agencies.

DARPA prepared the EA to evaluate potential environmental impacts from proposed assembly, testing, launch, demonstration operations, and decommissioning that would make up the DRACO program. The EA also analyzes the No-Action Alternative. Vandenberg Space Force Base (SFB) in California was considered as an alternative launch site for DRACO, as it the only other launch site with facilities to support nuclear-enabled payloads. Vandenberg SFB was eliminated from further analysis because the DRACO launch would need to avoid traversing above populated areas while targeting an eastward trajectory.

Under the Proposed Action, DARPA would conduct pre-launch assembly, testing, and delivery of the DRACO spacecraft to Cape Canaveral Space Force Station (CCSFS) or Kennedy Space Center (KSC). The DRACO launch would occur no earlier than 2027. DARPA will select a space launch vehicle that has previously been assessed under NEPA for launch from CCSFS or KSC. After achieving safe orbit, the DRACO NTP system would be activated and evaluated. At the end of the DRACO program, the spacecraft and its reactor would be decommissioned and left in an orbit that will allow for sufficient decay of radioactive fuel.

The EPA understands that DARPA's preferred alternative is the Proposed Action. The EPA has not identified any significant impacts from the Proposed Action that would require substantive changes to the EA. The EPA has enclosed detailed technical comments for your consideration (See enclosure).

The EPA appreciates the opportunity to review the Draft EA for the DRACO Program. If you have questions regarding our comments, please contact Douglas White, Project Manager in the NEPA Section at white.douglas@epa.gov, or at 404-562-8586.

Sincerely,

Kajumba,
Ntale

Digitally signed by
Kajumba, Ntale
Date: 2023.10.10
17:46:58 -04'00'

Ntale Kajumba
NEPA Section Manager

Enclosure

Enclosure

EPA Comments on the Draft Environmental Assessment for the Demonstration Rocket for Agile Cislunar Operations Mission, Brevard County, Florida

(1) **Nuclear Radiation Exposure:** Section 3.1.1.1, *Radiation and Uranium,* states that the primary energy source for DRACO is High Assay Low-Enriched Uranium (HALEU). Nuclear fission of HALEU fuel heats hydrogen that accelerates from a nozzle and provides propulsion for the spacecraft. DRACO's reactor would be held in a subcritical state during payload handling, shipment, integration, and launch. Radiation-producing power operation would not occur until DRACO has achieved a predefined safe orbit, which is when the reactor would be turned on and the propulsion for the spacecraft would be demonstrated. The final project phase, referred to as in-space decommissioning, would occur after the demonstration phase and would be conducted in accordance with Presidential Memorandum on the National Strategy for Space Nuclear Power and Propulsion Space Policy Directive 6. In-space decommissioning would ensure the reactor is left in the sufficiently high orbit chosen for the demonstration phase or a higher orbit. The EA states that final mission parameters will be evaluated by a Safety Analysis Report as required by the National Security Presidential Memorandum-20 (NSPM-20) and compared to the EA's analysis that has determined that credible mishap scenarios would result in effects that are negligible to moderate.

Recommendation: In accordance with Section 3.1.2.1 of the EA, the EPA recommends compliance with NSPM-20, including determination of the likelihood of an accident resulting in an exposure in excess of 0.025 Roentgen Equivalent Man (REM) Total Effective Dose (TED) to members of the public. The EPA also recommends that DARPA make the Safety Analysis Report available to the public.

***Response**:*
The project will comply with NSMP-20. Additionally, the Mission Safety Analysis Report (MSAR) will contain information on the DRACO nuclear thermal rocket design which is Controlled Unclassified Information (CUI) and marked according to International Traffic in Arms Regulations (ITAR) and the Export Administration Regulations (EAR). Therefore, the MSAR as written will not be publicly releasable.

(2) **Environmental Justice:** Executive Order 12898 directs federal agencies to identify and address the disproportionately high and adverse human health and environmental effects of their actions on minority and low-income populations, to the greatest extent practicable and permitted by law. The EA states that DARPA used the EPA's EJScreen mapping tool to assess potential environmental justice concerns and determined that there is no disproportionate presence of communities with environmental justice concerns near the Proposed Action.

Recommendation: The EPA recommends that DARPA coordinate with Brevard County and communities near the project area to address impacts as they are identified and to disseminate project status updates. Consistent with Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations.* and Executive Order 14096, *Revitalizing Our Nation's Commitment to Environmental Justice for All*, please ensure protected populations are not disproportionately or adversely impacted by the project.

***Response**:*
As stated in Section 2.4.2, the Proposed Action would not disproportionately impact minority and low-income populations.

DARPA would follow the established outreach processes for CCSFS launches.

(3) Biological Resources: Table 3.4-1 indicates that there are 34 federal and state listed species with the potential to be present at CCSFS and KSC, including birds, sea turtles, reptiles, amphibians, and mammals. The EPA understands that DARPA has coordinated with the U.S. Fish and Wildlife Service (USFWS) and determined that formal consultation is not needed.

Recommendation: The EPA principally defers to the USFWS and the National Marine Fisheries Service (NMFS) regarding compliance with the Marine Mammal Protection Act and Endangered Species Act. The EPA recommends that any additional conservation measures identified by USFWS and NMFS be implemented.

***Response**:*
It was determined that formal Section 7 consultation was not necessary, given the remote possibility of effects on endangered species.

(4) Water Resources: The Proposed Action is primarily located on developed land between the Banana River and the Atlantic Ocean with onsite wetlands that flow to the Banana River. Section 3.3.1.2, *Groundwater,* identifies the boundaries of the three aquifer systems located within the region of influence of the Proposed Action and the primary location of municipal drinking water wells for Brevard County. The Claude H. Dyal water treatment plant and Taylor Creek Reservoir are located approximately 15-miles west of CCSFS and KSC. The EA states that the DRACO reactor is designed to prevent criticality if the reactor lands in water. In the event of a system failure, the surface deposition of HALEU and the fission products would be below regulatory limits after 30 days and levels would become even lower with dilution. DARPA has determined that potential impacts to groundwater are minor and temporary. According to the most recent EPA-approved Clean Water Act (CWA) Section 303(d) list for Florida (July 11, 2022), there are impaired waterbodies (e.g., Banana River) that receive waters from CCSFS and KSC. Section 2.1.4, *Onsite Construction*, states that there is no anticipated need for construction or other activities that may require surface disturbance of the otherwise undisturbed land associated with the Proposed Action at either CCSFS or KSC complex.

(5) Air Quality: The Proposed Action is located in Brevard County, Florida which is in attainment with the National Ambient Air Quality Standards. The EA identifies previous NEPA analysis of launch activities from CCSFS and KSC that have determined that no significant impacts are associated with the launch of rockets that will potentially be used for the DRACO launch.

Appendix 1.6A
National Historic Preservation Act Consultation Documents

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DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
675 NORTH RANDOLPH STREET
ARLINGTON, VA 22203-2114

22 July 2023

Tabitha Dodson, PhD, PhD
DRACO Program Manager
571-384-9739
tabitha.dodson@darpa.mil

MEMORANDUM FOR: Florida State Historic Preservation Office (SHPO)

FROM: Tabitha Dodson, PhD, PhD
DRACO Program Manager

SUBJECT: National Historic Preservation Act Section 106 Consultation for the Demonstration Rocket for Agile Cislunar Operations (DRACO) Program

1. The Defense Advanced Research Projects Agency (DARPA) requests your concurrence on a "no adverse effect" determination for National Register of Historic Places (NRHP) listed and eligible sites from the launching of the DRACO spacecraft from the United States Space Force (USSF) Cape Canaveral Space Force Station (CCSFS) or the National Aeronautics and Space Administration (NASA) Kennedy Space Center in Brevard County, Florida in 2027; however, the launch schedule is subject to change.

2. DARPA has prepared an environmental assessment (EA) per the National Environmental Policy Act (NEPA) regulations at 40 Code of Federal Regulations for the DRACO Mission. DARPA is the lead federal agency for this EA, and the Department of Energy's National Nuclear Security Administration (NNSA), National Aeronautics and Space Administration (NASA), and the US Space Force (USSF), are cooperating agencies. The EA analyzes the environmental effects of launching the DRACO spacecraft. The goal of the DRACO program is to demonstrate an operable nuclear thermal propulsion (NTP) system. NTP uses a nuclear reactor to heat propellant to temperatures in the range of 3,600 to 5,400 degrees Fahrenheit before expelling the hot propellant through a nozzle, thereby producing thrust. Compared to chemical space propulsion technologies, NTP offers two-to-three times greater efficiency at comparable thrust.

3. Through the environmental review process, DARPA has determined that there would be no impacts to NRHP-listed or eligible sites at CCSFS or KSC from a successful launch. The only potential risk to NRHP-listed and eligible sites relate to the potential cleanup activities that would occur after a launch mishap. As explained in Section 3.1 *Nuclear Radiation Exposure* of the EA, all of the potential mishap scenarios, which would require cleanup, have a probability considerably less than 1 in 1,000,000 (Table 3.1-3 in the EA).

4. Furthermore, as explained in Section 3.2, *Land Use* of the EA, the surface deposition of HALEU and fission products (after 90 days) is below regulatory limits, and cleanup activities would not require the excavation of soil on a NRHP-listed or eligible archeological resource. Consequently, the

potential for impacting a known or unknown archeological site present in a contaminated area is limited.

5. We appreciate your review and concurrence of this proposed action. A copy of the EA is provided with this letter. The US Space Force is a cooperating agency for this project and Taylor Janise, NEPA Program Manager, Cape Canaveral Space Force Station, may also be contacted on this matter. Taylor Janise can be reached by telephone at 321-853-6638 or via e-mail at taylor.janise.1@spaceforce.mil. NASA is also a cooperating agency for this project and Donald Dankert, Kennedy Space Center NEPA Manager, may also be contacted on this matter. Donald Dankert can be reached at 321-861-1196 or via email at donald.j.dankert@nasa.gov. Please feel free to contact either Taylor Janise, Donald Dankert, or me (contact information above), if you have any questions or concerns.

Signed

______________________________ Date___22 July 2023___
Dr. Tabitha Dodson, PhD
Program Manager
DARPA TTO

Appendix 3.1A
DRACO NEPA Consequence Analysis

If you need help accessing this document, please contact us at michelle.rau.ctr@darpa.mil.

Appendix 3.1A: DRACO NEPA Consequence Analysis

Defense Advanced Research Projects Agency
675 North Randolph Street Arlington, VA
22203-2114

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Executive Summary

The Defense Advanced Research Project Agency (DARPA) seeks to develop, build, and conduct an in-space flight demonstration of a nuclear thermal rocket (NTR), as part of the Demonstration Rocket for Agile Cislunar Operations (DRACO) program. Compared to conventional space propulsion technologies, nuclear thermal propulsion (NTP) offers a thrust-to-weight ratio approximately 10,000 times greater than electric propulsion and two-to-three times greater propellent efficiency than conventional chemical propulsion. This improved efficiency is important for conducting missions that would support a human presence on the moon or on Mars, and advanced maneuver and logistics missions, for example. These propulsion attributes would enable missions otherwise impractical for conventional chemical rockets. The current design includes the use of High Assay Low Enrichment Uranium (HALEU) fuel. The HALEU fuel has a slightly higher enrichment of uranium-235 (U-235) compared to conventional nuclear power reactors, but a lower enrichment of U-235 as compared to historical NTRs.

The plans for the DRACO mission include engineering development of an NTR and its host platform that would notionally be placed in a 2,000-kilometer (km) high orbit for testing. The testing orbit would be calculated to minimize the risk to Earth of debris that might be created if there was an accident during testing and to allow for decay of fission and activation products created during testing. The NTR would contain the original uranium fuel inventory and a residual amount of activation and fission products from the testing at the time of eventual reentry.

The safety guidelines incorporated in the launch safety criteria in National Security Presidential Memorandum (NSPM)-20 are doses to an individual member of the public (the maximally exposed individual [MEI]) as measured in total effective dose (TED). The TED, calculated in units of Roentgen Equivalent Man (rem), is a measure of the biologically equivalent hazard associated with ionizing radiation energy deposited in human tissues. To prevent adverse radiological consequences, the DRACO mission is designing the following safety features for the reactor:

- The reactor would not be operated at power prior to launch, so that fission and activation products are not present in the inventory until the NTR begins test operations in a sufficiently high test orbit
- Neutron-absorbing materials, often referred to as reactor poisons, decrease the reactivity of the initial fuel load and are intended to prevent inadvertent criticality during the assembly activities and transportation
- A reactor destruct system that destroys the geometry of the reactor core during a launch or orbital accident, preventing inadvertent criticality on impact with the surface of the Earth
- A reactor control system that ensures proper startup and operations of the reactor
- Operation in a sufficiently high orbit to prevent premature reentry of the reactor or debris from power testing mishaps
- Spacecraft controls that prevent deorbiting the spacecraft or debris from mishaps during thrust testing
- The mission design limit for criticality during an accident that causes the reactor to impact the surface of the Earth is less than 1 event in 1,000,000 missions (a 99.9999% probability of criticality prevention during the mission)

The DRACO mission is committed to using and testing the safety features that would ensure compliance with the following exposure limits and established radiation exposure standards:

- National Security Presidential Memorandum-20 (NSPM-20), *Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems* (White House, 2019)

- *Code of Federal Regulations* (CFR) Title 10, Part 20.1301, "Dose Limits for Individual Members of the Public"
- 40 CFR Part 190, "Environmental Radiation Protection Standards for Nuclear Power Operation*s"*
- 29 CFR Part 1910.1096, "Ionizing radiation"

Some mission parameters that are important to safety are:

- A reactor design that prevents criticality in the event of an accidental impact at the surface of the Earth
- A reactor self-destruct system that would disrupt reactor geometry prior to an accidental impact during a launch failure
- A sufficiently high orbit for testing
  - Long-term storage in orbit of hundreds of years
  - Natural radioactive decay of fission or activation radionuclides prior to reentry
- Spacecraft control system to prevent accidental deorbiting during testing

The potential early launch cycle accidents involved in the safety evaluations of the DRACO mission include mishaps that are common to space missions and accidents that are related to the nuclear reactor. The major accident types and their associated mitigations for DRACO are described as follows:

1. Potential accidents associated with DRACO, such as fires, explosions, and ground impacts early in the launch cycle, are similar to standard space missions and have relatively low radiological consequences, because the initial radioactive inventory in the DRACO reactor is solely unirradiated uranium. Potential early-stage fires or explosions (without criticality) have mean dose consequences below the 25 millirem threshold for evaluation in NSPM-20 or the National Aeronautics and Space Administration (NASA) National Environmental Policy Act (NEPA) Handbook.
2. Inadvertent criticality is the predominant accident concern prior to the reactor and spacecraft reaching the test orbit. Inadvertent criticality is avoided by designing the reactor to survive ground impacts without causing a large reactivity insertion. The spacecraft would be equipped with a self-destruction system that would explosively alter the physical configuration of the reactor to prevent criticality if a launch accident results in loss of control of the launch vehicle or spacecraft prior to reaching orbit. Inadvertent criticalities in a launch accident have mean dose consequences below the 25-rem threshold of concern in NSPM-20 or the NASA NEPA Handbook.
3. The major criticality safety design challenge is preventing criticality if the reactor lands in water at the end of the mission. The reactor self-destruct system is designed to prevent criticality on land or in water prior to conducting the demonstration test in a high orbit. The reactor self-destruct system would be disabled prior to testing the reactor in a high orbit. The reactor core is designed to land intact at the end of the mission. An impact on land would likely deform the core in such a way that the reactivity is decreased, and criticality is less likely than the case of the intact geometry. The scenario of a water landing at the end of the mission is the major design challenge for meeting the NSPM-20 criterion of a probability less than 1 in 1,000,000 for the mission. The consequences of a criticality excursion in water are less severe than a criticality excursion on land because the population density of the oceans is very small.
4. Accidents during operation in space are expected to be dominated by accidents that could damage the reactor during startup and create debris. The spacecraft systems that support spaceflight are reliable and proven systems that have evolved from decades of spaceflight experiences. The reactor is a unique system that has not previously operated in space. The probabilities of mishaps that interfere with the mission are highest for scenarios that involve the reactor. Accidents that prevented the testing of the reactor would not create consequences that are outside the magnitude of the eventual reentry

scenarios. The reactor control system mitigates potential reactor accidents in space by minimizing the possibility of inadvertent operation of the reactor. The reactor startup process would likely involve gradual increases in power that mitigate thermal or mechanical failures of the reactor or propulsion system. In the event of a mishap, the decay of radioactive material in orbit prior to reentry would reduce the amount of radioactive material that enters the Earth's atmosphere. Depending on the nature of the specific accident, the most likely consequences would be below 25 rem to an individual.

5. The most likely result of the mission is the reactor would return to Earth after hundreds of years of natural orbital decay and radionuclide decay with an inventory of radioactive material similar to the initial core fuel load. The reactor core would be heated during reentry and the calculated radiation dose to a member of the public from a release of uranium following a land impact scenario at the end of the mission is 2.4 rem. If a land impact resulted in an accidental criticality, the calculated radiation dose to a member of the public is 460 rem. However, the reactor core would be designed to have a probability of less than 1 in 1,000,000 for this event, which is considered beyond extremely unlikely. The calculated uranium release for a water impact is similar to a land impact, but the population density of the Earth's oceans is very low and the probability of an actual exposure to a member of the public is negligible. The calculated criticality release for a water impact is similar to a land impact, but exposure to an actual person is beyond extremely unlikely.

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Acronyms and Abbreviations

Acronym	**Definition**
$\mu Ci/m^2$	microcurie(s) per square meter
$\mu g/m^3$	microgram(s) per cubic meter
AED	aerodynamic equivalent diameter
AFSPCMAN	Air Force Space Command Range Safety Policies and Procedures
ARF	airborne release fraction
Ba	barium
Bq	Becquerel
CCSFS	Cape Canaveral Space Force Station
Ce-144	cerium-144
CFR	*Code of Federal Regulations*
Ci	curies
Cs-137	cesium-137
DAFMAN	Department of the Air Force Manual
DARPA	Defense Advanced Research Project Agency
DOE	U.S. Department of Energy
DR	damage ratio
DRACO	Demonstration Rocket for Agile Cislunar Operations
EA	environmental assessment
ECE	Encapsulated Cargo Element
EIS	environmental impact statement
EOL	end of life
FDA	Food and Drug Administration
HALEU	High Assay Low-Enriched Uranium
I	iodine
INL	Idaho National Laboratory
kg	kilogram(s)
km	kilometer(s)
Kr	krypton
Kr-85	krypton-85
KSC	Kennedy Space Center
LEO	low Earth orbit
LLNL	Lawrence Livermore National Laboratory
LPF	leak path factor

Acronym	Definition
LWRHU	Light Weight Radioisotope Heater Unit
m	meter(s)
m/s	meter(s) per second
MAR	material at risk
MEI	maximally exposed individual
mg	milligram(s)
MSAR	Mission Safety Analysis Report
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
NSPM	National Security Presidential Memorandum
NTP	nuclear thermal propulsion
NTR	nuclear thermal rocket
Pa-234m	protactinium-234m
PEL	permissible exposure limit
Pm-147	promethium-147
Pr-144	praseodymium-144
Pu-239	plutonium-239
Rb	rubidium
rem	Roentgen Equivalent Man
rem/hour	Roentgen Equivalent Man per hour
RF	respirable fraction
Rh-106	rhenium-106
RSAC	Radiological Safety Analysis Computer
Ru-106	rhodium-106
Sb-125	antimony-125
Sm	samarium
SPD	Space Policy Directive
Sr	strontium
Sr-90	strontium-90
ST	source term
STEL	short-term exposure limit
TED	total effective dose
Th-230	thorium-230
Th-231	thorium-231
Th-234	thorium-234

Acronym	**Definition**
TNT	trinitrotoluene
TNT-Eq	Trinitrotoluene-Equivalent
U-234	uranium-234
U-235	uranium-235
U-238	uranium-238
UN	United Nations
U.S.	United States
U.S.C.	United States Code
WANL	Westinghouse Astronuclear Laboratory
Y-90	yttrium-90

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SECTION 1

Introduction

The Defense Advanced Research Project Agency (DARPA) seeks to develop, build, and conduct an in-space flight demonstration of a nuclear thermal rocket (NTR), referred to as the Demonstration Rocket for Agile Cislunar Operations (DRACO) mission. The DRACO mission would test an NTR intended for advanced maneuver and logistics missions. The NTR is not intended to be used in a launch vehicle capable of lifting payloads from the surface of the Earth into space. The NTR is only intended to be operated in sufficiently high Earth orbits or for interplanetary missions. For the DRACO mission, the NTR would not be operated at an orbit less than 2,000 kilometers (km). Compared to conventional space propulsion technologies, NTRs offer a high thrust-to-weight ratio around 10,000 times greater than electric propulsion and two-to-three times greater specific impulse (that is, propellant efficiency) than conventional chemical propulsion. These propulsion enhancements would enable space missions that are impractical with conventional chemical propulsion.

Testing would comply with National Security Presidential Memorandum-20 (NSPM-20), *Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems*; *Code of Federal Regulations* (CFR) Title 10, Part 20.1301, “Dose Limits for Individual Members of the Public”; 40 CFR Part 190, “Environmental Radiation Protection Standards for Nuclear Power Operations”; and 29 CFR Part 1910.1096, “Ionizing Radiation.” Testing of nuclear components would be performed in facilities designed to control routine and accidental radiation exposures. These facilities’ activities have been disclosed under other NEPA assessments. The mockup testing would also qualify the cold flow performance characteristics and demonstrate endurance under mechanical loads.

The final design of the NTR would be loaded with High Assay Low Enriched Uranium (HALEU) fuel. The reactor system would undergo additional testing, such as zero-power criticality testing in a government facility to validate neutronic models. A zero-power test would not result in the buildup of radioactive fission products in the reactor prior to launching it into space. Prior to testing the reactor in a high orbit, the uranium fuel has a relatively low radiological hazard potential, compared to the radionuclide inventory that would be created when the reactor is operated at full power. The testing would be sufficient to demonstrate the reliability of the systems and to support the mission design limit for criticality during an accident that causes the reactor to impact the surface of the Earth, which is less than 1 event in 1,000,000 missions.

The testing to full power of the NTR would not start before the spacecraft is in a high orbit, notionally at least 2,000 km from Earth. During the time that it takes objects at this altitude to undergo natural orbital decay, the fission and activation product inventory of the reactor would be greatly reduced by natural radioactive decay. Current testing plans would operate the reactor for two propulsion test burns of about 20 minutes each. The operation of the reactor would produce hundreds of fission and activation radionuclides in the fuel and the structure of the spacecraft. This test would consume a small fraction of the uranium fuel. Consequently, the buildup of long-lived fission and activation radionuclides in the reactor core is minimized.

At the end of the second test burn, the core would contain in excess of 200,000,000 curies (Ci) of radioactivity. After about 12 days of radioactive decay, the radionuclide inventory of fission and activation products would be reduced to about 200,000 Ci. At this time, the inventory would contain about 70 radionuclides that have at least 1 curie of activity. Included in this inventory, there would be about 30 radionuclides with individual activities ranging from 100 to 20,000 Ci. After about 3 years of radioactive decay, the radionuclide inventory in the core would be reduced to less than 400 Ci. Of this total, about 10 radionuclides would have activities of 1 curie or more. These high activity radionuclides would include krypton-85 (Kr-85), strontium-90 (Sr-90), yttrium-90 (Y-90), rhodium-106 (Ru-106), rhenium-106 (Rh-106), antimony-125 (Sb-125), cesium-137 (Cs-137), cerium-144 (Ce-144), praseodymium-144 (Pr-144), and promethium-147 (Pm-147).

After about 300 years of radioactive decay, there would be 4 fission or activation radionuclides in the core with a total activity of less than 1 curie. These radionuclides (Sr-90, Y-90, Cs-137, and plutonium-239 [Pu-239]) and the uranium fuel inventory, are listed in Table 2-1. Activation radionuclides that were produced in the structural elements of the NTR and the spacecraft would also have decayed to negligible quantities.

The most likely outcome is that the testing would be completed, and the intact spacecraft would orbit Earth in a high orbit for hundreds of years. During this time, the inventory of radioactive materials in the reactor would decrease to approximately the level that was in the reactor core at the time of launch. Under normal conditions of operation, the spacecraft would eventually reenter Earth's atmosphere due to gradual decrements in the height of the orbit caused by drag and other forces. The current intent of the program is to design the reactor such that the reactor core impacts the Earth intact with radiation dose consequences to members of the public that are within safety guidelines.

The demonstration would include the startup of the reactor and operating the reactor up to full power. The reactor may be shut down and restarted multiple times. The reactor should be designed to prevent or mitigate potential consequences of potential accidents during the launch into space and the testing program. The risks of potential consequences have been analyzed using conservative assumptions that bound the expected range of actual accident probabilities and consequences.

The most likely result of the DRACO mission would be a successful launch and performance of planned testing in a high orbit of at least 2,000 km. Mission design parameters and engineered safety systems ensure the probability of potential mishaps are minimized. Furthermore, the testing would be sufficient to demonstrate the reliability of the systems and to support the mission design limit for criticality. The adequacy of the testing would be validated before the mission is flown. After testing is complete, the reactor would be left in a sufficiently high orbit for at least 300 years until the orbit path eventually decays and the spacecraft returns to Earth. Accident scenarios are analyzed to determine if the likely outcome and deviations from this plan due to potential mishaps result in consequences that are within acceptable guidelines.

SECTION 2

Description of the DRACO System

2.1 Reactor General Description

The reactor of an NTR engine heats liquid hydrogen to temperatures that reach between 2,000 to 3,000 kelvin (or about 3,600 to 5,400 degrees Fahrenheit) after the hydrogen passes through the reactor core. Hot hydrogen gas is expelled through a rocket nozzle to produce thrust. The NTR differs from a chemical rocket in that a chemical rocket uses the combustion of a propellent to create hot gases. Both types of rockets produce thrust by exhausting hot gases through a rocket nozzle. Expansion of the hot gas in the nozzle, which accelerates the flow of hot gas, propels the spacecraft.

An artist's rendition of an NTR is shown on Figure 2-1. A tank of liquid hydrogen propellent (not shown) is attached to the reactor and the hydrogen is fed to the reactor by a turbopump.

The hydrogen tank, NTR core, and exhaust nozzle are assembled in a spacecraft that can be placed in the payload fairing of a launch vehicle. The spacecraft controls the direction of thrust and turns the NTR on or off. The NTR provides the thrust that propels the spacecraft during the testing phase of the mission.

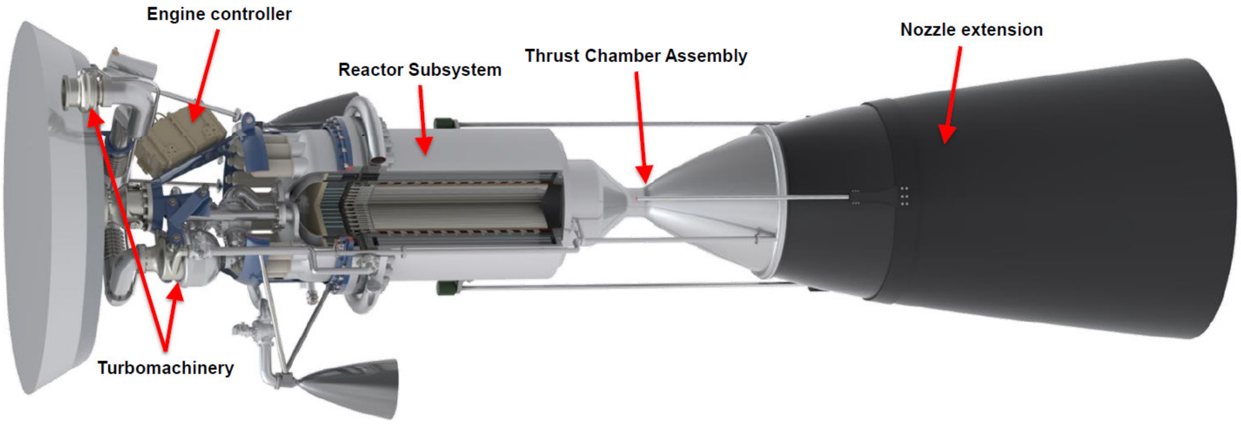

Figure 2-1. Artist Rendition of a Nuclear Thermal Rocket (Courtesy of the National Aeronautics and Space Administration [NASA])

2.2 Description of the Nuclear Fuel

The fuel in an NTR core is made specifically to withstand very high temperatures approaching 3,000 kelvin (approximately 5,400 degrees Fahrenheit). Solid-core NTR fuel is formed from uranium in a high-temperature matrix, which has historically been a refractory metal or graphite suitable for these very high temperatures.

Table 2-1 provides the estimated radioactive inventory in units of Ci for uranium-238 (U-238), uranium-235 (U-235), and uranium-234 (U-234) that would be in an NTR core at the time of launch and at the end of the mission (also known as end of life [EOL]) assuming 300 years of decay in orbit. This inventory corresponds to approximately 297 kilograms (kg) of HALEU uranium in the reactor fuel at the time of launch. Table 2-1 also provides the associated inventories of radioactive thorium and protactinium that would be present at EOL. The thorium and protactinium are natural decay products of uranium. In addition, Table 2-1 shows the quantity of plutonium that would be in the core at the end of the mission. Plutonium is an activation product created from uranium during the time when the reactor is operational.

Table 2-1 shows the calculated radionuclide inventory for some of the long-lived actinides of the NTR at the end of the mission. This milestone occurs after testing and approximately 300 years of decay in orbit. The data in Table 2-1 show that the amount of uranium fuel burned during the testing is negligible. Thorium-230 (Th-230), thorium-231 (Th-231), thorium-234 (Th-234), and protactinium-234m (Pa-234m) result from the natural decay of the uranium radionuclides in the fuel. Pu-239 in the reactor inventory is the result of neutron activation of U-238. After hundreds of years of decay, the fission products have decayed to inconsequential levels.

Additionally, beryllium is expected to be used as neutron-reflecting material and lithium hydride is expected to be used as reactor shielding. The exact quantities of these materials are not known.

Table 2-1. Radioactive Material Inventory of NTR Core at Launch and End of the Mission

Radionuclides[a] in Fuel	**Uranium Decay Products[a]**	**Fission or Activation Product[b]**	**Activity at Launch (Ci)**	**Activity at End of Mission (Ci)**
U-234			2.7	2.7
U-235			0.13	0.13
U-238			0.08	0.08
	Th-230			0.02
	Th-231			0.12
	Th-234			0.08
	Pa-234m			0.08
		Sr-90		0.01
		Y-90		0.01
		Cs-137		0.02
		Pu-239		0.23

[a] Th-230, Th-231), Th-234, and Pa-234m are natural decay product of uranium.

[b] Pu-239 is an activation product of U-238.

2.3 The DRACO Spacecraft

The DRACO hydrogen tank, reactor core, and exhaust nozzle would be assembled as an integral part of the DRACO spacecraft. When the spacecraft is totally assembled, it would look very much like any other spacecraft; its main difference being the innovative nature of the NTR. The spacecraft would incorporate a conventional attitude control system to orient the spacecraft and, therefore, position it to direct engine thrust in the desired direction. The DRACO spacecraft would also incorporate electronics, star trackers, solar arrays and software for guidance, navigation and control, as well as software to operate the nuclear thermal engine.

SECTION 3

Locations for Activities

The DRACO program activities include reactor assembly and testing activities, storage of the reactor, transportation of the reactor components, assembly at the launch site, launching of the reactor into space, full power testing in space, and final disposition of the reactor in a safe orbit. The locations of these activities are discussed below.

3.1 Development Activities

Development of the reactor's hardware and control systems, and the space vehicle's hardware and control systems, would occur in the facilities of commercial contractors. These hardware and control system activities involve no nuclear fuel material or nuclear operations. Testing would involve non-nuclear mockups. There are no additional risks to the public other than routine industrial operations that are conducted under U.S. Environmental Protection Agency or Occupational Safety and Health Administration regulations. As such these activities are not subject to the National Environmental Policy Act (NEPA) because there is no potential for impacts. HALEU fuel would be provided from the U.S. Department of Energy's (DOE's) Y-12 facility. HALEU fuel development has been evaluated in previous NEPA studies (DOE, 1996, 2011, 2018).

3.2 Assembly and Testing Activities

Potential assembly and testing activities are to be done at either industry sites licensed for nuclear work or DOE sites. These facilities are designed to mitigate or control potential consequences of potential accidents. The safety aspects of testing and storing the DRACO reactor at industry and DOE sites have been evaluated in a previous Environmental Impact Statement (EIS) (DOE, 2013).

3.3 Transportation

The transport of the DRACO reactor would be compliant with U.S. Department of Transportation regulations governing the transport of nuclear material (Hazardous Materials Transportation Act of 1975, 49 *United States Code* (U.S.C.) Section 5101 et seq.; 49 CFR Parts 171–180). The transportation of HALEU fuel and radioactive components by truck and rail to and from sites under consideration for use in DRACO have been addressed under NEPA (DOE, 2013).

3.4 Assembly at CCSFS

The process of assembling the spacecraft at Kennedy Space Center (KSC) or Cape Canaveral Space Force Station (CCSFS) would include combining the NTR engine with the non-nuclear engine hardware. Assembly and testing would comply with the risk limitation mandate of NSPM-20, *Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems*. During this assembly process, the radioactive material would be secured within a building engineered to meet fire safety standards and to mitigate the potential release of radioactivity from the building in the case of a fire or explosion. Small fires would be mitigated with fire suppression systems. Following standard safety protocols, using specialized handling techniques, and having experienced engineers complete the assembly of the spacecraft would reduce the potential for accidents during this process to negligible.

3.5 Launch and Prelaunch

The DRACO launch is planned to occur no earlier than 2027 at either CCSFS or the KSC, adjacent facilities located in Brevard County, Florida; however, the launch schedule is subject to change. The CCSFS is the primary designated location for the launch. KSC would provide support, coordination or backup facilities for CCSFS as required. Activities ascribed to CCSFS could be shifted to KSC.

The DRACO spacecraft, including the NTR engine, would be launched into space by a launch vehicle. The assembly of the spacecraft and integration with the launch vehicle are expected to be conducted according to the procedures described in the Routine Payload Environmental Assessment (EA) issued by NASA (NASA, 2011). The unique environmental consequences associated with DRACO are the focus of this consequence analysis.

3.6 Reactor Demonstration

The reactor demonstration phase would occur when the spacecraft is notionally at 2,000 km and in a "sufficiently high orbit" in accordance with United Nations (UN) Resolution 47/68, *Principles Relevant to the Use of Nuclear Power Sources in Outer Space* (UN, 1992) and Presidential Memorandum on the National Strategy for Space Nuclear Power and Propulsion Space Policy Directive (SPD) – 6 (White House, 2020). The orbit would be sufficiently high to ensure that the fission products created by the full power operation of the reactor would decay sufficiently prior to reentry. Once the spacecraft is in the sufficiently high orbit, the reactor would be turned on, and propulsion for the spacecraft would be demonstrated.

In-space disposal would occur after the demonstration and would be conducted in accordance with SPD – 6 (White House, 2020). The disposal would entail ensuring the reactor is deactivated and in a proper orbit to eliminate the possibility of the reactor reentering Earth's atmosphere prematurely or colliding with another spacecraft.

SECTION 4

DRACO Mission Parameters and Engineered Safety Systems

Engineered safety systems and mission operating parameters are being considered that can further help mitigate consequences of potential accidents during the DRACO launch sequence. During operation, the NTR would be propelled to a higher orbit. Once the mission is complete, the NTR would be safely shutdown and stored in a long-term orbit consistent with SPD-6. The mission parameters have been established to fully comply or exceed the stipulations of UN Resolution 47/68, *Principles Relevant to the Use of Nuclear Power Sources in Outer Space* (UN, 1992). This resolution requires a space nuclear reactor to be stored in a sufficiently high orbit to provide sufficient time for radioactive decay of the fission products produced by the operation of the reactor. The UN stipulates the orbit should be high enough to allow the fission products to decay to approximately the radioactivity level of the actinide activation products of uranium. This duration has been calculated for the DRACO mission to be approximately 300 years.

The DRACO mission would be designed such that all the reactor operations would be performed at a sufficiently high altitude that debris from potential mishaps during the NTR test phase would not be expected to return to Earth before approximately 300 years of decay time. For a destructive failure that generates radioactive debris, the probability that a piece of debris would be created with sufficient delta-v force in the direction optimized for early re-entry would not be allowed and, therefore, would not be credible. This would be ensured by tailored thrust vectors mandated by the program office, highly reliable control and direction hardware, guidance navigation and control, and highly reliable altitude control systems (such as vector control thrusters).

During the test demonstration, the thrust vector would be oriented such that if debris were generated from a damaged reactor, it would not be ejected in a direction optimized for expedited re-entry. For instance, the demonstration system could undergo a series of inclination changes that have a thrust vector perpendicular to the circular orbit in which the demonstration would be taking place. Debris in this case (if generated) would go in the opposite direction at a different inclination, but it would maintain the same circular orbit at the same altitude as the reactor and, therefore, have the same timeline of predicted reentry and would not be conducive to an earlier reentry.

In addition, the design and construction of the NTR would ensure the probability of a criticality excursion before the reactor reaches the operating orbit, which is within the risk mandate of NSPM-20. This means the probability and consequences of a criticality excursion that would involve impact on land or water (UN, 1992) are within mission criteria. The final design of launch safety features would be analyzed by an independent review board. The proposed mission would comply with NASA and Space Force safety analysis guidelines for all credible accidents.

Zero power criticality testing would be conducted prior to launch. Zero power critical testing produces negligible amounts of fission products, less than 0.01% of the radioactivity activity in the uranium itself.

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SECTION 5

Accident End States

5.1 Fire and Explosions

A fire that could aerosolize the reactor's HALEU fuel (but does not cause the reactor to go critical) would release a fraction of the irradiated uranium fuel into the atmosphere as a respirable particulate. This particulate plume could produce adverse radiological or chemical consequences in humans. The radiation dose consequence of the uranium release and the potential chemical exposure depend on the intensity and duration of the fire. Not every fire has the potential to result in a release of uranium. Sustained high temperatures are needed to oxidize the reactor fuel and release a respirable particulate. Although the launch vehicle has not been selected for the DRACO mission, the selected launch vehicle would likely have an inventory of more than 1,000,000 kg of rocket fuel. The configuration may be either liquid or solid fuel, or a combination of fuels. The rocket fuels may be contained in first or second stage rockets or attached boosters. Depending on the specific circumstances of a mishap, the spacecraft may be attached to all or part of a launch vehicle at the time of a fire, or the spacecraft could be detached. A fire could also result in a release of hazardous non-nuclear components of the reactor, that is, beryllium and lithium hydride.

During integration of the spacecraft and the NTR, maneuvering propellant would be loaded in the spacecraft's attitude control system tanks. Approximately 2,000 kg of liquid hydrogen would be loaded into the spacecraft as propellant for the NTR. The other liquid rocket propellants would be loaded on the launch pad, subsequent to mounting the fairing onto the launch vehicle and transporting the assembled entity to the launch pad. The encapsulated payload fairing (containing the DRACO spacecraft, launch vehicle adapter, and any secondary payloads) would be mated to the launch vehicle prior to final movement of the launch vehicle to the launch pad. If the mission includes secondary payloads, the secondary payloads may have their own propellant(s), ordnance, and associated hazards that would be assessed as part of the final safety analysis of the final design prior to launch.

During the integration of the NTR with the spacecraft and the launch vehicle, the potential for a fire due to liquid rocket propellant ignition would be mitigated by careful design of fuel storage and transfer systems, as well as extensive leak monitoring programs. Similar safeguards would apply to prevention of ignition of solid rocket fuels.

Explosions may also result in the release of radioactive material to the air. Large explosions, or explosions associated with fires or elevated temperatures of the fuel, may result in airborne releases. Accidental explosions would be mitigated by numerous launch vehicle and spacecraft safety systems designed into the launch process at CCSFS and KSC. However, a reactor self-destruct explosive system may be incorporated into the mission design to mitigate the potential for criticality excursions. The reactor self-destruct system would be designed to fracture the reactor to prevent a criticality excursion. Initiation of the reactor self-destruct system would also likely ignite the liquid hydrogen and other components inside the fairing.

5.2 Inadvertent Criticality Accidents

The potential for an unintended reactor criticality would be mitigated prior to launch (that is, during transportation, assembly, etc.) by designing neutron absorption features or "poisons" into the preflight configuration of the reactor. These neutron poisons are a well-understood way to absorb neutrons without creating fissions, reducing the ability of the neutrons to create a chain of increasing number of fission reactions in the U-235 fuel. This neutron reduction reduces the amount of energy released, prevents the creation of fission products, and dampens the number of subsequent fissions. The neutron poisons could be installed as neutron-absorbing wires in the reactor core hydrogen flow holes. The neutron poisons are primarily effective in preventing a criticality excursion while the reactor is being assembled. These features are currently planned to be removed from the reactor prior to attachment to the launch vehicle.

A reactor self-destruct system would provide an additional level of protection against a criticality excursion. In the event of an uncontrolled situation on the launch pad or during flight, the self-destruct system would prevent criticality by explosively breaching the geometry of the reactor fuel and dispersing the nuclear material in fragments that would individually be too small to initiate a criticality event.

The preliminary design locates the anti-criticality destruct system with the DRACO vehicle, firing at the reactor. In this configuration, the self-destruct system would be removed at upper stage separation during launch to avoid any issues of ordnance remaining on the reactor during operation. Therefore, the self-destruct ordnance would not be carried in the spacecraft during the in-space testing phase or the eventual reentry. This design may allow the self-destruct ordnance to be integrated with the flight termination system of the launch vehicle. A design of this type would minimize uncertainties or hazards associated with the self-destruct system ordnance.

The explosive destruct mechanism may also be tested with non-nuclear mockups. The final design would be subject to qualifications that include appropriate redundancies and assess all potential failure modes and likelihoods. This would be sufficient in conjunction with other safety features to render the probability of a criticality excursion beyond credible.

In addition to these external safety systems, the reactor core and control system would be designed with numerous features that would prevent inappropriate activation or positioning of the reactor controls and control excessive reactivity. There would be a period of time during the launch preparations when the criticality poison wires would be removed and the self-destruct system would not yet be armed. Administrative and engineering controls would be applied during this period to maintain a safe configuration of the reactor.

Although it is possible to describe a scenario where the launch vehicle suffers a mishap that causes the reactor to impact the surface of the Earth, all of the criticality controls fail, and the impact results in a reconfiguration of the reactor core that results in a criticality excursion, the probability of such an event is too low to be credible. The safety analyses performed on the final design would ensure that the probability of such an event is not credible.

5.3 Cold Reentry Accidents

Once launched, the launch vehicle and spacecraft may fall back to Earth prior to reaching the test orbit and initiating its on-orbit fission reaction. The explosive destruction system and other features would prevent the reactor from going critical upon return to Earth. The expected consequences following a cold reentry scenario are therefore determined by the fire and explosion scenarios for both radiological and non-radiological exposures (that is, beryllium, lithium hydride, and chemical uranium). These consequences may vary according to the distance to exposed individuals and other aspects of the impact scenario. A cold reentry accident early in the mission would have low radiation dose consequences because the thermal impact of the launch vehicle’s fuel would disperse the uranium aerosol into air. A cold reentry scenario that occurred later in the mission with a low thermal content would have higher radiation dose consequences but still be below mission guidelines.

Although the reactor may return to Earth intact, the aerothermal loads would heat the spacecraft and break it apart. The reactor core may lose mass as a result of friction heating as it falls back to Earth. This would release uranium into the atmosphere. Heating the reactor core in the upper atmosphere would result in a diffuse aerosol that would spread over a larger area of land or water, compared to a fire or explosion at impact. The loss of uranium in the atmosphere would be expected to be negligible because of the heat resistant design of the reactor core. The radiation dose consequences of the reentry heating scenario would be negligible, compared to the intact return scenario.

If a criticality excursion occurred in conjunction with a cold reentry, the expected consequences would vary according to the distance to individual members of the public and other aspects of the impact location. A cold reentry criticality accident early in the mission would have lower radiation dose consequences because the thermal impact of the launch vehicle fuel would disperse the uranium aerosol into air. A cold reentry scenario that occurred later in the mission with a low thermal content would have higher radiation dose consequences that would exceed mission guidelines. However, as noted in Section 5.3, the probability of such an event is not credible.

5.4 Hot Reentry Accidents

A hot reentry is an accident that occurs after the reactor has been activated for a test burn. The reactor would not be allowed to create a fission reaction until it is in a sufficiently high orbit with a trajectory vector that precludes premature hot reentry. The height of this orbit is notionally 2,000 km. As any spacecraft undergoes natural orbital decay and its altitude decreases, it begins to experience atmospheric drag, which additionally reduces the altitude of the reactor's orbit. The decay of the orbit becomes comparatively very rapid below 200 km and the satellite soon makes a reentry to the surface of the Earth. Certain materials of the reactor, such as aluminum, vaporize readily. High temperature metal alloys and refractory materials may impact as intact items or in granular forms. The reactor core would be designed to operate at high temperatures and, as a result, should survive temperatures experienced during reentry.

Currently, the appropriate orbit for reactor operation has been determined by DARPA for DRACO to be at least 2,000 km above the Earth. This high orbit means the reactor would not reenter the Earth's atmosphere for hundreds of years, to accommodate fission product decay lifetime requirements, as described in previous sections of this document.

Another design feature that prevents hot reentry of a recently operated reactor (a hot reactor) is the spacecraft control system that points the rocket in the right direction during the thrust. This would prevent the spacecraft from lowering its orbit after the main NTR engine and its reactor are turned on and during the primary thrust phase of the mission. Redundant features would preclude this accident scenario from being credible.

It is possible that the testing activity would result in partial or complete destruction of the reactor. Reactor destruction could create loose debris outside the pressure vessel or outside the spacecraft. The probability that this debris could have sufficient energy to allow it to reenter the Earth's atmosphere prematurely is too low to be credible. The reactor control system and active control of the mission by mission control personnel would ensure that the reactor is not operated with thrust vectors that would allow premature reentry of accident debris. A robust reactor control system would reduce the probability of this accident to acceptable, non-credible probability levels. Potential exposure to non-radiological constituents are likewise not considered to be credible in this scenario.

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SECTION 6

Mission Phases

The spacecraft would be launched from CCSFS or KSC on an eastward trajectory over the Atlantic Ocean, currently planned at an orbital inclination of 28.5 degrees. During the prelaunch and early launch phases of the mission, a fire or explosion could result in a release of uranium. The DRACO mission statement requires that accidental criticality due to a launch accident must be prevented. Practically speaking, this means that the probability of an accidental criticality excursion must be reduced to an appropriate level, such as, a probability less than 1.E-05 or 1.E-06. The threshold for categorizing the consequences to a member of the public is 25 Roentgen Equivalent Man (rem) of TED. Current federal guidance for space reactor missions (NSPM-20, 2019) stipulates that "mission planners and launch authorization authorities should … ensure that the total mission probability of an accident resulting in exposure in excess of 25 rem TED to any member of the public does not exceed 1 in 100,000."

Launches of nuclear reactors into space that have greater than 0.0001% probability of 5 rem to 25 rem TED radiation dose are categorized as Tier II activities under NSPM-20. The U.S. Department of Defense would manage the safety of the DRACO launch by ensuring that the safety design satisfies NSPM-20 Tier II requirements and that a conforming Mission Safety Analysis Report (MSAR) is reviewed and approved prior to launch, and approval to launch would be granted by the head of the Sponsoring Agency. In the case of DARPA, the head of the Sponsoring Agency would be the Secretary of Defense. These requirements are specified in Air Force Space Command Range Safety Policies and Procedures (AFSPCMAN) 91-710 and Department of the Air Force Manual (DAFMAN) 91-110.

Potential accidents related to the startup or operation of the NTR would be mitigated by appropriate design of the geometry of the reactor and the reactivity insertion controls. The startup process would be incremental and monitored in real time to control the potential for unintentional excursions. These features would reduce the probability of an explosive destruction or melting of the reactor and the velocity that might be imparted to the debris. The primary mitigation for adverse consequences to humans, however, are the provisions for not operating the reactor unless a sufficiently high orbit is achieved. When testing is completed, the spacecraft would be left in the 2,000 km orbit to prevent reentry to Earth's atmosphere until the fission products have decayed sufficiently.

6.1 Phases of Launch

A template for the phases of the DRACO launch can be taken from the Mars 2020 launch safety analysis (Clayton et al., 2014) performed by Sandia National Laboratories and supported by other governmental organizations. This analysis broke the launch into six separate phases, ranging from pre-launch to long-term reentry, and is shown on Figure 6-1.

For the DRACO mission, the mission activities are organized into five phases and a final long-term reentry. Applying this template facilitates comparisons between DRACO and prior NASA missions that involved nuclear materials. Further, these activities capture the range of potential mishaps and allow consideration of the probabilities, consequences and mitigations involved in this mission.

- Phase 0: Pre-Launch, from the point when the components would be delivered to CCSFS until the start of launch vehicle engines
- Phase 1: Early Launch, from the end of Phase 0 to the time when there would be no potential for accident debris or intact vehicle components to impact land in the launch area
- Phase 2: Late Launch, from the end of Phase 1 to the time when the vehicle would reach an altitude of roughly 30 km, an altitude above which heating could occur

- Phase 3: Suborbital Flight, from the end of Phase 2 to when low Earth orbit (LEO) would be reached, which corresponds to a height roughly 160 km, where low Earth orbit begins
- Phase 4: Low Earth Orbital Flight, from the beginning of LEO to a suitable testing orbit, which is defined by DARPA to be at least 2,000 km
- Phase 5: Reactor Testing Orbit, from the time the NTR full power testing would be conducted in the testing orbit until long-term decay has occurred and the NTR would begin reentry.

Eventually, after natural orbital decay of hundreds of years, the NTR would return to Earth.

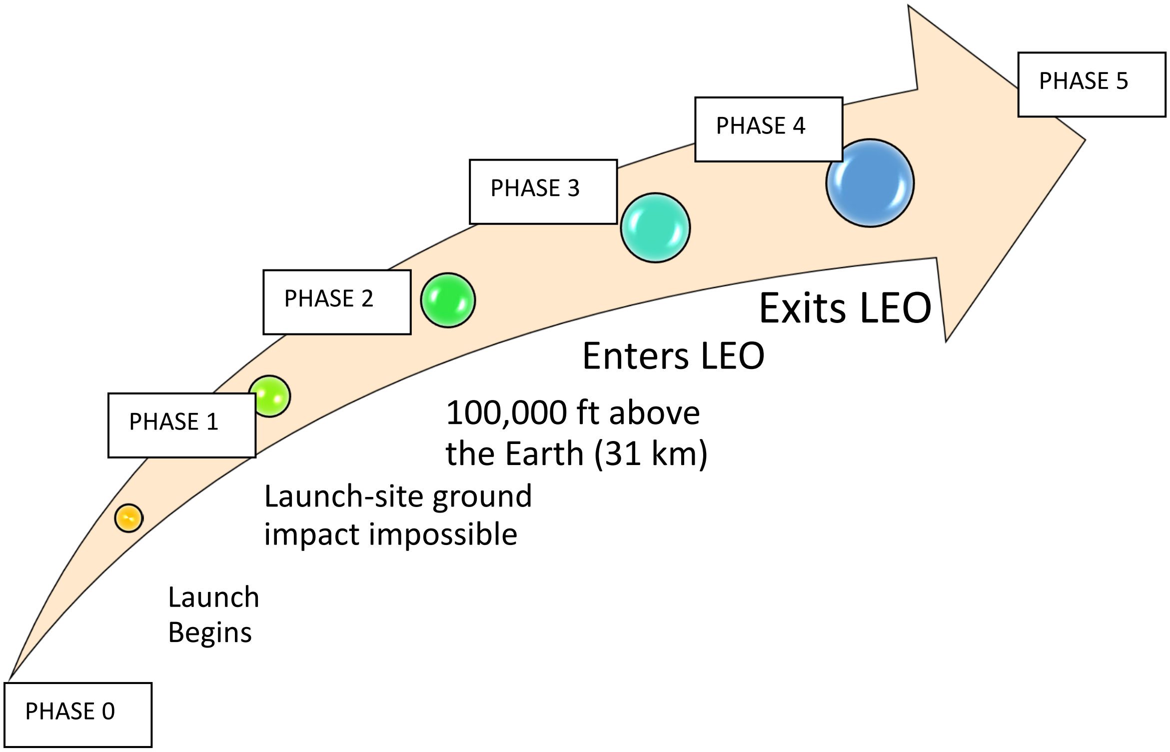

Figure 6-1. Preliminary Launch Phases

6.2 Combining Accident Phases and Accident End States

In order to describe the types of potential accidents analyzed in this document, it is easier if these potential accidents are grouped into accidents that end in similar accident conditions or similar accident end states. To group the potential accidents, the systematic safety analyses conducted for previous space reactor projects such as SNAP (Otter et al., 1973), SP-100 (Bartrum and Weitzberg, 1988), Topaz (Marshall, 1993), and the Rover/NERVA (Westinghouse Astronuclear Program, 1965) projects were used as a basis. These projects examined many of the same accidents one would expect for the DRACO Nuclear Thermal Propulsion (NTP) system. Together these studies examine specific failures leading to accidents. These accidents then lead to similar accident end states such as hot reentry and inadvertent criticality. The types of accidents and their end states can be binned by phases of the missions and are shown in Table 6-1.

Table 6-1. Potential Accidents and End States for Mission Phase

Mission Phase	Mission Phase Definition	Potential Accidents	Potential Accident End State
Pre-Launch (Phase 0)	At launch site activities	Criticality during assembly	Inadvertent Criticality
		Fire – Dispersal	Fire
		Fire leading to criticality	Inadvertent Criticality
		Reactivity insertion accident	Inadvertent Criticality
		Hydrogen leak leading to criticality	Inadvertent Criticality
		Explosion	Explosion/Fire
Early Launch (Phase 1)	Early Launch, from the start of rocket engines to the time when there is no potential for debris or intact vehicle components from an accident to impact land in the launch area	Land Impact	Inadvertent Criticality
			Cold Reentry
		Water Impact	Inadvertent Criticality
			Cold Reentry
		Break up – Dispersal	Cold Reentry
		Explosion	Explosion/Fire
			Inadvertent Criticality
Late Launch (Phase 2)	Late Launch, from the point when land impact on the launch site is not possible to the time when the vehicle reaches an altitude of nominally 30,480 meters (m) (100,000 feet), an altitude above which heating reentry could occur	Land Impact	Inadvertent Criticality
			Cold Reentry
		Water Impact	Inadvertent Criticality
			Cold Reentry
		Break up	Cold Reentry
		Explosion	Explosion/Fire
			Inadvertent Criticality
Sub-Orbital Reentry (Phase 3)	Suborbital Reentry, from the point when heating reentry is possible to when LEO is reached. This corresponds to a height roughly 160 km above Earth's surface, when LEO begins.	Land Impact	Inadvertent Criticality
			Cold Reentry
		Water Impact	Inadvertent Criticality
			Cold Reentry
		Break up	Cold Reentry
			Burn Up in Atmosphere
		Explosion	Explosion/Fire
			Inadvertent Criticality

Mission Phase	Mission Phase Definition	Potential Accidents	Potential Accident End State
Low Earth Orbit (Phase 4)	LEO Reentry, from the beginning of LEO (near 160 km) to the end of LEO at a notional 2,000 km	Land Impact	Inadvertent Criticality
			Cold Reentry
		Water Impact	Inadvertent Criticality
			Cold Reentry
		Break up	Cold Reentry
Orbital Operations (Phase 5)	Long-term Orbital Reentry, from the time the system is above low earth orbit and in its operation location until the completion of the demonstration mission	Inadvertent reentry	Inadvertent Criticality
			Hot Reentry
		Loss of cooling	Core Melts in Space – Hot Reentry
		Reactivity excursion	Core Thermally Disassembles – Hot Reentry
High Orbit Disposal	Final disposition of reactor	Long-term reentry	Hot Reentry

Based on the information in Table 6-1, the following potential accident end states are the focus of the safety analysis:

- Fire and Explosions
- Inadvertent Criticality
- Cold Reentry
- Long-term Reentry

Probability of Accident End-States by Launch Phase

The probability of each potential accident end state by launch phase is presented in the following sections. The estimate of probability starts with the estimation of the initiating event probabilities, followed by the probability of each accident end-state by launch phase.

7.1 Launch Vehicle Accident Analysis

A launch vehicle has not been selected for the DRACO mission. For this assessment, conservative launch vehicle accident probabilities have been selected based on upward scaling of assessments performed for the Mars 2020 mission, data on overall mission failure rates, and additional conservatism. The safety analysis methodology that was applied for the Mars 2020 mission represents the state-of-the-art in launch vehicle safety analysis. The Mars 2020 mission failure probabilities were adapted as the basis of point estimates in this assessment.

7.2 Overall Launch Vehicle Failure Probability

The total launch vehicle failure rate is based on NASA data for failure for satellite launches. A report on accident rates, titled *Small Satellite Mission Failure Rates* (Jacklin, 2019), shows a total failure rate of 6.1%. As stated in this report:

"From 2000 to 2017, the average failure rate is also 6.1%, indicating that the launch vehicle failure rate doesn't seem to be improving with increases in launch vehicle technology. One possible explanation for this outcome is that the introduction of new launch vehicles also restarts the learning curve for those platforms. In any event, it seems reasonable to conclude that about 6 percent of all satellites (large and small) will be lost due to failures of the launch vehicles."

The data for launch failures from Jacklin (2019) are reprinted on Figure 7-1.

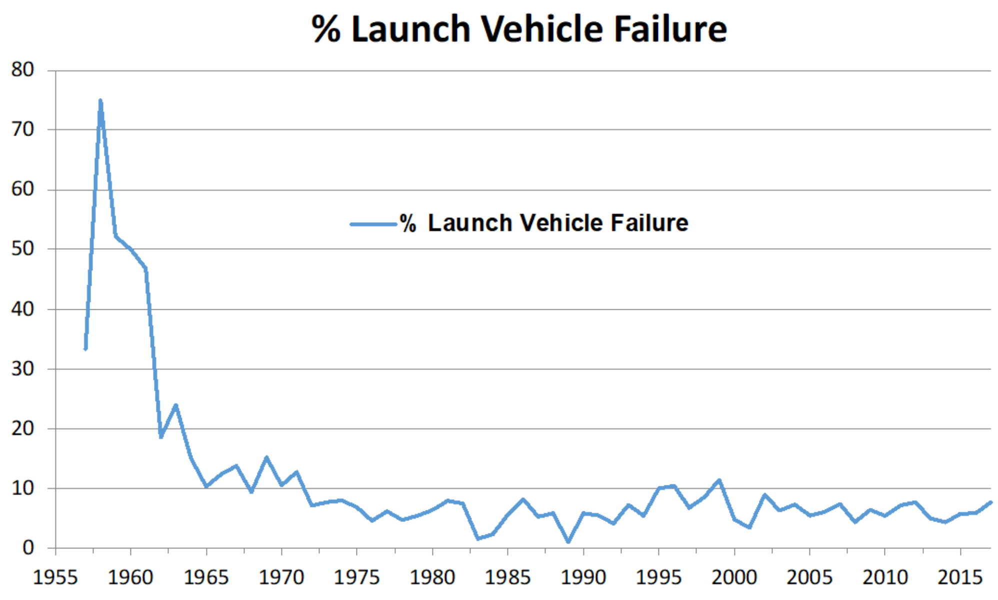

Figure 7-1. Percent of Launch Vehicle Failures from 1957 to 2017 (Reprinted from Jacklin)

The 6.1% failure rate noted in the report applies to all types of launches, including small satellite missions. Small satellite missions typically are flown on less mature launch vehicles because they are lower value payloads. The owner is typically willing to accept a greater risk of failure in exchange for lower total mission cost. The launch of the NTR system would require a higher level of safety analysis, compared to typical small satellite launches, because the safety programs require safety analyses and reviews by independent experts and approval under NSPM-20. The scrutiny required for launches with significant nuclear payloads is expected to result in a lower-than-average accident experience. On the other hand, some features of the mission, such as the NTR, would be unique and this aspect might increase uncertainty in Phase 5. The 2013 EIS for the Mars 2020 mission estimated the overall launch accident probability for a composite launch vehicle was 2.5%. In this assessment, the overall launch accident probability of the Mars 2020 mission in Phase 1 to Phase 4 was scaled up to the 6.1% reported by Jacklin.

The accident probabilities for the relevant launch phase in the Mars 2020 EIS and the Supplemental EIS were reviewed and the higher probability was selected for each phase. The Phase 0 accident probability was multiplied by 10, compared to Mars 2020 mission analyses, to provide a point estimate of mission failure due to the unique aspects of the proposed mission. The corresponding Phase 5 accident probability was multiplied by 100 to provide a corresponding point estimate of operational test failures. A total failure probability of 7.6% was developed to build up a reasonably conservative model of Phase 0 to Phase 5 mission accident probabilities for the DRACO mission. In the referenced analyses, a launch accident does not always result in a release of radioactivity. However, in this assessment, all accidents are conservatively assumed to result in a release of radioactivity. The resulting mission probability values are shown in Table 7-1.

The events that might cause a failure of the NTR to reach the desired orbit for testing are included in Phases 1, 2, 3 and 4. These phases constitute about 80% of the failure probability. The phase of the mission that involves operating the NTR and placing the reactor is a long-term orbit constitutes about 20% of the accident probability.

Table 7-1. Initiating Event Probabilities

Launch Phase	Activity	Probability
Phase 0	Prelaunch Activities	1.0E-03
Phase 1	Early launch overall	8.0E-03
Phase 2	Late launch	9.0E-03
Phase 3	Suborbital flight	3.2E-02
Phase 4	Orbital flight	1.2E-02
Phase 5	Reactor Operations Mishap	1.4E-02
Phase 5	Reactor Operations and Long-term Reentry	9.24E-01
Phases 0-5	Overall Mission Inadvertent Criticality	1.0E-06
Phases 0–5	Overall Mission Hot Debris Reentry	Not credible

7.3 Evaluation of Accident Probabilities by Phase

The most likely outcome of the DRACO mission is that the launch and orbital insertion of DRACO would perform as planned and the mission is successful. Eventually, as described in previous sections, the fission products would have decayed sufficiently and the NTR's orbit would decay, leading to reentry and intact impact on the Earth's surface. The most likely release event is that the reactor eventually falls to Earth and a fraction of the end of mission inventory disperses upon impact, but the reactor does not experience a criticality event. Potential accidental dispersals of radioactive materials at the end of the mission are similar to scenarios that model severe fires and explosions.

7.3.1 Phase 0 – Prelaunch Activities

The NTR engine and non-nuclear components are integrated first at the launch facility integration building. These are then integrated with the (unfilled) hydrogen tank and spacecraft. This assembly is mated to the launch vehicle adapter, the destruct system ordnance is installed (but not armed), the poison wires are removed, and the payload fairing is installed. This assemblage is called the Encapsulated Cargo Element (ECE). The ECE (with poison wires removed and destruct system not armed) is transported to the launch complex at CCSFS and mated to the launch vehicle. The entire stack is then moved to the launch pad. Once at the pad, hydrogen is loaded into the NTR tank (along with propellants for the launch vehicle itself) just prior to launch. This assessment pessimistically assumes that all Phase 0 accidents result in a release of uranium from the reactor core due to accidents that are outside of the control of the NTR engine. The probability of a uranium release is therefore pessimistically assessed to be 1.E-03 (0.1%) (Table 7-1). This probability is also applicable to a release of chemical uranium and non-radiological constituents, that is, beryllium and lithium hydride.

A criticality excursion could occur due to equipment failures, errors in assembly or testing, or a deformation of the reactor core following an explosion or fire that resulted in a reactive configuration. There is a period of time during Phase 0 when the poison wires have been removed but the self-destruct system is not yet activated. The NTR is designed to avoid criticality excursions during mechanical impacts. The overall mission criticality failure limit is 1.E-06 (0.0001%).

7.3.2 Phase 1 – Early Launch

During early launch flight, failures of the launch vehicle could result in fires, explosions, or impacts with the Earth's surface. Phase 1 fires are pessimistically assumed to result in an explosion that releases uranium from the NTR as an airborne plume of radioactive material from the reactor core. The probability is 8.E-03 (0.8%) (Table 7-1). This probability is assumed to be applicable to a release of chemical uranium and non-radiological constituents, that is, beryllium and lithium hydride.

Criticality excursion scenarios could involve acute or prolonged criticality excursion. A reactor self-destruction safety system would be operable during Phase 1. The purpose of the self-destruction system is to break the reactor core into fragments that cannot sustain a nuclear chain reaction.

7.3.3 Phase 2 – Late Launch

During this late launch phase, the launch vehicle (and its DRACO NTR payload) is over the ocean. The altitude is below 30 km and the NTR would not experience significant heating if a flight failure terminated the mission. The most likely sequence for an accidental return to Earth is that the self-destruct system was actuated and the broken reactor falls into the ocean. A small amount of uranium is assumed to be released. The probability of a Phase 2 accident is 9.E-03, which is assumed to be the probability of a uranium release. Chemical releases are also considered in the ocean impact scenario of this mission phase.

7.3.4 Phase 3 – Launch Sub-Orbital

It is possible that an accident could cause the reactor/spacecraft to reenter and impact a land mass or water body. The most likely scenario is that the reactor or major components return to Earth essentially intact; this scenario would also have the highest radiation dose consequence because the resulting radiation release would be more concentrated. The types of accidents are similar to Phase 1 accidents. The probability of the flight terminating and the reactor falling back to Earth is 3.2E-02. This probability is assumed to be applicable to a release of chemical uranium and non-radiological constituents, that is, beryllium and lithium hydride.

7.3.5 Phase 4 – Spacecraft and reactor in orbit, prior to operations

The DRACO spacecraft would be placed in an orbit with a notional altitude of 2,000 km. During this phase, the reactor would still be assumed to be cold and not have operated and the self-destruct system would be operable. The potential accident sequences would be similar to those in Phase 3. The most likely event would be that the reactor falls to Earth, has a small amount of dispersal upon impact, but does not go critical. The probability of the flight terminating accidentally would be 1.2E-02 (Table 7-1). The probability that a Phase 4 accident leads to a uranium release is pessimistically assumed to be 1.1E-02. This probability is also assumed to be applicable to a release of chemical uranium and non-radiological constituents, that is, beryllium and lithium hydride.

7.3.6 Phase 5 – Reactor Operations and Long-term Storage

Once the reactor is in a suitable orbit for testing, reactor operations would be conducted for demonstration testing. The major accident scenarios related to radiation dose consequences would be as follows:

1) The reactor and spacecraft are pointed in the wrong direction, and when the NTR engine is operating, it creates thrust in an undesired direction, initiating entry of the spacecraft into the Earth's atmosphere.
2) The reactor overheats (the structure fails/melts with the fuel intact) during startup, and fuel is ejected out the nozzle.
3) A reactivity transient occurs that destroys the reactor and spacecraft, imparting velocity to the fuel fragments.

7.3.6.1 Hot Reentry

The analysis of this event assumes that the spacecraft guidance, navigation, and control systems exhibit a fault in which the spacecraft does not know its direction and incorrect information about the fault is downlinked to the control center; the NTR is subsequently fired for a duration that would reduce the amount of time of the DRACO spacecraft in orbit. This scenario is beyond extremely unlikely due to the decades of experience the U.S. has in designing spacecraft and their control systems; the use of proven control systems designs (star trackers, reaction control systems, etc.) and components with solid/reliable pedigrees; and positioning of the spacecraft and NTR operation are observed, monitored, and commanded by engineers in the control room. These controls are used in chemical rocket systems and they have a long history and a highly reliable pedigree. The DRACO program office has placed a requirement that the controls be very highly reliable, and the probability of this event occurring is not credible.

7.3.6.2 Hot Debris Reentry from Fuel Melt

NTRs have a potential for failure because operational temperatures are close to the design limits of the core materials. The startup process would involve real time control of incremental increases in reactivity and monitoring of critical system parameters. If any fault occurs that prevents the hydrogen from cooling the reactor, there is a potential for thermal destruction of the core structure and the debris will exit the reactor nozzle. One possible fault mode is cracking of the core structure that plugs the hydrogen passages and over pressurizes the core. Other failure modes may produce similar results. The ballistic coefficient of the new debris may give rise to more drag and cause the debris to reenter earlier than desired, but the vector of the spacecraft during testing will prevent premature reentry. The U.S. Government's debris generation requirements mandate a probability of less than 1 in 1,000 for generating debris (U.S. Government, 2019). Therefore, the reactor control is to be designed with a probability of less than 0.1% for debris ejection. This debris creation mandate is not directly relevant to potential consequences because debris creation is only relevant to human consequences if a mishap that creates debris causes hot reentry. As noted previously, the reactor control system and active control of the mission by mission control personnel would ensure that the probability of premature reentry of debris is too low to be credible.

7.3.6.3 Long-term Reentry

Once the mission phase is over, the reactor would be left in a high orbit that would preclude reentry prior to radioactive decay of the fission products. This is the cold reentry scenario that is the basis of mission planning. The reactor would have a low radioactive fission product inventory.

The conservative assumption that the overall accident rate is 7.6% results in an overall mission success probability of 94.4%. The mission is planned to end with a long-term reentry after at least 300 years of decay in orbit. The mission parameters require that the probability of a criticality excursion on impact be within the overall criticality probability of less than 0.0001% (1.E-06). The design of the mission must satisfy this requirement. The likely scenario is that the aerothermal loads would heat the spacecraft and break it apart during reentry. The reactor core may lose mass as a result of friction heating as it falls back to Earth. This would release non-radiological constituents, that is, beryllium and lithium hydride, into the atmosphere. A minor amount of chemical uranium may be released.

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Uranium Fire or Explosion Consequence

This section provides the methodology used for the dose consequence analysis following a potential release of uranium. This consequence analysis includes a deterministic calculation that identifies the impact to the maximally exposed individual (MEI). Deterministic safety analyses do not require detailed modeling of launch accidents because the consequence analysis assumes that an accident of sufficient severity to breach the confinement features has occurred. Only the quantity of radioactivity released and the method of radiation exposure to the public are pertinent in calculating the consequences of the accident. In the case of accidents involving a nuclear payload, the highest radiation doses to members of the public would occur if an airborne plume of gases or tiny respirable particles was released and remained airborne long enough to expose members of the general public who are downwind from the launch accident. Further, the receptors are assumed to stay at the location of the highest airborne concentration for the entire duration of the plume passage. The receptor who would receive the highest radiation dose is called the MEI. No protective measures are assumed for the MEI in order to calculate a conservative estimate of the potential radiation dose consequence. A discussion of the potential consequences from chemical uranium is also included.

8.1 Consequence Analysis Methods

The standard DOE accident analysis methodology consists of two parts. The first part establishes the quantity of airborne radioactivity that is released into the air as a plume. The second part determines the atmospheric dispersion and radiation dose consequence of the airborne release.

The quantity of airborne radioactivity is called the source term (ST) and is established in units of Ci:

$$ST = MAR * DR * ARF * RF * LPF$$

Where:

MAR:	Material-at-risk, the amount of uranium in the DRACO payload (Ci)
DR:	Damage ratio, the fraction of MAR affected by the accident
ARF:	Airborne release fraction, the fraction of affected uranium suspended in the air
RF:	Respirable fraction, the fraction of airborne uranium that can be inhaled
LPF:	Leak path factor, the effect of filtration or mitigation

Table 2-1 provides a conservative radioactive inventory, or MAR, in units of Ci for each uranium isotope that would be in the NTP reactor core at the time of launch. This inventory corresponds to approximately 297 kg of HALEU fuel. For a conservative deterministic accident, the scenario in this analysis assumes that the entire radioactive inventory of the HALEU is damaged in the accident; therefore, DR = 1. For the purposes of this calculation and in accordance with DOE-HDBK-3010, no filtration or mitigation is assumed to be available and the value of LPF is 1 (DOE, 2013). The ARF and RF are accident-specific and are established as follows.

8.1.1 Accident Release Fractions

The release fractions for a fire were obtained from a summary of a Sandia National Laboratory risk assessment for Mars 2020 (Clayton et al., 2014).

For an estimate of the expected value for peak blast overpressure, large rockets like the U.S. Saturn 5 and Russian N-1 are analyzed. NASA studies have indicated that the Saturn 5 would have an explosive force of less than 400 tons of trinitrotoluene (TNT) (Day, 2019), and the Soviet N-1 rocket explosion would be approximately 250 tons of TNT, although other sources estimate it as high as 1 kiloton (1,000 tons) of TNT range (Wikipedia, n.d.). Using 250 tons and the same simple model for surface explosions as before produces approximately 3400 psi at 10 m. The average of 150- and 400-tons TNT (325 tons TNT) is used as a reasonable estimate of blast overpressure.

To estimate the release fraction research conducted by the DOE, Nuclear Regulatory Commission (NRC), and their international partners were examined. This research examined the impact of high explosives on both fresh and spent nuclear fuel and stretches back into the 1980s. Using experimental data that was collected by Jardine (Jardine et al., 1982) and Ruhmann (Ruhmann et al., 1985), Durbin (Durbin et al., 2016) developed a function fit to the data for both high and low energy density regimes. In this work ARF x RF was taken to be the mass fraction of initial mass that was aerosolized to an aerodynamic equivalent diameter (AED) below 10 microns, which can enter the deep lungs.

The ARF x RF value is calculated for explosions using the 250-ton (1.05E+12 J) explosion as a frame of reference. Assuming the explosion is spherical, the reactor is approximately 10 m from the center, and the bottom of the reactor has a cross-sectional area of 0.3 square meter, approximately 0.000225 of the blast would hit the reactor. Then, if the reactor has a height of 1 m, the energy density for the reactor system is estimated to be 7.88E+08 J/m^3. Using the RRF$_{ALL}$ equation from Durbin shown on Figure 8-1, that yields an ARF x RF value of 0.012. However, for this analysis specifically, a conservative ARF x RF value of 0.02 was chosen for the explosion scenario. More information on the formulation of these values can be found in Andrews, McClure, and Blood (Andrews et al., 2021).

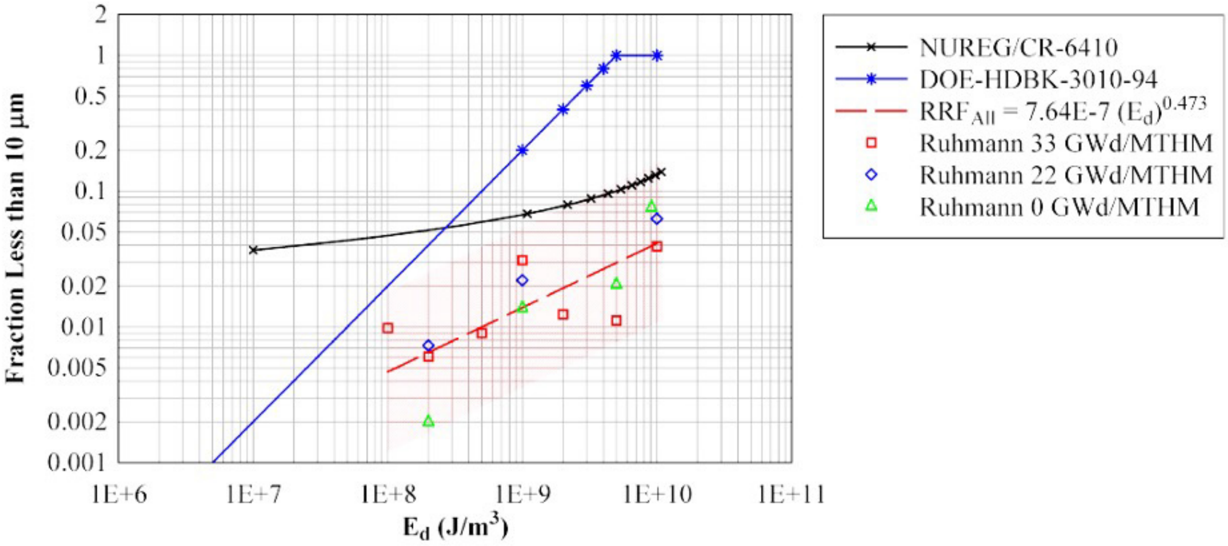

Figure 8-1. Release Fraction as a Function of Energy Density for Explosions

Short-term accidents are defined as ones where “the reactor has a step insertion of reactivity (initial burst) and the reactor self disassembles in an ‘explosive-like’ manner due to phase change of core materials.” Long-term accidents are defined as ones where “the reactor survives the initial burst and is in critical or pulsing critical condition for a long period.” This analysis considers both accident types with and without water present. Water is important as it can scrub or retain the fission products prior to their release to the atmosphere.

8.1.2 Consequence Analysis

Using the explosion scenario as the analyzed case, the ST is:

$$ST = 297 \text{ kg U} * 9.79E\text{-}6 \text{ Ci/g} * 1000 \text{ g/kg} * 1 * 1 * 0.02 = 5.8E\text{-}2 \text{ Ci}$$

This ST value corresponds to the most likely severe accident resulting in a release of uranium that would occur during the launch of the DRACO mission. However, more severe accidents are possible, although such accidents are less likely to occur. The most likely outcome of the launch is that the launch is successful and there is no radiation exposure to the general public

The second part of the consequence analysis uses the calculated ST to calculate a radiological dose:

$$\text{MEI Dose (rem)} = \text{ST} * \mathrm{X}/\text{Q} * \text{BR} * \text{DCF}$$

Where:

ST: Source term discussed above
X/Q: Dispersion factor, the effect of dissipation of the plume as it travels downwind
BR: Breathing rate, the amount of air inhaled per unit of time
DCF: Dose conversion factor, the amount of radiation dose per unit of inhaled uranium

The DCF is calculated based on the cumulative radiation dose that a person would receive for a period of 50 years following an inhalation exposure. The DCFs used in this assessment are consistent with the dose coefficients presented in Federal Guidance Report Number 13 (Eckerman et al., 1999; Eckerman and Leggett, 2010). All pathways were considered for conservatism, although non-inhalation pathways do not provide material contributions to the total effective radiation dose to the MEI.

8.1.3 Atmospheric Dispersion Calculation

Air dispersion calculations were performed using Version 2.07.1 of DOE's HotSpot model (LLNL, 2010), which is approved for use in safety analyses. This model is a single source Gaussian plume dispersion model that provides ground-level concentrations at user-specified distances from the release. The calculations are consistent with Equation A-11 of the Radiological Safety Analysis Computer (RSAC) Program Version 7.2 User's Manual (INL, 2010).

The X/Q factor is dependent on several variables relating to atmospheric dispersion, such as the wind speed, the degree of turbulence and the height of the release. Dispersion factors for a range of representative variables were reviewed from prior consequence analyses (INL, 2019, 2021). Actual X/Q factors are calculated in HotSpot. The following assumptions were made in the development of the atmospheric dispersion modeling.

- The parameters of the air dispersion conditions are standard default parameters in DOE-STD-3009-2014 (DOE, 2014). These standardized parameters establish the expected atmospheric dispersion and dose consequences to the MEI.
- Three meteorological conditions were assumed:
  - Pasquill stability class D with 80 m release elevation and 4.5 meters per second (m/s) windspeed, which represents the 50th percentile neutral meteorological conditions and is the most frequent of the stability classes, and
  - Pasquill stability class F with 80 m release elevation and 1 m/s windspeed, which represents the 95th percentile moderately stable meteorological conditions with minimal mixing and plume spread, and
  - Pasquill stability class F with 41 m release elevation and 1 m/s windspeed, which represents the 95th percentile moderately stable meteorological conditions with minimal mixing and plume spread.
- A deposition velocity of 0.1 centimeter per second for respirable particles (INL, 2021; DOE, 2014).
- The BR is established in DOE-STD-3009-2014 as 3.3E-04 m^3/s (DOE, 2014).

Low wind speeds are generally associated with atmospheric conditions that restrict dilution of released contaminants in air. Restrictive low wind speed conditions (e.g., 1 m/s) result in higher radiation doses from inhaled contamination, compared to typical wind speeds. Note that under low wind speed conditions, the plume may not arrive at the location for the MEI for several hours after the accident occurred. However, the MEI is assumed to remain at the plume centerline, the location of the highest uranium concentration, for the duration of the time required for complete passage of the plume.

As stated in DOE-STD-3009-2014, "accidents with unique dispersion characteristics, such as fires and explosions, may be modeled using phenomenon-specific codes that more accurately represent the release conditions." The deterministic accident scenario is a severe accident that involves a significant release of HALEU fuel. Such an accident, among other occurring lesser phenomena, primarily involves contact of the HALEU fuel (and its components which may be dispersed) with burning propellant long enough to oxidize and release uranium. A thermal event of this magnitude would result in a plume that rises into the air. Therefore, to more accurately represent the atmospheric transport and dispersion characteristics of such an accident, the dose consequence calculation included an elevated plume release.

The quantity of propellant involved in the plume rise determination affects the dose analysis because larger quantities release more thermal energy and therefore result in higher plume rise. For a given release quantity and dispersion conditions, the radiation dose to the MEI is inversely related to the height of the released plume. Therefore, smaller propellant quantities are consistent with a conservative release height and a conservative radiological analysis. This analysis is relatively insensitive to the specific launch vehicle that may be used in the DRACO mission, unless the selected vehicle is different enough to result in a material difference in the anticipated size or distribution of solid propellant fragments or liquid propellant mishaps. In such case the EA may be revived to reflect a change in the calculated consequences.

A range of potential fire and explosion scenarios associated with large launch vehicles were analyzed by Idaho National Laboratory for two source terms and a range of accidents with varying plume rise estimates (INL, 2021). The plume heights were calculated assuming F-stability or D-stability dispersion conditions. Radiation doses consequences were reported for launch vehicle accidents involving 1-, 5-, 10-, 20-, 1,000-, or 10,000-megawatt fires; and for 100-, 500-, 1,000-, 5,000-, 10,000-, or 82,500-pound TNT-Equivalent (TNT-Eq) explosions.

The INL analysis shows that the highest dose consequences are associated with the larger source term and accident conditions that result in a plume rise of 80 m to 130 m. For conservatism, a release height of 80 m was used in this analysis. The scenario that resulted in the highest relative exposure concentrations was also included to demonstrate the most pessimistic elevated plume release conditions that were analyzed by INL. This pessimistic scenario is characterized by a 41 m release elevation and F-stability dispersion with wind speed of at 1 m/s. The D-stability class with wind speed of 4.5 m/s represents average dispersion characteristics and is the most representative of expected atmospheric conditions during a launch.

For a uranium fire or explosion associated with a cold reentry in a late phase of the mission, the dispersion parameter 3.5E-3 m/s was applied from DOE-STD-3009-2014 as representative of an MEI near an accident site. This dispersion parameter is consistent with exposure during D-stability conditions for a ground-level release with 2 m/s to 3 m/s windspeed.

8.2 Uranium Accident Radiation Dose

The specific launch complex at CCSFS has not yet been selected. An 8 km distance generally reflects the closest distance to a member of the public in the Port Canaveral area. For this analysis, the MEI was assumed to be located at the point of maximum dose for each scenario. The maximum dose is typically the location where the concentrated radioactive material in the plume comes down to the elevation of a person's breathing zone. However, the maximum dose location is also influenced by skyshine, ground shine and resuspension exposures. The radiation dose at locations closer than 8 km generally reflect potential doses to workers or invited visitors on federal property. Access to these close in locations is controlled by NASA and the Space Force.

For the representative air dispersion condition of D-stability, HotSpot calculates the dose to the MEI would be 0.002 rem at a distance of 1 to 2 km. If F-stability conditions occurred, the dose could be 0.001 to 0.010 rem and the maximum dose location could be 3 to 10 km from the point of impact. The occurrence of D-stability is more likely than F-stability at the launch site and at potential accident locations worldwide.

The 0.002 rem TED dose represents a reasonable estimate of the expected maximum dose to an individual following a uranium release from a mishap involving the DRACO mission in an early phase of the mission. The uranium source term is reasonably conservative, and it follows that the 0.002 rem TED dose is also conservative, but unfavorable atmospheric conditions could result in higher doses for the uranium source term. The dose estimate is not sensitive to the location of the MEI because the MEI is assumed to be located at the plume centerline for the duration of the plume's passage where the plume comes down to ground level with maximum concentration.

For an MEI near a uranium fire accident site in a late phase of the mission, the calculated dose is 2.4 rem TED from inhalation during plume passage. This dose represents an accident scenario with a low thermal contribution and a ground-level release of a respirable uranium aerosol. In this scenario, the ground shine dose rate is less than 0.0001 rem/hr.

8.3 Uranium Accident Contaminated Land

HotSpot reports the centerline ground surface deposition after passage of the plume. Assuming a deposition velocity of 0.1 centimeter per second, D-stability and a 4.5 m/s windspeed, the contamination level would be less than 0.0002 microcuries per square meter (μCi/m^2). The maximum contamination under F-stability would be 0.0009 µCi/m^2. For a cold reentry of a reactor core at impact sites in a late phase of the mission, the calculated concentration is 0.22 µCi/m^2, which is equal to the regulatory standard.

The regulatory standard for control of uranium surface contamination on personal property is 5,000 disintegrations per minute per 100 square centimeters, which is approximately 0.227 µCi/m^2. This regulatory standard is also suitable for screening of surface contamination on soil during an emergency response. The calculated 0.0002 to 0.22 μCi/m^2 level of surface deposition of uranium resulting from a fire or explosion of the reactor covers a range of 0.1% to 100% of the regulatory limit for surface contamination. Therefore, no widespread mitigations related to contamination of soil or personal property from the plume are expected. In the case of a reactor core impact, the site would require remediation for removal of 297 kg of uranium metal. The uranium dispersed by the impact is calculated to be 6 kg of uranium.

8.4 Chemical Toxicity of Uranium

The atmospheric dispersion parameters used to model uranium radiation doses were used to calculate conservative estimates of potential intake and concentrations of chemical uranium in air. Occupational dose limits in 10 CFR Part 20.1201 also include a limit for the intake of soluble chemical uranium of 10 milligrams (mg) per week. The modeled intake for a uranium fire accident in the early and late phases of the mission ranges from 0.01 to 7 mg of uranium. These values are less than the 10 mg limit for intakes of uranium. The Occupational Safety and Health Administration regulations in 29 CFR Part 1910.1000 include the occupational permissible exposure limit (PEL) of 50 micrograms per cubic meter (μg/m^3) based on a time-weighted average concentration over an 8-hour period. The modeled concentration of uranium in air for a uranium accident in the early phase of the mission is 34 μg/m^3 for a 10-minute exposure, which corresponds to an 8-hour time-weighted average of 0.7 μg/m^3. This concentration is below the PEL. The calculation of uranium in air for a uranium accident in the late phase of the mission is 36,000 μg/m^3 for a 10-minute exposure, which is an 8-hour time-weighted average of 750 μg/m^3, which is above the 8-hour PEL.

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SECTION 9

Accidental Criticality Consequences

This section provides the methodology used for the dose consequence analysis following a potential accidental criticality excursion. In this accident scenario, the reactor core is deformed or otherwise experiences excess reactivity such that a nuclear chain reactor is created for a brief period of time. The chain reaction scenario creates fissions and results in thermal and mechanical destruction of the core, which terminates the nuclear reaction. A portion of the fission products created by the excursion are released to the atmosphere as gases, vapors or particulates. This consequence analysis includes a deterministic calculation similar to the consequence calculations for a uranium release.

For inadvertent criticality accidents, the source term is based upon the number of fissions that could occur. Several methods can be used to estimate the number of fissions in an accident, including:

- Dividing the amount of energy needed to reach the destructive limit of the core (sensible heat and heat needed for phase change) by the energy of a single fission,
- Using a slightly modified version of the Nordheim-Fuchs model that includes phase change, or
- From experimental data.

The number of fissions used to calculate dose consequences for a potential NTR criticality accident is based on guidance from experimental data compiled in NUREG/CR-6410. NUREG/CR-6410 provides a discussion of historical criticality accidents and develops guidance for safety analyses. For solid metal systems, the estimated number of fissions in an accident is 1.E+18. For a solid uranium system, NUREG/CR-6410 lists an estimate of 3.E+20 fissions. To be conservative, 1.E+19 fissions was applied to the NTR safety analysis.

Table 9-1 provides the fission product radioactive inventory, or MAR, in units of activity (Bq) for each gaseous radionuclide that would be in the NTP reactor core after a criticality excursion. Table 9-2 provides the inventory of the non-gaseous radionuclides in the fission product inventory.

Table 9-1. Gaseous Fission Products from a Criticality Excursion

Radionuclide	MAR Activity (Bq)
Kr-83m	7.49E+13
Kr-85m	4.55E+13
Kr-85	6.78E+06
Kr-87	5.56E+14
Kr-88	3.44E+14
Kr-89	2.33E+16
Xe-133	1.42E+09
Xe-133m	9.71E+09
Xe-135	2.73E+12
Xe-135m	1.72E+14
Xe-137	1.21E+16
Xe-138	5.26E+15

Kr = krypton

Xe = xenon

Table 9-2. Non-Gaseous Fission Products from a Criticality Excursion

Radionuclide	MAR Activity (Bq)
Cs-137	6.37E+09
Sr-91	1.62E+14
Sr-92	5.97E+14
Ba-139	1.32E+15
Ba-140	5.56E+12
I-131	3.74E+12
I-132	5.26E+14
I-133	8.70E+13
I-134	2.12E+15
I-135	2.63E+14
Ru-106	1.21E+10
Ce-143	5.26E+13
Rb-89 (from Kr-89)	4.90E+15
Cs-137 (from Xe-137)	2.92E+09

Ba = barium

I = iodine

Rb = rubidium

The deterministic accident scenario in this analysis assumes that the entire radioactive fission product inventory of the core is involved in the release: DR = 1. In accordance with DOE-HDBK-3010, no filtration or mitigation is assumed to be available and the value of LPF is 1 (DOE, 2013). The released K-89 decays to Rb-89 and the released Xe-137 decays to Cs-137. Therefore, a Rb-89 source term and an additional Cs-137 source term were added to the consequence calculations.

9.1 Criticality Excursion Accident Release Fractions

The criticality accident release fractions were established for each radionuclide by evaluating inadvertent criticality during either the launch phase or reentry phase, which can result in an impact on land or on water. The following four scenarios were examined:

- Case 1: short-term accident with no water present
- Case 2: short-term accident with water
- Case 3: long-term accident with no water present
- Case 4: long-term accident with water

The short-term accidents are defined as the “reactor has a step insertion of reactivity (initial burst) and the reactor self disassembles in an ‘explosive-like’ manner due to phase change of core materials.” The long-term accidents, on the other hand, are scenarios in which the reactor survives the initial burst and is in a critical pulsing condition for a long period. This analysis considers both accident types, with and without water present.

The four cases all use the same source term but specific ARF x RF values, which are based on expected values derived from experiments. The experiments include the measured releases from the KIWIT-TNT test, the SNAPTRAN-2 test, and the SNAPTRAN-3 test performed in the 1960s. The specific ARF x RF values are used to exemplify the differences between the different scenarios. More information on how these values were formulated is found in McClure and Blood's "Release Fractions for Inadvertent Criticality for Space Fission Reactor Launch Safety." A summary of the release fractions for each chemical group is shown in Table 9-3. The average value of ARF x RF was used to calculate the source term for each radionuclide. Consequences from "no water" scenarios represent impacts on land. These consequences would be higher than consequences from "water" scenarios. The release fractions presented in Table 9-3 are calculated from average ARF x RF values. The probability of any criticality excursion is less than 1.E-06.

Table 9-3. ARF x RF Values for Criticality Excursions

Group No.	Group Name	Case 1	Case 2	Case 3	Case 4	ARF x RF
		ST-NW	ST-W	LT-NW	LT-W	Avg.
1	Noble Gases	7.50E-01	7.00E-02	5.00E-01	3.00E-01	4.05E-01
2	Alkali Metals	7.00E-01	7.00E-03	2.00E-01	1.00E-01	2.52E-01
3	Alkali Earths	4.00E-02	4.00E-03	3.00E-02	2.00E-02	2.35E-02
4	Halogens	7.00E-01	7.00E-03	5.00E-02	3.00E-02	1.97E-01
6	Platinoids	4.00E-02	4.00E-04	2.00E-03	1.00E-03	1.09E-02
8	Tetravalent	4.00E-02	4.00E-04	4.00E-04	2.00E-04	1.03E-02
6B	Mod Rb-89	7.50E-01	7.00E-02	5.00E-01	3.00E-01	4.05E-01
2B	Mod Cs-137	7.16E-01	2.68E-02	2.94E-01	1.63E-01	3.00E-01

9.2 Criticality Excursion Radiation Dose

The radiation dose to a person exposed to a plume of radionuclides released following a criticality excursion is composed of several parts. The gamma radiation from the airborne gaseous radionuclides has the characteristic of cloud immersion, which is also called skyshine. The particulate radionuclides also exhibit this pathway, but also contribute to radiation dose by inhalation, ground shine, and resuspension.

Similar to the meteorological dispersion model developed for uranium accidents, the radiation dose to an individual following a criticality excursion was calculated at the point where the maximum dose occurs. This distance may differ between gaseous and particulate emissions. To be conservative, the maximum doses for each pathway, irrespective of distance, were summed to establish the maximum consequence. In this context, the particulate emissions include radionuclides that might be released as vapors that later cool and condense to fine particulate or otherwise attach to particulates. The radiation dose at locations closer or further than the maximum dose would be lower than the maximum dose under the conditions of this scenario. The maximum dose can be larger or smaller depending on the amount of energy released in the fire or explosion associated with the accident. The spacecraft would contain hydrazine and liquid hydrogen in addition to the NTR.

HotSpot calculates the dose to the MEI would be 0.14 rem from noble gas releases and 0.08 rem from particulate releases under representative air dispersion and conservative energy release conditions. Under these representative conditions, the maximum projected dose to the MEI is 0.22 rem at a distance of 1 to 2 km following a criticality excursion. If F-stability conditions occurred or the thermal energy released was smaller, the maximum dose could range from 0.018 rem to 0.40 rem and the highest dose location would be 1 km to 6 km from the point of impact of the spacecraft. The 0.22 rem TED dose represents a reasonably conservative estimate of the expected MEI dose following a criticality excursion from a mishap involving the DRACO mission because the number of fissions is conservative, and the MEI is located where the plume comes down to ground level and produces a maximum concentration of radioactive material at ground level. The MEI dose would likely occur on CCSFS or KSC property.

The criticality excursion would likely not result in individual radiation doses greater than 0.01 rem at distances beyond 10 km from the impact site. If F-stability dispersion occurred or the energy release was smaller, the 0.01 rem dose boundary could extend more than 20 km downwind. However, the D-stability model is representative of the likely air dispersion condition.

In addition to radiation doses associated with the criticality excursion, the consequences of a criticality event include the radiological consequences of a uranium fire and the associated chemical hazards. Exposure to radiation dose from uranium, as well as chemical plumes of uranium, lithium hydride, and beryllium are expected to occur at the low end of the exposure ranges calculated for a uranium fire scenario.

For an unlikely accident scenario following a launch vehicle mishap that causes the reactor to impact with the surface of the Earth during a late mission phase, the dose to the MEI was calculated without a thermal component, that is, the release occurs at ground level. Assuming D-stability and 4.5 m/s wind speed, HotSpot calculates the dose to the MEI would be 460 rem. The exposure to chemical uranium would be an 8-hour time-weighted average of 750 $\mu g/m^3$, which is above the 8-hour PEL of 50 $\mu g/m^3$. However, as noted previously, the probability of such an event is too low to be credible.

9.3 Criticality Excursion Contaminated Land

The noble gas releases in this scenario do not result in contaminated land or property surfaces. For the modeled particulate release, HotSpot calculates the centerline ground surface deposition after passage of the plume. Assuming D-stability and a 4.5 m/s windspeed, the maximum contamination level would be 160 $\mu Ci/m^2$ and the associated ground shine would be 0.0044 Roentgen Equivalent Man per hour (rem/hour) at a distance of approximately 1.5 km. This value is higher than regulatory limits for control of surface contamination on personal property for beta-gamma emitting radionuclides. In the event of F-stability conditions or lower thermal energy release, the surface contamination could range from 26 to 530 $\mu Ci/m^2$. The associated ground shine could be 0.0007 to 0.0150 rem/hour.

In this air dispersion scenario, the radioactive contamination is not deposited evenly throughout the area surrounding of the impact location. The air dispersion scenario assumes the radioactive material is carried by the wind in a relatively narrow plume. This assumption is pessimistic for calculating radiation dose to individuals. HotSpot calculates a downwind area equivalent to 6% of the total circumferential area would be contaminated. For a 20-km distance, approximately 79 square kilometers would be contaminated at a level requiring control or decontamination. For a 100 km distance, approximately 400 square kilometers would require contamination controls. If the contaminated area was populated, temporary relocation may be required.

This estimate of the amount of contaminated land is based on a pessimistic model of invariant wind direction. Using this model, the MEI dose and the potential concentration of radioactivity per unit area of land is maximized. If the wind direction is variable during the period of release and transport of the radioactive plume, the average concentration of the deposited radioactivity would be lower and the area that is contaminated would be higher.

The fission products produced by the criticality excursion have short half-lives and 99.997% of the deposited radioactivity would decay within a 30-day period. The maximum contamination level would be reduced from 160 $\mu Ci/m^2$ to approximately 0.0051 $\mu Ci/m^2$, and the ground shine would be less than 0.0001 rem/hour. After 30 days, the likely residual radioactivity in downwind locations would be less than 0.02 $\mu Ci/m^2$, which is below regulatory standards for control of surface contamination on soil or personal property (AEC, 1974; NRC, 1983, 1993). The ground shine radiation level would also be reduced to levels consistent with natural background radiation. Therefore, a quarantine up to 30 days may be required under this scenario for land

and personal property in some downwind locations until the radioactive contamination has decayed to background levels.

For agricultural land, specific U.S. Food and Drug Administration (FDA)-derived action levels are applicable to potential contamination of food crops. These FDA action levels only apply to specific long-lived radionuclides in the fission product inventory. These radionuclides are I-131, Cs-137 and Ru-106. After 90 days of decay, the I-131 would have decayed to negligible concentrations. The residual radioactive Cs-137 and Ru-106 would contribute less than 0.0001 rem/year of radiation dose from ingestion of food crops. This dose level is below the FDA's criteria for interdiction of foods (FDA, 1998), which are 0.5 rem TED or 5 rem to any organ of the body.

9.4 Additional Hazards

Other components of the NTR, specifically beryllium and lithium hydride, present additional potential hazards. Exposures could occur if mishaps cause releases of these materials as airborne plumes.

The atmospheric dispersion parameters used to model uranium radiation doses from an early phase and late phase uranium fire accident were also used to calculate conservative estimates of exposure concentrations of beryllium and lithium hydride in air. As a point estimate, the quantity of beryllium and lithium hydride available were each assumed to be equal to the quantity of uranium (approximately 297 kg). The release fraction was assumed to 0.000015 for beryllium and 0.0001 for lithium hydride (DOE-HNBK-3010).

The exposure standards in 29 CFR Part 1910.1024 include a short-term exposure limit (STEL) for beryllium of 2 $\mu g/m^3$ based on a 15-minute exposure period. The calculated air concentration for beryllium in a uranium fire during the early mission phases was 0.025 $\mu g/m^3$, which is equivalent to a 15-minute time-weighted average of 0.02 $\mu g/m^3$, below the STEL. The corresponding equivalent time-weighted average for a uranium fire accident in the late stages of the launch is 20 $\mu g/m^3$, above the STEL.

Atmospheric dispersion of beryllium was also evaluated for the SP-100 program (Coppa, 1988). The evaluation assumed approximately 600 kg of beryllium in the reactor system. Peak concentrations were several hundred micrograms per cubic meter within 10 km of the launch site and greater than 0.2 micrograms per cubic meter tens of kilometers from the accident. The evaluation for the SP-100 program applied a different approach to calculating dispersion near the source of a plume, compared to the present assessment. Taking this into consideration, the results are consistent with the present calculations.

The potential impacts from beryllium used in optical mirrors and windows, as well as in structural and electrical components, have been previously evaluated for launching routine payloads (NASA, 2011). For an accident at the launch site, thermal conditions following exposure to burning solid propellant were not expected to cause a release of beryllium. For early phase launch accidents, it is unlikely that beryllium in the reactor system would be exposed long enough to burning propellant to result in a release. During reentry, the beryllium would be eroded to small particles that enter the atmosphere and the potential hazard is mitigated by dilution at high elevations since the particles would be dispersed throughout the Earth's atmosphere before any particles would reach ground (NASA, 2011). Compared to NASA's assessment in 2011, the present calculations are conservative.

The risks of beryllium exposures in launch mishaps have been evaluated in previous EAs and EISs that considered the probabilities and consequences of launch mishaps involving beryllium. The risks associated with the incorporation of beryllium in payloads were not found to present significant impacts (NASA 1994, 1997, 2002, 2005, 2011, 2014b, 2020a).

For lithium hydride, the regulatory basis in 29 CFR Part 1910.1000 includes an occupational PEL of 25 $\mu g/m^3$ based on a time-weighted average over an 8-hour period. The calculated air concentration for lithium hydride in a uranium fire during the early mission phases was 0.17 $\mu g/m^3$, which is equivalent to an 8-hour time-weighted average of 0.004 $\mu g/m^3$, below the PEL. The corresponding equivalent time-weighted average for a uranium fire accident in the late stages of the launch is 4 $\mu g/m^3$, below the PEL.

Long-term Reentry

The relatively low burn time planned for the demonstration test of the NTR would mitigate the potential accumulation of fission and activation radionuclides in the NTR's core at the time of hot reentry. Mission parameters and engineered safety systems would ensure that scenarios involving premature reentry are not credible. Therefore, this scenario represents the dose consequences following long-term reentry at the end of the mission.

The dose consequence for the long-term reentry scenario is calculated by assuming that the reactor core survives reentry heating and returns to Earth intact after about 300 years of decay storage in orbit. After about 300 years of decay, most of the radiation dose calculated for the hot reentry scenario is due to long-lived radionuclides. Radionuclide decay in subsequent years is miniscule. There is no significant reduction in radiation dose from additional decay in orbit. The total amount of radioactivity in the core is shown in Table 10-1.

Table 10-1. NTR Long-term Reentry Radionuclide Inventory

Radionuclide	Activity (Ci)
Sr-90	0.01
Y-90	0.01
Ba-137m	0.02
Cs-137	0.02
Sm-151	0.06
U-234	2.70
U-235	0.12
U-238	0.08
Th-230	0.00
Th-231	0.12
Th-234	0.08
Pa-234m	0.08
Pu-239	0.22

Sm = samarium

The impact of the bare reactor core is assumed to create a concentrated source of radioactive emissions. This is a pessimistic assumption that overestimates radiation doses, compared to a scenario when the reactor core returns in pieces or is otherwise distributed over a wide area. The potential consequences include radiation doses from a plume of airborne radioactivity as well as direct radiation exposure to discrete metal or fuel components.

For an MEI near the site of the long-term reentry impact, the calculated dose is 2.4 rem TED, assuming the DOE standard dispersion factor for a receptor located 100 m from the point of release. This dose represents an accident scenario with a low thermal contribution and a ground-level release of a respirable uranium aerosol with a small amount of additional fission and activation products.

The radioactive surface contamination in this scenario would result in a ground shine radiation dose rate of approximately 2E-08 rem/hour at a downwind distance of 100 m. If a person approached the reactor core after impact, the external dose rate would be 0.023 rem/hr at 1 m. A person would have to be exposed to the higher dose rate for 4 hours in order to receive a total dose of 0.1 rem, which is the regulatory annual dose limit for members of the general public. The surface deposition would be approximately 0.22 μCi/m^2 at a distance of 100 m (0.1 km) from the point of impact. The surface deposition of the radionuclide mixture would be reduced below regulatory limits at distances greater than 0.1 km. Ground surface deposition of Pu-239 would be measurable in some locations. The calculated ground surface deposition of uranium would be identical to the uranium fire or explosion scenario for a late mission phase impact.

The above scenario assumes that the reactor or major components survive reentry essentially intact. If the reactor enters the atmosphere as debris or disintegrated material, the resulting average concentrations of radioactive material and associated radiation dose rates would be lower than the above scenario and the contaminated area would be larger. In the case of the reentry of the Russian Kosmos 954 spacecraft in 1977, a hot reentry resulted in radioactive debris spread over approximately 40,000 square miles (100,000 square kilometers) of northern Canada. The radioactive fuel was dispersed as small particles that were surveyed and removed using aircraft equipped with radiation surveying instruments.

The debris recovered after the reentry of Kosmos 954 also included several intact structural components with dose rates as high as 200 rem/hour. Intact structural debris is expected in the event of a hot reentry. Structural components or discrete fragments of reactor fuel could exhibit high local dose rates, compared to the air dispersion scenarios.

The most analogous project to DRACO is the Rover/NERVA project. Westinghouse Astronuclear Laboratory (WANL) performed much of the early safety analysis for the Rover/NERVA project and examined hot reentry. WANL's efforts are documented in the Flight Safety Program Review (Westinghouse Astronuclear Laboratory, 1965). As part of this early safety analysis, WANL examined an accident where the reactor breaks into individual fuel elements. The accident analyzed by WANL assumes the individual fuel elements reenter in an intact condition and remain intact upon impact to the Earth. An analysis by the Los Alamos National Laboratory of the earlier WANL work scaled the proposed DRACO reactor profile to Rover/NERVA project data. This analysis showed that direct doses from intact fuel elements should be considered.

Using the EOL source term for the DRACO mission, a dose of 0.1 rem was calculated for a member of the public at a distance of 1 m from the intact reactor core. Structural components with activation radionuclides could be dispersed during reentry and could also result in potential direct external dose rate to a member of the public. Potential exposure rates to activation radionuclides in structural components are expected to be less than dose rates from exposure to intact fuel elements. This dose calculation uses the default exposure period in HotSpot as a point estimate of the exposure time for a member of the public who dwells 1 m from the impacted core. Truncating the exposure rate after 4 hours of exposure assumes that corrective measures would be employed by governments to retrieve the reactor fuel and isolate human populations. The intact reentry scenario would not result in significant long-term contamination of land. In the intact reentry scenario, the 297-kg core is essentially intact. A remediation effort would be required to remove the core and adjacent dispersed radioactive material. However, the area subject to remediation is expected to be minimal.

In addition to radiation doses associated with the impact of the reactor core, the consequences of this scenario include chemical hazards. Exposure to chemical uranium and beryllium plumes are expected to occur at the high end of the ranges calculated for a uranium fire scenario. The lithium hydride component of the payload is expected to disperse in the upper atmosphere due to the heat of reentry and the lithium hydride is not expected to present a chemical hazard at the location of the long-term reentry impact.

SECTION 11

Summary of Consequence Calculations

The radiation dose consequences to an expected MEI are presented in Tables 11-1 and 11-2.

Table 11-1. DRACO Credible Accident Probabilities and Consequences

Launch Phase	Activity	Probability of Release	MEI Dose (rem)
Phase 0	Prelaunch		
	Uranium	1.E-03	0.002
	Criticality	***	0.22
Phase 1	Early Launch		
	Uranium	8.E-03	0.002
	Criticality	***	0.22
Phase 2	Late Launch		
	Uranium	9.E-03	0.002
	Criticality	***	0.22
Phase 3	Suborbital Flight		
	Uranium	3.2E-02	2.4
	Criticality	***	460
Phase 4	Orbital Flight		
	Uranium	1.2E-02	2.4
	Criticality	***	460
Phase 5	NTR Testing		
	Long-term Reentry	9.24E-1	2.4
	Criticality per Mission***	1.E-06	

Table 11-2. Summary of Credible DRACO Accidents

Accident Scenario	Probability of Release	MEI Dose (rem)
Uranium Fire/Explosion	6.E-02	0.002 to 2.4
Criticality	1.0E-06	0.22 to 460
Long-term Reentry	9.24E-01	2.4

Calculated intakes of chemical uranium were below the occupational limit of 10 mg. The modeled air concentrations of lithium hydride were below the Occupational Safety and Health Administration occupational PEL for all uranium fire scenarios. For exposure to beryllium, the calculated concentrations were 10 times lower than the STEL for early phase accidents and 10 times higher than the STEL for late phase accidents.

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