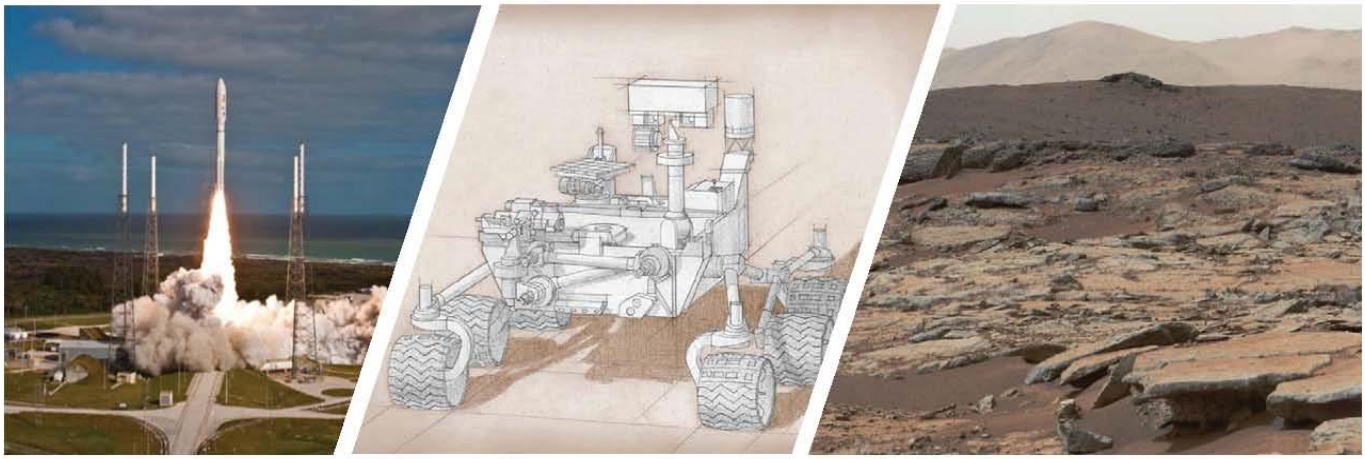
National Aeronautics and Space Administration



Draft Environmental Impact Statement for the Mars 2020 Mission

June 2014

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

Availability of the Draft Environmental Impact Statement for the Mars 2020 Mission

NASA will maintain a website that provides the public with the most up-to-date project information, including electronic copies of the EIS, as they are made available. The website may be accessed at *http://www.nasa.gov/agency/nepa/mars2020eis*

Comments on this Mars 2020 Mission DEIS may be submitted by any of the following means:

- Web site: http://www.nasa.gov/agency/nepa/mars2020eis
- Email: Comments by electronic mail may be sent to mars2020-nepa@lists.nasa.gov.
- Mail: Mr. George Tahu, Planetary Science Division, Science Mission Directorate, Mail Suite 3E46, NASA Headquarters, Washington, DC 20546-0001.

DRAFT ENVIRONMENTAL IMPACT STATEMENT FOR THE MARS 2020 MISSION

ABSTRACT

LEAD AGENCY:	National Aeronautics and Space Administration Washington, DC 20546
COOPERATING AGENCY:	U.S. Department of Energy Washington, DC 20585
POINT OF CONTACT FOR INFORMATION:	George Tahu Planetary Science Division Science Mission Directorate NASA Headquarters Washington, DC 20546 (202) 358-4800
DATE:	June 2014

This Draft Environmental Impact Statement (DEIS) has been prepared by the National Aeronautics and Space Administration (NASA) in accordance with the National Environmental Policy Act (NEPA) of 1969, as amended, to assist in the decision-making process for the proposed Mars 2020 mission. This Environmental Impact Statement (EIS) is a tiered document (Tier 2 EIS) under NASA's Programmatic EIS for the Mars Exploration Program.

The Proposed Action addressed in this DEIS is to continue preparations for and implement the Mars 2020 mission. The Mars 2020 spacecraft would be launched on an expendable launch vehicle during a launch opportunity from July through August 2020. The Mars 2020 spacecraft would deliver a large, mobile science laboratory (rover) with advanced instrumentation to a scientifically interesting location on the surface of Mars early in 2021. The design of the Mars 2020 spacecraft and rover would be based upon and similar to that used in the 2011 Mars Science Laboratory Mission, including the use of a Multi-Mission Radioisotope Thermoelectric Generator.

The purpose of the Mars 2020 mission would be to continue NASA's in-depth exploration of Mars. The mission described by the Mars 2020 Science Definition Team Report provides a basis for the proposed Mars 2020 mission recommending it consist of a science-focused, highly mobile rover designed to explore and investigate in detail a site on Mars that was likely once habitable. The mission concept includes new *in situ* scientific instrumentation designed to seek signs of past life. This instrumentation would be used to select a suite of samples that would be stored in a sealable cache that could be returned to Earth by a future mission. The mission would also demonstrate new technology for future exploration of Mars (both robotic and human missions).

This DEIS presents descriptions of the proposed Mars 2020 mission, spacecraft, and candidate launch vehicles; an overview of the affected environment at and near the launch site and globally; and the potential environmental consequences associated with the Proposed Action and alternatives, including the No Action Alternative.

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EXECUTIVE SUMMARY

This Draft Environmental Impact Statement (DEIS) for the Mars 2020 mission has been prepared in accordance with the National Environmental Policy Act of 1969, as amended (NEPA), (42 U.S.C. 4321 et seq.); Executive Order 12114, *Environmental Effects Abroad of Major Federal Actions*; the Council on Environmental Quality (CEQ) regulations for Implementing the Procedural Provisions of NEPA (40 CFR parts 1500-1508); and the National Aeronautics and Space Administration's (NASA's) NEPA policy and procedures (14 CFR subpart 1216.3).

This DEIS for the Mars 2020 mission is a tiered document (Tier 2 EIS) under the Mars Exploration Program (MEP). The Mars 2020 DEIS will focus on reasonable alternatives to implement the purpose and need of the Mars 2020 mission and the potential environmental impacts associated with each alternative.

The purpose of this DEIS is to assist in the decision-making process concerning the Proposed Action and Alternatives, including the No Action Alternative, for the proposed Mars 2020 mission planned for launch in 2020. This DEIS provides information associated with potential environmental impacts of implementing a proposed Mars 2020 mission, which would employ new *in situ* scientific instrumentation in order to seek signs of past life, select and store a promising suite of samples in a returnable cache, and demonstrate technology for future robotic and human exploration of Mars. NASA's proposed Mars 2020 mission would use the proven design and technology developed for the Mars Science Laboratory (MSL) rover Curiosity that arrived on Mars in August 2012. Like Curiosity, the proposed Mars 2020 rover would be powered by a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). NASA would select a scientifically important landing site based upon data from past and current missions.

PURPOSE AND NEED FOR ACTION

The purpose of the proposed Mars 2020 mission would be to both conduct comprehensive science on the surface of Mars and demonstrate technological advancements in the exploration of Mars. Mars 2020 mission investigations would reflect several of the high-priority scientific investigations recommended to NASA by the planetary science community. The overall scientific goal would be to address the questions of habitability and the potential origin and evolution of life on Mars.

NASA further characterized these mission objectives in an Announcement of Opportunity (AO) released on 24 September 2013 (NASA 2013d) for the competitive acquisition of payload investigations for the Mars 2020 mission as follows:

- Characterize the processes that formed and modified the geologic record within a field exploration area on Mars selected for evidence of an astrobiologically relevant ancient environment and geologic diversity.
- Perform astrobiologically-relevant investigations on the geologic materials at the landing site.
- Assemble a returnable cache of samples for possible future return to Earth.

- Contribute to the preparation for human exploration of Mars by making significant progress towards filling at least one major Strategic Knowledge Gap (gaps in knowledge or information required to reduce risk, increase effectiveness, and improve the design of robotic and human space exploration missions).

In addition to the objectives identified as part of the AO, NASA would also retain the objective, as identified by the Mars 2020 Mission Science Definition Team, of demonstrating improved technical capabilities for landing and operating on the surface of Mars for the benefit of future Mars missions.

ALTERNATIVES EVALUATED

This DEIS for the Mars 2020 mission evaluates the following alternatives in sufficient detail to make a meaningful comparison of technical feasibility and potential environmental impacts.

- **Proposed Action (Alternative 1) [NASA's Preferred Alternative] —** NASA proposes to continue preparations for and implement the Mars 2020 mission to the surface of Mars. The proposed Mars 2020 spacecraft would be launched on board an expendable launch vehicle from Kennedy Space Center (KSC) or Cape Canaveral Air Force Station (CCAFS), Brevard County, Florida, during a 20-day launch opportunity that runs from July through August 2020, and would be inserted into a trajectory toward Mars. Should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022. The rover proposed for the Mars 2020 mission would utilize a radioisotope power system to continually provide heat and electrical power to the rover's battery so that the rover could operate and conduct science on the surface of Mars.

- **Alternative 2 —** In this Alternative, NASA would discontinue preparations for the Proposed Action (Alternative 1) and implement an alternative configuration for the Mars 2020 mission to Mars. The Mars 2020 rover would utilize solar power as its source electrical power to operate and conduct science on the surface of Mars. The alternative Mars 2020 spacecraft would still be launched on board an expendable launch vehicle from KSC or CCAFS, Brevard County, Florida, during a 20-day launch opportunity that runs from July through August 2020, and would be inserted into a trajectory toward Mars. Like Alternative 1, should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022.

- **Alternative 3 —** In this Alternative**,** NASA would discontinue preparations for the Proposed Action (Alternative 1) and implement an alternative configuration for the Mars 2020 mission to Mars. The Mars 2020 rover would utilize solar power as its source of electrical power to operate and conduct science on the surface of Mars. The rover thermal environment would be augmented by the thermal output from Light-Weight Radioisotope Heater Units (LWRHUs) to help keep the rover's onboard systems at proper operating temperatures. The Mars 2020 spacecraft would still be launched on board an expendable launch vehicle from KSC or

CCAFS, Brevard County, Florida, during a 20-day launch opportunity that runs from July through August 2020, and would be inserted into a trajectory toward Mars. Should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022.

- **No Action Alternative** — Under this alternative, NASA would discontinue preparations for the Mars 2020 mission and, in turn, the spacecraft would not be launched.

FUNCTIONAL AND SCIENCE CAPABILITIES AND RISKS

ALTERNATIVES 1, 2, and 3. The Mars 2020 rover designs in both the Proposed Action (Alternative 1) and Alternatives 2 and 3 would carry the same science instruments; therefore, each of the three alternatives would have common mission science objectives. The main difference between these three alternatives is that the radioisotope-powered rover, using an MMRTG, proposed for Alternative 1 would be capable of operating for a full Martian year within a significantly broader range of latitudes on Mars than either of the solar-powered rovers (Alternatives 2 and 3). The capability to land the rover within a broad range of latitudes is important because doing so maintains NASA's flexibility to select the most scientifically interesting location on the surface and would maximize the rover's capability to collect the most desirable surface samples and conduct comprehensive science experiments.

A pure solar mission (Alternative 2), with current state-of-the-art solar arrays that remain 40 percent dust free[1] with MSL heritage avionics and mechanical systems (e.g., actuators) would not be feasible for an entire Martian year at any latitude. If one assumes that the solar arrays would remain 70 percent free of dust, then a mission would be possible at a narrow band of southern latitudes between 0-5° degrees. With current dust mitigation technology, operation over a larger latitude range for an entire year is not possible. To extend the range of operations, new dust mitigation technology would require development and flight certification.

A solar mission with the same state-of-the-art solar arrays, the same assumption that the solar arrays remain 40 percent free of dust, and the addition of LWRHUs (Alternative 3), allow for some half-year missions in northern latitudes as well as a full year constrained mission in a latitude band between 5-20° south latitude. The drawback of the southern latitude missions is that periods of constrained science operations and hibernation would be necessary. In hibernation, all science operations would be halted and only activities needed for the rover to survive would be performed. If one assumes that the solar arrays remain 70 percent free of dust, then a mission would be possible between 20° south and 20° north latitudes. Even with this improved operating range, there would be periods of constrained science operation and hibernation.

[1] Note that of the solar-powered Mars Exploration Rovers (MERs), Opportunity has remained at least 40% dust free for the entire mission to date, while Spirit experienced high dust accumulation following a global dust storm; and at one point in the mission had less than 25% dust free solar arrays.

Any of the solar-powered mission architectures would be expected to increase the technical risk and resulting cost of mission design and development. A number of design changes (modifications from the Curiosity heritage design) would also be necessary to modify the rover's power control electronics. Small increases in rover mass on the order of less than10 kilograms (22 pounds) may also be expected relative to the baseline MMRTG powered rover, primarily in the area of the solar array support structure. The rover's thermal design would have to be amended as well, since survival heating would be provided by electrical output as opposed to any use of the MMRTG thermal energy. The changes required to accommodate solar power for the Mars 2020 rover could potentially impact the accommodation of science instruments for the mission.

Should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022. The science potential associated with Alternatives 1, 2, and 3 with a 2022 launch would be similar to those projected for each alternative with a 2020 launch. Under all circumstances, an MMRTG-powered rover would provide more power and heat for science activities.

No Action Alternative. Under the No Action Alternative, NASA would discontinue preparations for the Mars 2020 mission and the spacecraft would not be launched. Therefore, none of the recommended science objectives would be met.

ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION AND THE ALTERNATIVES

For the proposed Mars 2020 mission, the potentially affected environment would include the areas on or near the vicinity of the launch site and portions of the global environment. For each of the alternatives, the potential non-radiological and radiological environmental consequences of launch site preparation for and launch of the Mars 2020 mission are summarized below. The non-radiological consequences associated with Alternatives 1, 2, and 3 have been addressed in prior U.S. Air Force (USAF) and NASA environmental documents (NASA 2011, USAF 2000). DOE's preparation of an MMRTG or LWRHUs for the proposed Mars 2020 mission would be very similar to their process in preparing the nearly identical MMRTG for the MSL mission. The environmental impacts of preparing an MMRTG by the DOE for the Mars 2020 mission have already been evaluated in existing DOE NEPA documents (DOE 1993, 2000, 2002, 2002b, 2008, 2013).

The evaluations presented in this DEIS are based on representative configurations of Atlas V, Delta IV Heavy, and the Falcon Heavy class of expendable launch vehicles. NASA considers these evaluations to adequately bound the potential environmental consequences of the alternatives described in this DEIS.

Environmental Impacts of a Normal Mission

Alternatives 1, 2, and 3. The environmental impacts associated with successfully implementing either the Proposed Action (Alternative 1), Alternative 2, or Alternative 3 would principally be with the exhaust emissions from the launch vehicle. These impacts were addressed in the *Final Environmental Assessment for Launch of NASA Routine Payloads on Expendable Launch Vehicles* (Routine Payload EA) (NASA 2011) for all candidate launch vehicles. These effects would include short-term impacts on air quality from the exhaust cloud at and near the launch pad, and short-term acidic deposition on the vegetation and surface water bodies at and near the launch complex. These effects would be transient and there would be no long-term or cumulative impacts to the environment. Some short-term ozone degradation would occur along the flight path of the vehicle as the vehicle passes through the stratosphere and deposits ozone-depleting chemicals (primarily hydrogen chloride) from its solid rocket boosters. These effects would be transient and no long-term or cumulative impacts to the ozone layer would be expected (USAF 2000).

No Action Alternative. There would be no environmental impacts associated with the No Action Alternative.

Non-Radiological Environmental Impacts of Potential Launch Accidents

Alternatives 1, 2, and 3. Non-radiological accidents could occur during preparation for and launch of the Mars 2020 spacecraft at the KSC or CCAFS. As with the impacts associated with a successful launch, these impacts were addressed in the *Final Environmental Assessment for Launch of NASA Routine Payloads on Expendable Launch Vehicles* (Routine Payload EA) (NASA 2011) for all candidate launch vehicles. The two non-radiological accidents of principal concern for the proposed Mars 2020 mission would be a liquid propellant spill associated with fuel loading operations and a launch vehicle accident. Propellant spills or releases would be minimized through standard remotely operated actions that close applicable valves and safe the propellant loading system. Propellant loading would occur only shortly before launch, further minimizing the potential for accidents.

Range Safety at CCAFS uses models based on dozens of past launches over many years to predict potential launch hazards to the public and to launch site personnel prior to a launch. These models are used to calculate the risk of injury resulting from exposure to potentially toxic exhaust gases from normal launches, and from exposure to potentially toxic concentrations of propellant, blast overpressure, or debris due to a failed launch. A launch could be postponed if the predicted collective risk of injury from exposure to toxic gases, blast overpressure, or debris, exceeds acceptable established limits (USAF 2004).

A launch vehicle accident on or near the launch area during the first few seconds of flight could result in the release of the propellants onboard the launch vehicle and the spacecraft. The resulting emissions from the combusted propellants would chemically resemble those from a normal launch. Debris would be expected to fall on or near the launch pad or into the Atlantic Ocean. Modeling of postulated accident consequences with meteorological parameters that would result in the greatest concentrations of

emissions over land areas (as reported in previous USAF environmental documentation (NASA 2011)) indicates that the emissions would not reach levels threatening public health. As indicated above, Range Safety confirms prior to launch that public safety would be assured even in the event of a launch accident.

No Action Alternative. Under the No Action Alternative, NASA would not complete preparations for the Mars 2020 mission. The No Action Alternative would not involve any of the environmental impacts associated with potential launch-related accidents.

Potential Radiological Environmental Impacts of Launch Accidents

A principal concern associated with the launch of the proposed Mars 2020 mission involves potential launch vehicle (LV) accidents that could result in the release of some of the radioactive material onboard the spacecraft. Under Alternative 1, the Mars 2020 rover electrical power would be supplied by one MMRTG, which would use the natural decay of its radioisotope fuel to produce electricity. The MMRTG contains 4.8 kg (10.6 lb), or approximately 60,000 curies, of plutonium dioxide (consisting primarily of plutonium-238). Alternative 3 complements the power from solar arrays with up to 71 LWRHUs, each containing a pencil eraser-sized pellet of approximately 2.7 grams, or (a total of 192 grams (0.42 lb)), 33 curies (a total of 2,300 curies), of plutonium dioxide (also primarily plutonium-238). In addition, the rover designs proposed for alternatives 1, 2, and 3 for the Mars 2020 mission may incorporate science instruments that make use of small quantities of radioisotope sources. Alternative 2 would not involve any radioactive material other than what may be used in selected science instruments.

The U.S. Department of Energy (DOE) provides the MMRTG/LWRHUs for the Mars 2020 mission and would retain responsibility for the plutonium during both the preparation and launch of the mission and in the event of a launch accident. As a cooperating agency, DOE has prepared the *Nuclear Risk Assessment for the Mars 2020 Mission Environmental Impact Statement* (SNL 2014). The nuclear risk assessment for the Mars 2020 mission considers: (1) potential accidents associated with the launch, their probabilities and accident environments; (2) the response of the MMRTG, LWRHUs, and science instrument sources to such accidents in terms of the release probabilities and estimated amounts and form of radioactive material released; and (3) the radiological consequences and risks associated with such releases.

Information on potential launch vehicle accident scenarios and related probabilities was developed by NASA based on information provided by the potential launch service providers and the spacecraft provider. DOE then assessed the response of the MMRTG, LWRHUs, and the science instrument radionuclides to these accident environments, and estimated the amount of radioactive material that could be released. Finally, DOE determined the potential consequences of each release to the environment and to the potentially exposed population. Accidents were assessed over all mission launch phases—from pre-launch operations through escape from Earth orbit—and consequences were assessed for both the regional population near the launch site and the global population.

Results of the risk assessment for this DEIS show that the most likely outcome of implementing the Proposed Action (Alternative 1) would be a successful launch with no

release of radioactive materials. However, the risk assessment did identify potential launch accidents that, while not expected, could result in a release of radioactive material in the launch area for accidents occurring early in the launch, in southern Africa for events resulting in a suborbital reentry, and in other global locations following orbital reentry. In each of these regions, the probability of an accident resulting in a release of radioactive material would be, at worst, 1 in 150 for the instrumentation radiological sources, 1 in 3,800 for the MMRTG, and 1 in 16,000 for the LWRHUs.

The radiological impacts for each postulated accident were calculated in terms of (1) impacts to individuals in terms of the maximum individual dose (the largest expected dose that any person could receive for a particular accident); (2) impacts to the population in terms of the potential for additional latent cancer fatalities due to a radioactive release (i.e., cancer fatalities that are in excess of those latent cancer fatalities which the general population will normally experience from all causes over a long-term period following the release); and (3) impacts to the environment in terms of land area contaminated at or above specified levels. The analysis conservatively assumes no mitigation actions, such as sheltering and exclusion of people from contaminated land areas. NASA would develop a Radiological Contingency Plan that would be implemented in the event of an accident. This plan would identify mitigation actions designed to minimize radiological impacts.

Potential environmental contamination was evaluated in terms of areas exceeding various specific screening levels and dose-rate-related criteria. For this DEIS, land areas would be considered to be contaminated to the point of requiring detailed characterization for potential cleanup actions when radiological deposition exceeds a screening level of 0.2 microcuries per square meter ($\mu Ci/m^2$) (SNL 2014).

Should any active decontamination be required, the costs associated with these efforts could vary widely depending upon the characteristics of the contaminated area and its size. Previous estimates by the Environmental Protection Agency (EPA), adjusted for inflation to 2013 dollars, for general land/water radiological cleanup, range from $110 million to $600 million per square kilometer or about $285 million to $1.6 billion per square mile) (Chanin et al. 1996).

Should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022. Since this launch period is in a similar season as the 2020 launch period, the projected radiological impacts would be similar, with only a small increase in population impacts due to population growth. Thus, within the overall uncertainties, the radiological impacts associated with a 2022 launch would be the same as those for the proposed 2020 launch.

Alternative 1: As shown in Figure ES-1, the most probable outcome is a successful launch. In the event of a launch accident, most accidents do not result in the release of plutonium dioxide. Between one and two percent of the launch accidents do however result in a release. These accidents may occur near the launch area, resulting in a release within the launch area; or they may occur later in the launch and result in a release beyond the launch area. The risk assessment shows that for the Mars 2020 mission using an MMRTG:

- There is a 97.5% chance of a successful launch.
- There is a 2.5% chance of a launch accident.
- There is a 1 in 2,600 chance of a launch accident that would release plutonium dioxide.
  - There is a 1 in 11,000 chance of a launch accident that would result in a release of plutonium dioxide in the launch area.
  - There is a 1 in 3,500 chance of a launch accident that would result in a release of plutonium dioxide outside the launch area.
- No radiological fatalities would be expected to occur as a result of any accident.
- The average maximum dose to any member of the public from an accident with a release would be equal to about 3 months of exposure to natural background radiation for a person living in the United States.

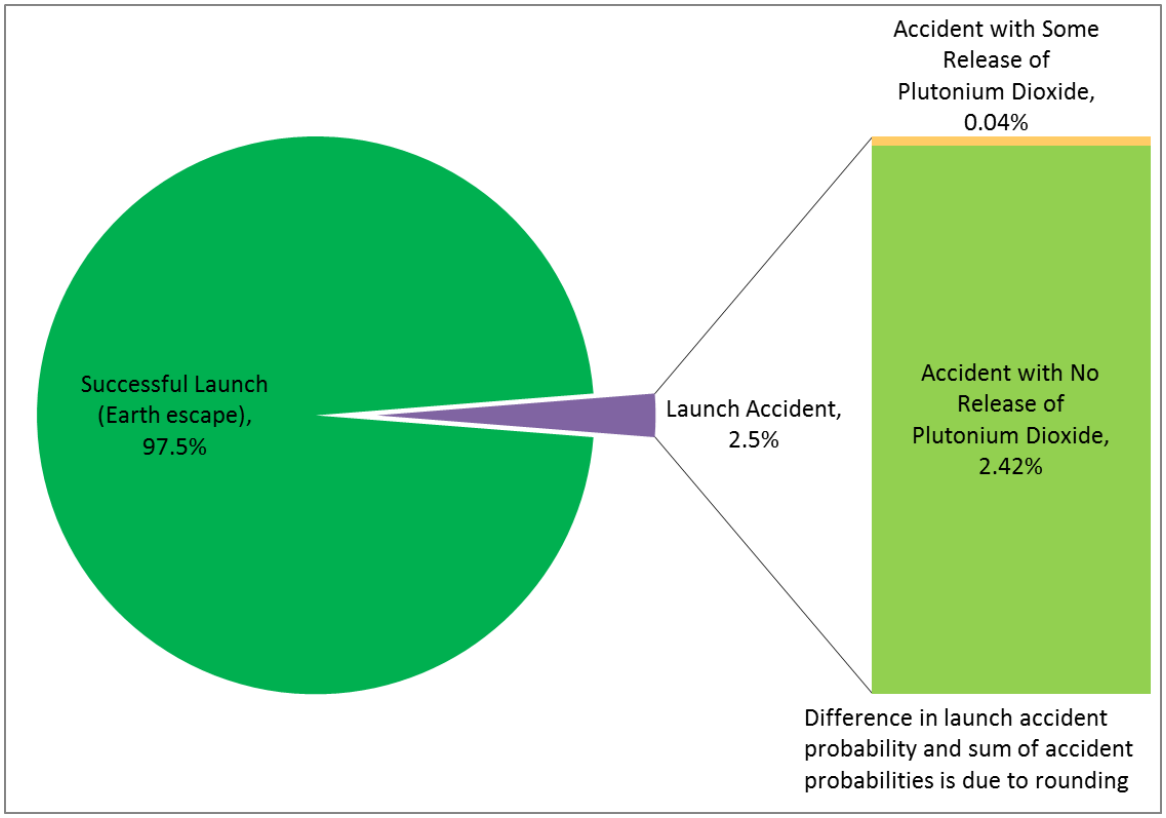

Figure ES-1: Alternative 1 - MMRTG Accident Probabilities

The accident probabilities and mean consequences are the result of the summation of individual accidents that have a wide range of consequences and probabilities. For launch-related issues that could occur prior to launch, the most likely result would be a safe hold or termination of the launch countdown with no radiological consequences. After lift-off, most accidents would lead to activation of safety systems that would result in automatic or commanded destruction of the launch vehicle.

For post launch accidents near the launch area that result in a radiological release, the predicted mean radiological dose to the maximally exposed individual would be about 0.06 rem. The probability for such an accident is about 1 in 11,000. No near-term

radiological health effects would be expected from such an exposure. Each exposure would, however, yield an increase in the statistical likelihood of a latent cancer fatality over the long term. For a launch area accident resulting in a release, a mean of 0.29 additional latent cancer fatalities could occur among the potentially exposed members of the local and global populations.

The risk assessment concludes that the average land contamination above 0.2 μCi/m^2 for all launch area accidents that result in a release is 7.4 km^2 (less than three square miles).

For accidents that occur prior to or shortly after the spacecraft reaches Earth orbit for which debris could impact land, the total probability of an accident resulting in a release during this phase is about 1 in 68,000. The maximum (mean value) dose received by an individual close to the impact site would be about 0.043 rem. The collective dose received by all individuals within the potentially exposed global population would result in about 0.20 mean additional latent cancer fatalities within the exposed population.

For accidents after the spacecraft reaches Earth orbit during which debris could impact land, the total probability of an accident resulting in a release is about 1 in 3,800. The maximum (mean value) dose received by an individual close to the impact site would be about 0.0005 rem. The collective dose received by all individuals within the potentially exposed global population would result in about 0.0026 mean additional latent cancer fatalities within the exposed population.

Considering all launch accidents assessed in this DEIS, the maximally exposed member of the exposed population faces a much less than 1 in a million chance of incurring a latent cancer due to a launch failure of the Mars 2020 mission.

Alternative 3: Under Alternative 3 the Mars 2020 rover would utilize solar energy as its primary source of electrical power. Alternative 3 would not involve any MMRTG-associated radiological risks. However, NASA may consider the use of up to 71 LWRHUs to provide additional heat to help maintain the solar-powered rover's functionality during extreme cold temperature conditions. The use of LWRHUs for this alternative could also result in mission risks and related radiological consequences.

As shown in Figure ES-2, the most probable outcome is a successful launch. In the event of a launch accident, most accidents do not result in the release of plutonium dioxide. Less than one percent of the launch accidents do however result in a release. These accidents may occur near the launch area, resulting in a release within the launch area; or they may occur later in the launch and result in a release beyond the launch area. The risk assessment shows that for the Mars 2020 mission using LWRHUs:

- There is a 97.5% chance of a successful launch.
- There is a 2.5% chance of a launch accident.
- There is a 1 in 15,000 chance of a launch accident that would release plutonium dioxide.
    - There is a 1 in 16,000 chance of a launch accident that would result in a release of plutonium dioxide in the launch area.

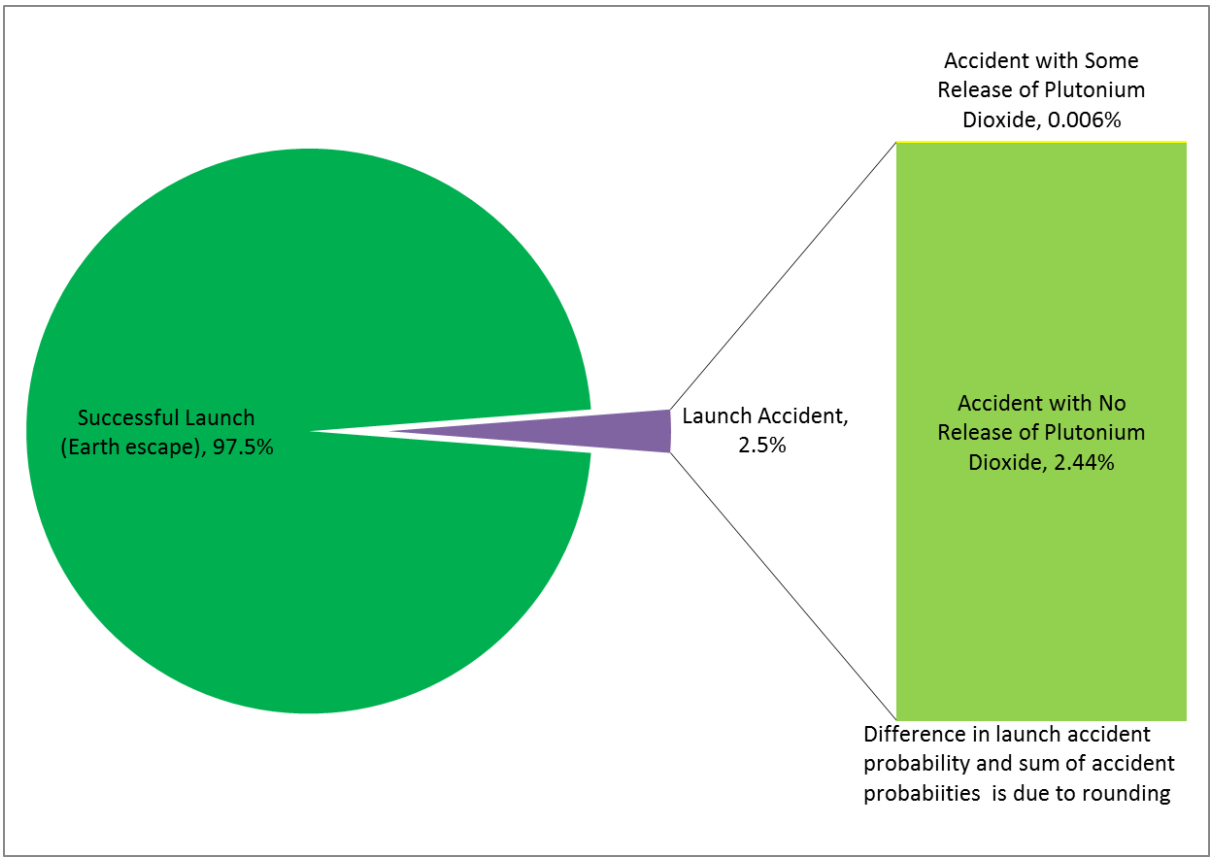

Figure ES-2: Alternative 3 - LWRHU Accident Probabilities

  - There is a 1 in 420,000 chance of a launch accident that would result in a release of plutonium dioxide outside the launch area.
- No radiological fatalities would be expected to occur as a result of any accident.
- The average maximum dose to any member of the public would be equal to about 5 days of exposure to natural background radiation for a person living in the United States.

Most of the radiological accident impacts for Alternative 3 would be associated with accidents that occur on or near the launch area. The LWRHUs would be expected to survive most launch accidents beyond the immediate launch area without releasing any plutonium dioxide. For accidents near the launch area that result in a radiological release, the predicted mean radiological dose to the maximally exposed individual would be about 0.004 rem. The probability for such an accident is about 1 in 16,000. No near-term radiological health effects would be expected from such an exposure. Each exposure would, however, yield a small increase in the statistical likelihood of a latent cancer fatality over the long term. For a launch-area accident with a release, a mean of 0.020 additional latent cancer fatalities could occur among the potentially exposed members of the local and global populations.

The risk assessment concludes that the average land contamination above 0.2 $\mu Ci/m^2$ for all launch area accidents that result in a release is 0.51 km^2 (less than a quarter of a square mile).

Considering all of the launch accidents assessed in this DEIS, the maximally exposed member of the exposed population faces a much less than 1 in a million chance of incurring a latent cancer due to a failure of the Mars 2020 mission.

Alternatives 1, 2 and 3: Scientific Instrument Small Quantity Radiological Sources. The risks associated with small quantity radiological sources would be applicable to all of the alternatives (with the exception of the No Action Alternative) being considered for the Mars 2020 mission. While the quantity of radioactive material used for any instrument would be much smaller than that contained in either the MMRTG or the LWRHUs, this material would be much more likely to be released in an accident. The release probabilities are typically higher, roughly ten times or more, than those for the MMRTG or LWRHUs. The post-launch accident in the vicinity of the launch area has a probability of release of 1 in 1,700 compared to the 1 in 16,000 (LWRHUs) or 1 in 11,000 (MMRTG).

The percentage of the material released would also be higher for the small quantity instrument sources compared to the MMRTG or LWRHUs. However, since there is considerably less radioactive material present, the subsequent impacts would be much smaller. Maximally exposed individual doses for each launch phase are in the 0.00001 rem range and the potential health effects are less than 0.0003 additional latent cancer fatalities, much smaller than the corresponding values for accidents involving either the MMRTG or LWRHUs. These competing factors (higher probability, lower consequence) result in the risks associated with these small quantity sources being comparable to those identified for the LWRHUs (Alternative 3).

No Action Alternative. Under the No Action Alternative, NASA would not complete preparations for and implement the Mars 2020 mission. The No Action Alternative would not involve any of the radiological risks associated with potential launch accidents.

SUMMARY COMPARISON OF THE ALTERNATIVES

Table ES-1 presents a summary comparison of the Proposed Action (Alternative 1), Alternative 2, Alternative 3, and the No Action Alternative in terms of each alternative's capabilities for operating and conducting science on the surface of Mars, the anticipated environmental impacts of normal implementation of each alternative, and the potential environmental impacts in the event of an unlikely launch accident for each alternative.

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Table ES-1. Summary Comparison of the Mars 2020 Mission Alternatives

	Proposed Action (Alternative 1)	Alternative 2	Alternative 3	No Action Alternative
Rover Power Alternative	MMRTG	Solar Array no LWRHUs	Solar Array with LWRHUs	Not applicable
Functional Capability	Capable of operating for at least one Mars year at landing sites between 30° north and 30° south latitudes on Mars	Unable to operate for a full Mars year at any latitude[(a)]	Limited-lifetime capability for operating at landing sites between 20° south and 5° south latitudes on Mars[(a)]	Not applicable
Science Capability	Capable of accomplishing all science objectives at any scientifically desirable landing site between 30° north and 30° south latitudes	Capable of accomplishing up to 33% of science objectives during partial year operation at limited latitudes[(b)]	Capable of accomplishing up to 70% of science objectives at limited latitudes[(b)] due to constrained operations during northern winter	No science achieved
Anticipated Environmental Impacts	Short-term impacts associated with exhaust emissions from the launch vehicle during a normal launch	Short-term impacts associated with exhaust emissions from the launch vehicle during a normal launch	Short-term impacts associated with exhaust emissions from the launch vehicle during a normal launch	No impacts
Potential Environmental Impacts in the Event of a Launch Accident	Potential impacts associated with combustion of released propellants and falling debris Potential radiological impacts associated with release of small quantity radioisotopes from science instruments and release of some of the plutonium dioxide from the MMRTG	Potential impacts associated with combustion of released propellants and falling debris Potential radiological impacts associated with release of small quantity radioisotopes from science instruments	Potential impacts associated with combustion of released propellants and falling debris Potential radiological impacts associated with release of small quantity radioisotopes from science instruments and release of some of the plutonium dioxide from the LWRHUs	No potential impacts

(a) These numbers assume a dust factor of 40%. Assuming dust mitigation technology improvements on the Mars Exploration Rover solar array performance, the rover (without LWRHUs) is estimated to survive for a full year at latitudes between 0° and 5° south and, with LWRHUs, full year constrained operation between 20° south and 15° north latitudes is possible.

(b) Improved solar array performance from dust mitigation technology would result in a corresponding increase in science capability, expanding the range of latitudes the rover could operate for a full year.

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ABBREVIATIONS AND ACRONYMS

A

ABL	atmosphere boundary layer
ac	acre
ADS	Automatic Destruct System
AEC	Atomic Energy Commission
AFI	Air Force Instruction
AFPD	USAF Policy Directive
AIAA	American Institute of Aeronautics and Astronautics
Al_2O_3	aluminum oxide
AO	Announcement of Opportunity
APXS	Alpha Particle X-Ray Spectrometer
ASRG	Advanced Stirling Radioisotope Generator

B

BEBR	Bureau of Economic and Business Research
BEIR	Biological Effects of Ionizing Radiation
BLS	Bureau of Labor and Statistics
BMAP	Basic Management Action Plan
Bq	Becquerel
BTU	British thermal unit

C

ºC	degrees Celsius
CADS	Centaur Automatic Destruct System
CBC	common booster core
CCAFS	Cape Canaveral Air Force Station
CDS	Command Destruct System
CEQ	Council on Environmental Quality
CFC	chlorofluorocarbon
CFR	Code of Federal Regulations
Ci	curie
Cl_2	chlorine
Cm	curium
cm	centimeter
CMS	Corrective Measures Study
CNS	Canaveral National Seashore
CO	carbon monoxide
CO_2	carbon dioxide
COMPLEX	Committee on Planetary and Lunar Exploration
CWA	Clean Water Act

D

DAN	Dynamic Albedo of Neutrons
dB	decibel
dBA	decibels (A-weighted)
DEIS	Draft Environmental Impact Statement
DHS	Department of Homeland Security
DIL	derived intervention level
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOS	U.S. Department of State

E

EDE	effective dose equivalent
EDL	entry, descent, and landing
EEZ	Exclusive Economic Zone
EFH	essential fish habitat
EIS	Environmental Impact Statement
EO	Executive Order
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ETR	extended test range
EXM	ExoMars Lander Mission
	ExoMars Rover

F

^{o}F	degrees Fahrenheit
FAA	Federal Aviation Administration
FDEP	Florida Department of Environmental Protection
FEIS	Final Environmental Impact Statement
FEMA	Federal Emergency Management Agency
FFWCC	Florida Fish and Wildlife Conservation Commission
FONSI	finding of no significant impact
FMO	Fishery Management Officials
FR	Federal Register
FS	Florida Statute
FSAR	Final Safety Analysis Report
FSII	full-stack intact impact
ft	foot
FTS	Flight Termination System
FWS	(U.S.) Fish and Wildlife Service

G

g	gram
gal	gallon
GCTL	ground water cleanup target level
GIS	Graphite Impact Shell
GMD	ground-based midcourse defense
GPHS	General Purpose Heat Source

H

H_2	hydrogen
H_2O	water
ha	hectare
HAP	hazardous air pollutant
HAPC	Habitat Areas of Particular Concern
HCl	hydrogen chloride (hydrochloric acid)
HEAST	health effects assessment summary table
HM/HW	Hazardous Materials and Hazardous Waste
HPS	Health Physics Society
hr	hour
HTPB	hydroxyl-terminated polybutadiene

I

IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
in	inch
INL	Idaho National Laboratory
INSRP	Interagency Nuclear Safety Review Panel

ISCORS	Interagency Steering Committee on Radiation Standards
ISDS	Inadvertent Separation Destruct System
ISRP	International Space Research Park
ISRU	In Situ Resource Utilization

J

JPL	Jet Propulsion Laboratory

K

K	degrees Kelvin
kg	kilogram
km	kilometer
km^2	square kilometers
KNPR	Kennedy NASA Procedural Requirement
KSC	Kennedy Space Center

L

LANL	Lo Alamos National Laboratory
lb	pound
lbf	pound-force
LC	Launch Complex
LH_2	liquid hydrogen
LOx	liquid oxygen
LSTO	Launch Service Task Order
LV	launch vehicle
LWRHU	Light-Weight Radioisotope Heater Unit

M

$\mu Ci/m^2$	microcuries per square meter
$\mu g/m^3$	micrograms per cubic meter
μm	micrometer
m	meter
MAVEN	Mars Atmospheric and Volatile EvolutioN
MBTA	Migratory Bird Treaty Act
MDRPRA	Marine Debris Research, Prevention, and Reduction Act
MEI	maximally exposed individual
MEP	Mars Exploration Program
MEP EIS	*Mars Exploration Program Environmental Impact Statement*
MER	Mars Exploration Rover
MEX	Mars Express
MFCO	Mission Flight Control Officer
MGS	Mars Global Surveyor
MHW	Multi-Hundred Watt
mi	mile
mi^2	square mile
MINWR	Merritt Island National Wildlife Refuge
MMH	monomethyl hydrazine
MMPA	Marine Mammal Protection Act
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MPF	Mars Pathfinder
mph	miles per hour
mrem	millirems
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
MSL FEIS	*Mars Science Laboratory Mission Final Environmental Impact Statement*
MST	mobile service tower
mt	metric ton

MVN	Maven (Mars Atmospheric and Volatile Evolution)

N

N_2	nitrogen
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act
NHL	National Historic Landmark
NLS	NASA Launch Service
NMFS	National Marine Fisheries Service
nmi	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NOx	nitrogen oxides
NPD	NASA Policy Directive
NPDES	National Pollutant Discharge Elimination System
NPR	NASA Procedural Requirement
NPS	National Park Service
NRC	National Research Council
NRC	Nuclear Regulatory Commission
NRF	National Response Framework
NRHP	National Register of Historic Places
NSF	National Science Foundation
NTO	nitrogen tetroxide

O

ODS	ozone depleting substance
ODY	Mars Odyssey
OFW	Outstanding Florida Waters
OPlan	Operation Plan
OSHA	Occupational Safety & Health Administration
oz	ounce

P

PAFB	Patrick Air Force Base
PAH	polychlorinated aromatic hydrocarbon
PCB	polychlorinated biphenol
PEIS	Programmatic Environmental Impact Statement
PHSF	Payload Hazardous Servicing Facility
PHX	Phoenix
PLF	payload fairing
$PM_{2.5}$	particulate matter less than 2.5 micrometers in diameter
PM_{10}	particulate matter less than 10 micrometers in diameter
ppm	parts per million
PPPG	Pollution Prevention Program Guide
psf	pound/square foot
Pt-30Rh	platinum-30 rhodium
Pu	plutonium
Pu-236	Plutoiniu-236
Pu-238	Plutonium-238
Pu-239	Plutonium-239
Pu-240	Plutonium-240
Pu-241	Plutonium-241
Pu-242	Plutonium-242
PuO_2	plutonium dioxide

R

rad	radiation absorbed dose
RCC	Range Commanders Council
RCRA	Resource Conservation and Recovery Act
rem	roentgen equivalent in man
RFI	RCRA facility investigation
RP-1	rocket propellant-1
RPS	Radioisotope Power System
RTG	radioisotope thermoelectric generator

S

s	second
S/A	similarity of appearance
SAFMC	South Atlantic Fishery Management Council
SAP	satellite accumulation point
SC	spacecraft
SCTL	soil cleanup target level
SDT	Science Definition Team
SDWA	Safe Drinking Water Act
SLC	space launch complex
SNAP	Systems for Nuclear Auxiliary Power
SPCC	Spill Prevention, Control, and Countermeasures
SRB	solid rocket booster
SSB	Space Studies Board
SSC	state species of special concern
SV	space vehicle
SVII	Space Vehicle Intact Impact
SWCTL	surface water cleanup target level
SWMU	solid waste management unit

T

TEDE	total effective dose equivalent
TGO	Trace Gas Orbiter
THC	toxic hazard corridor
TMDL	total maximum daily load
TSDF	Transportation, Storage, and Disposal Facility

U

UCMR	Unregulated Contaminant Monitoring Rule
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USAF	U.S. Air Force
USBC	U.S. Bureau of the Census
USCG	United States Coast Guard
USFWS	U.S. Fish and Wildlife Service
UV-B	ultraviolet

V

VIF	Vertical Integration Facility
VOC	volatile organic compound

Y

yd	yard
yr	year

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COMMON METRIC/BRITISH SYSTEM EQUIVALENTS

Length

1 centimeter (cm) = 0.3937 inch	1 inch = 2.54 cm
1 centimeter = 0.0328 foot (ft)	1 foot = 30.48 cm
1 meter (m) = 3.2808 feet	1 ft = 0.3048 m
1 meter = 0.0006 mile (mi)	1 mi = 1609.3440 m
1 kilometer (km) = 0.6214 mile	1 mi = 1.6093 km
1 kilometer = 0.53996 nautical mile (nmi)	1 nmi = 1.8520 km
	1 mi = 0.87 nmi
	1 nmi = 1.15 mi

Area

1 square centimeter (cm^2) = 0.1550 square inch (in^2)	1 in^2 = 6.4516 cm^2
1 square meter (m^2) = 10.7639 square feet (ft^2)	1 ft^2 = 0.09290 m^2
1 square kilometer (km^2) = 0.3861 square mile (mi^2)	1 mi^2 = 2.5900 km^2
1 hectare (ha) = 2.4710 acres (ac)	1 ac = 0.4047 ha
1 hectare (ha) = 10,000 square meters (m^2)	1 ft^2 = 0.000022957 ac

Volume

1 cubic centimeter (cm^3) = 0.0610 cubic inch (in^3)	1 in^3 = 16.3871 cm^3
1 cubic meter (m^3) = 35.3147 cubic feet (ft^3)	1 ft^3 = 0.0283 m^3
1 cubic meter (m^3) = 1.308 cubic yards (yd^3)	1 yd^3 = 0.76455 m^3
1 liter (l) = 1.0567 quarts (qt)	1 qt = 0.9463264 l
1 liter = 0.2642 gallon (gal)	1 gal = 3.7845 l
1 kiloliter (kl) = 264.2 gal	1 gal = 0.0038 kl

Weight

1 gram (g) = 0.0353 ounce (oz)	1 oz = 28.3495 g
1 kilogram (kg) = 2.2046 pounds (lb)	1 lb = 0.4536 kg
1 metric ton (mt) = 1.1023 tons	1 ton = 0.9072 metric ton

Energy

1 joule= 0.0009 British thermal unit (BTU)	1 BTU = 1054.18 joule
1 joule= 0.2392 gram-calorie (g-cal)	1 g-cal = 4.1819 joule

Pressure

1 newton/square meter (N/m^2) = 0.0208 pound/square foot (psf)	1 psf = 48 N/m^2

Force

1 newton (N) = 0.2248 pound-force (lbf)	1 lbf = 4.4478 N

Radiation

1 becquerel (Bq) = 2.703×10^{-11} curies (Ci)	1 Ci = 3.70×10^{10} Bq
1 sievert (Sv) = 100 rem	1 rem = 0.01 Sv

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1. PURPOSE AND NEED FOR THE ACTION

This Draft Environmental Impact Statement (DEIS) has been prepared by the National Aeronautics and Space Administration (NASA) and its cooperating agency, the U.S. Department of Energy (DOE), to assist in the decision-making process as required by: the National Environmental Policy Act of 1969, as amended (NEPA) (42 U.S.C. 4321 et seq.); Executive Order (EO) 12114, Environmental Effects Abroad of Major Federal Actions; Council on Environmental Quality (CEQ) regulations (40 CFR parts 1500-1508); and NASA policies and procedures at 14 CFR part 1216. This DEIS provides information associated with the potential environmental impacts of preparing for and associated with the launch of a proposed Mars 2020 mission, which would employ *in situ* scientific instrumentation to seek signs of past life, select and store a compelling suite of samples in a returnable cache, and demonstrate technologies for future robotic and human exploration of Mars. This document is a Tier 2 mission-specific DEIS under NASA's Mars Exploration Program Programmatic EIS (NASA 2005a). Launch of the Mars 2020 mission would take place at Cape Canaveral Air Force Station (CCAFS), Brevard County, Florida, or Kennedy Space Center (KSC), Brevard County, Florida, during the summer of 2020. The next launch opportunity for this mission would occur during the summer of 2022. Chapter 2 of this DEIS describes the alternatives considered to achieve the Mars 2020 mission.

1.1 BACKGROUND

In response to the recommendations by its advisory and analysis groups, NASA is currently undertaking a long-term systematic program of Mars scientific exploration—the Mars Exploration Program (MEP). To discover the possibilities for past or present life on Mars, NASA's MEP is currently following an exploration strategy known as "Seek Signs of Life."

This science theme marks an evolution in the Mars exploration strategy. It reflects a long-term process of discovery on the red planet built on strategies to understand Mars' potential as a habitat for past or present microbial life. Searching for this answer means delving into the planet's geologic and climate history to find out how, when, and why Mars underwent dramatic changes to become the planet we observe today.

Because water is key to life as we know it, earlier Mars missions (2001 Mars Odyssey, Mars Exploration Rovers (MERs), Mars Reconnaissance Orbiter, Mars Phoenix Lander) were designed to make discoveries under the previous MEP science theme of "Follow the Water." That strategy connected fundamental program goals pertaining to biological potential, climate, and the evolution of the solid planet. Progressive discoveries related to evidence of past and present water in the geologic record made it possible to take the next steps toward finding evidence of life itself.

The Mars Science Laboratory (MSL) mission and its Curiosity rover marked a transition between the themes of "Follow the Water" and "Seek Signs of Life." In addition to landing in a place with past evidence of water, Curiosity is seeking evidence of organics, the chemical building blocks of life. Places with water and the chemistry needed for life potentially provide habitable conditions.

The scientific objectives established by the program to address the goal of answering the question “Did life ever exist on Mars?” are to search for evidence of past or present life, characterize the climate and volatile history of Mars, understand the surface and subsurface geology (including the nature of the interior), and characterize the Martian environment quantitatively in preparation for human exploration. One common thread that links these objectives is to explore the role of water in all of its states within the “Mars system,” from the top of the atmosphere to the interior.

The MEP is fundamentally a science-driven program focused on understanding and characterizing Mars as a dynamic system and ultimately addressing whether life is or was ever a part of that system. The MEP further embraces the challenges associated with the development of a predictive capability for Martian climate and how the role of water and other factors, such as variations in the tilt of the planet’s polar axis, may have influenced the environmental history of Mars.

The core MEP addresses the highest priority scientific investigations directly related to the Program’s goals and objectives. These planned investigations were derived by means of a highly inclusive process involving a large segment of the broad planetary exploration science community. The MEP is currently implemented as a sustained series of flight missions to Mars, each of which will provide important, focused scientific return. NASA is taking advantage of launch opportunities available approximately every 26 months, to evolve a scientifically integrated architecture of orbiters, landers, and rovers. Figure 1-1 provides a timeline of the MEP missions since 1997, including proposed missions through 2020 and cooperative missions with the European Space Agency (i.e., 2016 Trace Gas Orbiter (TGO) and 2018 ExoMars Lander Mission (EXM)). The Mars Atmospheric and Volatile EvolutioN (MAVEN) mission has launched and is expected to arrive in Mars orbit in September 2014. The MEP has launched both orbiting and surface-focused missions with the orbiters providing both investigative and communication capabilities.

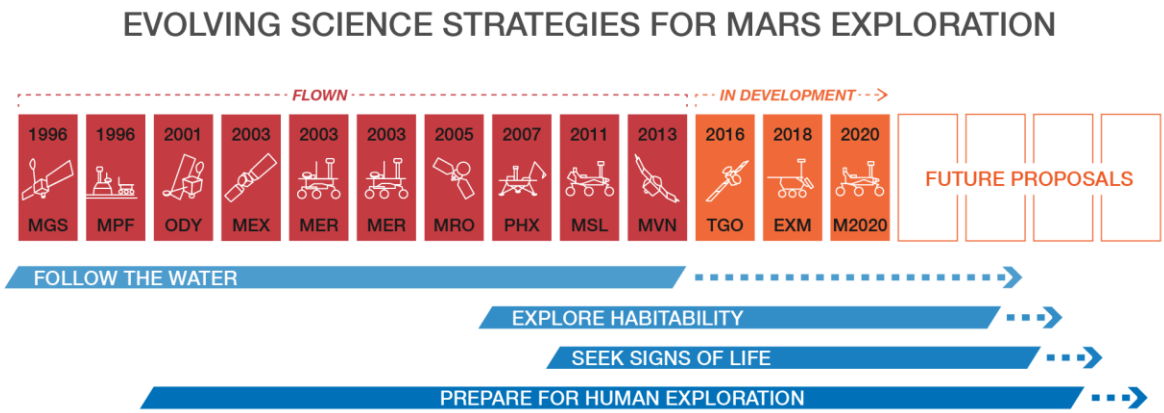
The goals of the MEP are outlined below (NASA 2014b). The science goals described in Section 1.2 for the proposed Mars 2020 mission support these MEP goals.

Determine if life exists or has ever existed on Mars

- Search for life where liquid water was once stable
- Look for energy sources (other than sunlight) necessary to support life
- Look for the signs of life on Mars, telltale markers of current and past life
  - Mineralogical clues indicating the sustained presence of water at one time
  - Environments amenable (similar to sedimentary soils on Earth) to preserving signs of life

Characterize the climate of Mars

- Characterize the current climate and climate processes of Mars
- Characterize the ancient climate of Mars



Landers - PHX: Phoenix
Rovers - MPF: Mars Pathfinder, MER: Mars Exploration Rovers, MSL: Mars Science Laboratory, EXM: ExoMars Rover, M2020: Mars 2020
Orbiting observatories and communications - MGS: Mars Global Surveyor, ODY: Mars Odyssey, MEX: Mars Express, MRO: Mars Reconnaissance Orbiter, MVN: MAVEN, TGO: ExoMars Trace Gas Orbiter
Source: NASA 2014a

Figure 1-1. MEP Missions 1997 - 2020

Characterize the geology of Mars

- Determine the geological processes (wind, water, volcanism, tectonics, cratering, etc.) that have resulted in formation of the Martian crust and surface
  - Identify the composition of surface materials, particularly those that may indicate the presence of water
- Characterize the structure, dynamics, and history of the planet's interior
  - Determine the impact of the magnetic field Mars once had, but no longer has

Develop an understanding of Mars in support of possible future human exploration

- Acquire appropriate Martian environmental data such as those required to
  - Characterize the radiation environment
  - Conduct *in situ* engineering and science demonstrations
- Advance spacecraft technology (e.g., entry descent and landing technology) for astronaut safety.

The MEP also ensures the development and demonstration of technologies required to enable attainment of these goals. Specifically, the program enables new classes of Mars science investigations, including remote astrobiology and new techniques for *in situ* life detection. Technology developments and improvements over the course of the program enable a progressive increase in the payload mass delivered to Mars orbit and to the surface by program spacecraft, enhance the capability to safely and precisely place payloads at any desired location on the surface, and enable full access to the subsurface, surface and atmospheric regions.

Technology improvements envisioned as part of MEP would also enhance long-lived (one Mars year (1.88 Earth years) or longer duration, as a goal) surface science investigations, and support the development of robotic assets to provide a nearly continuous data return from the surface (NASA 2005a).

1.2 PURPOSE OF THE ACTION

The purpose of the proposed Mars 2020 mission is to both conduct comprehensive science on the surface of Mars and demonstrate technological advancements potentially useful for the future exploration of Mars. The overall scientific goal is to address in detail questions of habitability and the potential origin and evolution of life on Mars. In July of 2013, the Mars 2020 Science Definition Team (SDT) outlined a mission concept for the Mars 2020 mission to explore and investigate in detail a site on Mars that likely was once habitable. This team identified four objectives for this mission (Mars 2020 SDT 2013). NASA further characterized these mission objectives in an Announcement of Opportunity (AO) released on 24 September 2013 (NASA 2013d) for the competitive acquisition of payload investigations for the Mars 2020 mission. The four objectives are to:

A. Characterize the processes that formed and modified the geologic record within a field exploration area on Mars selected for evidence of an astrobiologically relevant ancient environment and geologic diversity.

B. Perform astrobiologically relevant investigations on the geologic materials at the landing site:

   1. Determine the habitability of an ancient environment.

   2. For ancient environments interpreted to have been habitable, search for materials with high biosignature preservation potential.

   3. Search for potential evidence of past life using the observations regarding habitability and preservation as a guide.

C. Assemble a returnable cache of samples for possible future return to Earth.

   1. Obtain samples that are scientifically selected, for which the field context is documented, that contain the most promising samples identified in Objective B and that represent the geologic diversity of the field site.

   2. Ensure compliance with future needs in the areas of planetary protection and engineering so that the cache could be returned in the future if NASA chooses to do so.

D. Contribute to the preparation for human exploration of Mars by making significant progress towards filling at least one major Strategic Knowledge Gap[2]. The

[2] Gaps in knowledge or information required to reduce risk, increase effectiveness, and improve the design of robotic and human space exploration missions.

highest priority measurements that are synergistic with Mars 2020 science objectives and compatible with the mission concept are (in priority order):

1. Demonstration of In Situ Resource Utilization (ISRU) technologies to enable propellant and consumable oxygen production from the Martian atmosphere for future exploration missions.

2. Characterization of atmospheric dust size and morphology to understand its effects on the operation of surface systems and human health.

3. Collection of surface weather measurements to validate global atmospheric models.

A fifth objective, identified in the SDT, is to demonstrate improved technical capabilities for landing and operating on the surface of Mars to benefit future Mars missions.

The proposed Mars 2020 mission objectives align with the priorities of the *Decadal Survey* (the Space Studies Board's (SSB's) *Vision and Voyages for Planetary Science in the Decade 2013-2022*) (NAP 2011) for solar system exploration and investigations. It would address several of the high-priority scientific investigations recommended to NASA by the science community.

1.3 NEED FOR THE ACTION

The proposed Mars 2020 mission objectives align with the priorities of the National Research Council's (NRC) 2013 Planetary Science Decadal Survey for solar system exploration and investigations, *Vision and Voyages for Planetary Science in the Decade 2013-2022* (NAP 2011). This report was requested by NASA and the National Science Foundation (NSF) to review and assess the status of planetary science and to develop a comprehensive science and mission strategy that updates and extends the NRC's 2003 planetary decadal survey, *New Frontiers in the Solar System: An Integrated Exploration Strategy*. Drawing on extensive interactions with the broad planetary science community, the report presents a decadal program of science and exploration with the potential to yield revolutionary new discoveries. This report identifies fundamental questions that a planetary exploration program should address, including questions about past or present life in the solar system, and how they relate to a NASA's human exploration program. The Mars 2020 mission would address several of the high-priority scientific investigations recommended to NASA by the science community through the decadal survey.

The MEP forms a vital part of NASA's planetary exploration program. As stated in the NRC document, "Mars presents an excellent opportunity to investigate the major question of habitability and life in the solar system." Not only can we get to and explore Mars (as demonstrated by the success of a series of progressively larger, more complex, and scientifically rewarding missions), Mars holds the promise of providing answers to the questions identified for a planetary exploration program.

The past and current environments on Mars have resulted in conditions that are unique in the solar system (NAP 2011).

- Mars, early in its history, is thought to have had an environment in which prebiotic compounds may have formed and that its environment may have been conducive to the origin and continued evolution of life.
- Mars has also experienced major changes in surface conditions that have produced a wide range of environments.
- Mars has not been subjected to significant atmospheric and geological degradation resulting in the possibility that the early geologic record of Mars has been preserved. This means that there is potential evidence of prebiotic and biotic processes and how they relate to the evolution of the planet as a system.

Because of these conditions, the signs of past life on Mars may have been preserved in such a manner that we can find them. Mars, therefore, provides the opportunity to address questions about past and present life in the solar system such as: “Did life arise elsewhere in the solar system, and if so, how?” “How did Mars evolve into the planet it is today and what can be learned about Earth’s evolution?” and “How are the biological and geological history of a planet related?” Progress on these important questions can be made more readily at Mars than anywhere else in the solar system (NAP 2011).

The form of the proposed Mars 2020 mission—a landed rover carrying a suite of scientific instruments—is the result of a desire to maximize the potential science return from the mission. The rover’s mobility provides access to a significantly larger area than possible with a landed, stationary mission. As expressed by the Space Studies Board’s Committee on Planetary and Lunar Exploration (COMPLEX) (NAP 1999), mobility is essential because evidence for past or present life on Mars will very likely not be so abundant or widespread that it will be available in the immediate vicinity of the selected landing site. Without the mobility necessary to conduct *in situ* exploration, it may not be possible to uniquely characterize a target location. COMPLEX further emphasized the need for very capable mobile science platforms that could carry a suite of mutually complementary instruments, have an extensive range and long lifetime, and have one or more manipulative devices for acquiring and caching samples. Lessons from MER and MSL have demonstrated the advantages of mobility for conducting scientific investigations.

The scientific instrumentation to be carried aboard the rover is being selected to build upon the capabilities of previous missions. Discoveries from earlier missions of the MEP, including NASA’s Spirit and Opportunity rovers, Mars Science Laboratory rover Curiosity, the Phoenix lander, Mars Odyssey, Mars Reconnaissance Orbiter (MRO), and the European Space Agency’s Mars Express orbiter, point definitively to evidence of a past presence of water on Mars and the presence today of subsurface water ice. Data returned and analyzed from these ongoing missions continue to demonstrate a need for global exploration of the planet. Future exploration efforts could use that information as a basis for investigations intended to take the next step and “Seek Signs of Life.”

In 2002, Mars Odyssey found evidence of large amounts of subsurface water ice in the northern arctic plains. NASA’s Phoenix Lander mission, first in the series of Mars Scout missions within the MEP, was selected to examine this region in detail. Phoenix arrived at Mars in May 2008 in the beginning of Northern Summer on Mars. Phoenix confirmed

deposits of underground water ice. It also found calcium carbonate, which is indicative of the presence of liquid water at one time; and perchlorates, which some Earth microbes can use as food, in the ice-rich soil of the Martian arctic (NASA 2010a).

NASA's MRO mission entered orbit around Mars in March 2006 and, after a period of adjustments to its orbit, began its primary science mission in November 2006. In achieving its scientific objectives, MRO has searched for subsurface water and found safe and scientifically worthy landing sites for the MSL mission and continues to be used for reconnaissance of potential Mars 2020 landing sites.

The Mars Exploration Rovers found signs of the past presence of surface water: minerals that on Earth are formed in the presence of water and overlapping rock layers. The overlapping rock layers, formed as water evaporated, provide evidence that water may have been found on the surface of Mars over long time periods. Besides finding evidence of past surface water, the rovers identified additional chemical elements in the Martian soil that, although not definitive proof of past life, are needed for life (NASA 2013b).

The MSL began to provide new information even before arriving at Mars. During its journey to Mars, Curiosity instrumentation measured cosmic and solar radiation levels—measurements that will help NASA plan and design any future manned expedition to Mars. During the first year of its two Earth year mission, Curiosity found evidence that at one time Mars had an environment that could support microbial life and evidence of an ancient streambed has been found by the rover (NASA 2013c). In addition to landing in a place with past evidence of water, Curiosity is continuing to seek evidence of organics, the chemical building blocks of life. Places with water and the chemistry needed for life potentially provide habitable conditions.

These previous missions have yielded new information on ancient and recent habitability on Mars both globally and locally. To further increase our knowledge of the solar system and of life's evolution here on Earth, future Mars missions would be designed to build upon the findings from these missions to search for life itself in places identified as potential past or present habitats. Like previous MEP missions, this mission would be driven by scientific questions that evolve from discoveries by prior missions.

The goals proposed for the Mars 2020 mission, with its overarching theme to "Seek Signs of Life," build upon this heritage and would improve knowledge of the habitability of Mars from a scientifically promising location. The proposed Mars 2020 mission objectives would also address NASA's strategic goals of continuing to pave the way for future human exploration.

1.4 NEPA PLANNING AND SCOPING ACTIVITIES

On April 12, 2005, NASA published a Notice of Availability of the *Final Programmatic Environmental Impact Statement for the Mars Exploration Program* (PEIS MEP) (NASA 2005a, 70 FR 19102). The Record of Decision for the PEIS MEP was signed on June 22, 2005, enabling continued planning for the MEP, which represents NASA's overall plans for the robotic exploration of Mars through 2020. The PEIS MEP encompasses the launch of at least one spacecraft to Mars during each favorable launch opportunity,

which occurs approximately every 26 months. Overall environmental compliance in support of the MEP is addressed in the PEIS MEP, and allows planning to continue for the Mars 2020 mission.

On September 11, 2013, NASA published in the Federal Register (78 FR 55762) a Notice of Intent (NOI) to prepare an Environmental Impact Statement and conduct scoping for the Mars 2020 mission. Public input and comments on alternatives, potential environmental impacts, and concerns associated with the proposed Mars 2020 mission were requested. The scoping period ended on October 30, 2013.

NASA held scoping meetings to solicit written and oral comments on the scope of the Mars 2020 Mission EIS. Two scoping meetings were held in the vicinity of KSC. An open house, town hall meeting format was used for the scoping meetings. This format provided meeting participants the opportunity to familiarize themselves with the proposed Mars 2020 mission and EIS, as well as the NEPA process during the open house, followed by an opportunity to provide formal comments on the scope of the Mars 2020 Mission EIS.

The open house portion of the scoping meetings included displays of a variety of posters and printed material that supported the EIS and NEPA process. Technical experts were available to interact with the public at the various displays. In addition, there were several “floater” experts who provided additional technical expertise where needed. Each display was augmented with supporting written materials such as a fact sheet.

The town hall session followed the open house portion of the scoping meeting. After introductory remarks, presentations were made starting with videotapes by the NASA HQ Mars 2020 Program Executive and the NASA HQ NEPA Manager; and then followed by presentations by team members that were in attendance. In anticipation of the government shutdown, the NASA HQ Mars 2020 Program Executive and the NASA HQ NEPA Manager recorded their presentations at NASA TV in Washington, DC for use during the town hall sessions. At the conclusion of the presentations, the facilitator took leadership of the meeting, guiding individuals through the comment process.

Written comments were also received in response to the NOI. A summary of the comments on the suggested scope of the DEIS include:

- **Comment:** The EIS should discuss the impacts on local flora and fauna, including Mosquito Lagoon (where [in] winter bottlenose dolphin were found) and Merritt Island National Wildlife Refuge.

  Response: Chapter 4 of this DEIS discusses the impacts on local flora and fauna. The impacts of normal launches and the non-radiological impacts of launch accidents on local flora and fauna are addressed in Sections 4.1.2 and 4.1.3. The impacts on local flora and fauna associated with launch accidents that release radioactive material were addressed in the DOE Nuclear Risk Assessment through land contamination and are discussed in Sections 4.1.4 and 4.3.4.

- **Comment:** The EIS should discuss how the mission plans to limit the spread of radiological and non-radiological materials to the environment in a launch accident.

  Response: As discussed in Sections 2.1.3 and 4.1.4.3 (addressing the MMRTG). and 2.3.1.2 and 4.3.4.3 (addressing the LWRHUs), the MMRTG and LWRHUs are designed to contain the radioactive material during normal operations and under a wide range of launch accident conditions. In addition, NASA and the USAF have established a range safety program intended to limit the potential impacts associated with launch accidents (Section 2.1.6.5). For a launch involving radioactive material, NASA would also develop a radiological contingency plan, discussed in Sections 4.1.6 and 4.3.5, to minimize the impacts to the public and the environment should an accident occur.

- **Comment:** The EIS should discuss the risk assessment and results and impacts "to Earth's organisms (humans, flora and fauna, natural resources)." "The potentiality of such a scenario should be analyzed and a quantifiable system should be created in order to ensure that the benefits outweigh the costs of the mission, even if failed."

  Response: The DOE prepared a Nuclear Risk Assessment for the Mars 2020 mission and the results are incorporated in this DEIS. Sections 4.1.3 and 4.3.3 provide detailed assessments of the risks, and a summary is presented in Section 2.6.2.

- **Comment:** The EIS should discuss the nuclear wastes associated with using radioactive power sources.

  Response: Hazardous waste generation associated with this mission is discussed in Section 3.1.9, 4.1.1, and 4.1.2.10. No significant nuclear waste is produced during the activities addressed by this DEIS. Nuclear waste associated with the production of the MMRTG and LWRHUs are addressed in DOE NEPA documentation. Much of this information can be found in references DOE 1993, 2000, 2002, 2002b, 2008 and 2013.

Each of these scoping comments was considered in developing the DEIS.

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2. DESCRIPTION AND COMPARISON OF ALTERNATIVES

The purpose of the Mars 2020 mission is to continue the National Aeronautics and Space Administration's (NASA's) in-depth exploration of Mars. Specifically, the mission would consist of a science-focused, highly mobile rover designed to explore and investigate in detail a site on Mars that was likely once habitable. The mission concept includes new *in situ* scientific instrumentation designed to seek signs of past life. This instrumentation would be used to select a suite of samples, which would be stored in a returnable cache. The mission would also demonstrate technology for future exploration of Mars (both robotic and human missions).

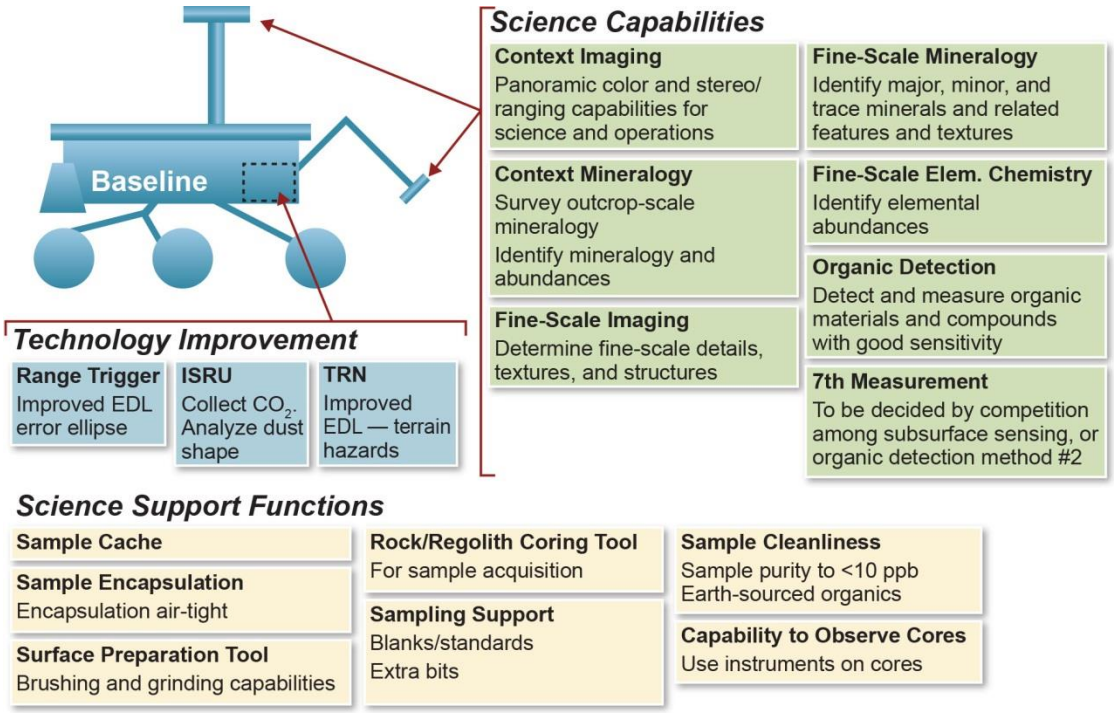
This chapter of the Draft Environmental Impact Statement (DEIS) for the Mars 2020 mission describes and compares the following alternatives:

- **Proposed Action (Alternative 1, NASA's Preferred Alternative)** — NASA proposes to continue preparations for and implement the Mars 2020 mission to the surface of Mars. The proposed Mars 2020 spacecraft would be launched on board an expendable launch vehicle from Kennedy Space Center (KSC) or Cape Canaveral Air Force Station (CCAFS), Brevard County, Florida, during a 20-day launch opportunity that runs from July through August 2020, and would be inserted into a trajectory toward Mars. Should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022. The rover proposed for the Mars 2020 mission would utilize a radioisotope power system to continually provide heat and electrical power to the rover's battery so that the rover could operate and conduct science on the surface of Mars. A description of the Proposed Action is presented in Section 2.1.
- **Alternative 2** — In this Alternative, NASA would discontinue preparation for the Proposed Action (Alternative 1) and implement an alternative configuration for the Mars 2020 mission to Mars. The Mars 2020 rover would utilize solar power as its source of electrical power to operate and conduct science on the surface of Mars. The alternative Mars 2020 spacecraft would still be launched on board an expendable launch vehicle from KSC or CCAFS, Brevard County, Florida, during a 20-day launch opportunity that runs from July through August 2020, and would be inserted into a trajectory toward Mars. Like alternative 1, should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022. A description of Alternative 2 is presented in Section 2.2.
- **Alternative 3 —** In this Alternative, NASA would discontinue preparations for the Proposed Action (Alternative 1) and implement an alternative configuration for the Mars 2020 mission to Mars. The Mars 2020 rover would utilize solar power as its source of electrical power to operate and conduct science on the surface of Mars. The rover thermal environment would be augmented by the thermal output from Light-Weight Radioisotope Heater Units (LWRHUs) to help keep the rover's onboard systems at proper operating temperatures. The Mars 2020 spacecraft would still be launched on board an expendable launch vehicle from KSC or CCAFS, Brevard County, Florida, during a 20-day launch opportunity that runs

from July through August 2020, and would be inserted into a trajectory toward Mars. Should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022. A description of Alternative 3 is presented in Section 2.3.

- **No Action Alternative** — NASA would discontinue preparations for any Mars 2020 mission and the spacecraft would not be launched. A description of the No Action Alternative is presented in Section 2.4.

The Mars 2020 Science Definition Team (SDT) report (Mars 2020 SDT 2013) suggested baseline[3] operational capabilities for the Mars 2020 mission. These capabilities were part of the basis for capability requirements that NASA provided both in an Announcement of Opportunity for Mars 2020 Investigations (NASA 2013d) and for the landing site selection process (NASA 2014b). The capability requirements for the proposed Mars 2020 mission are summarized in Figure 2-1 and Table 2-1. Achieving these baseline capabilities would maximize the potential for the mission to be most responsive to real-time discoveries and fulfill its comprehensive science objectives.



Source: Mars 2020 SDT 2013

Figure 2-1. Baseline Science and Technology Capabilities for Mars 2020 Mission

Table 2-1. Baseline Operational Capabilities for the Mars 2020 Mission

[3] Baseline is defined as measurements or capabilities necessary to achieve the science objectives of the mission and a point of departure from where implementation begins. The SDT report defined a threshold level as a measurement or capability level below which a mission may not be worth the investment.

Launch Related Capability
Be ready for launch during the 2020 Mars opportunity
Be compatible with an intermediate/heavy class expendable launch vehicle
Arrival and Landing-Site Related Capability
Provide data communication throughout critical events at a rate sufficient to determine the state of the spacecraft in support of fault reconstruction
Be capable of landing on the surface of Mars within a 25 km x 20 km (16 mi x 12 mi) elliptical target area. Improved ability to avoid terrain hazards within the targeted landing area.
Be capable of landing between 30° north and 30° south latitudes
Be capable of landing and operating at an elevation of up to +0.5 km (about 0.3 mi) as defined by the survey by the Mars Orbiter Laser Altimeter
Functional Capability
Be designed to operate for at least one Mars year (687 Earth days)
Be capable of adequate mobility to ensure representative measurement of diverse sites at distances of at least 20 km (12 mi)
Science Capability
Accommodate the NASA-selected science payload capable of definitively analyzing the mineralogy, chemistry, texture, and structure of surface and near-surface materials; and be capable of detecting organic material. Instrumentation suite would include the capability for: context imaging, context mineralogy, fine-scale imaging, fine-scale mineralogy, fine-scale elementary chemistry, and organic detection.
Be able to select, acquire, process, distribute, analyze and cache at least 38 samples of rock, rock fragments, and soil of high scientific interest.
Technology Capability
Demonstrate a technology enabling future human missions to Mars

2.1 DESCRIPTION OF THE PROPOSED ACTION (ALTERNATIVE 1)

The mission and spacecraft for the Proposed Action (Alternative 1) would be designed and developed to meet the baseline operational capabilities. The descriptions presented in this section are based on the information available at the time this DEIS was prepared. Should NASA make changes in the Proposed Action (Alternative 1) that are relevant to environmental concerns, NASA would evaluate the need for additional environmental analysis and documentation.

2.1.1 Mission Description

The Mars 2020 spacecraft (described in Section 2.1.2) would be launched from KSC or CCAFS onboard an Atlas V, Delta IV, or Falcon Heavy class of expendable launch vehicles. The launch would occur within an approximate 20-day launch period opening in July of 2020 and closing in August of 2020. Should the Mars 2020 mission not launch during this launch period, it would launch during the next available launch opportunity—August through September 2022. The mission cruise phase would begin when the spacecraft separates from the launch vehicle and would end prior to atmospheric entry

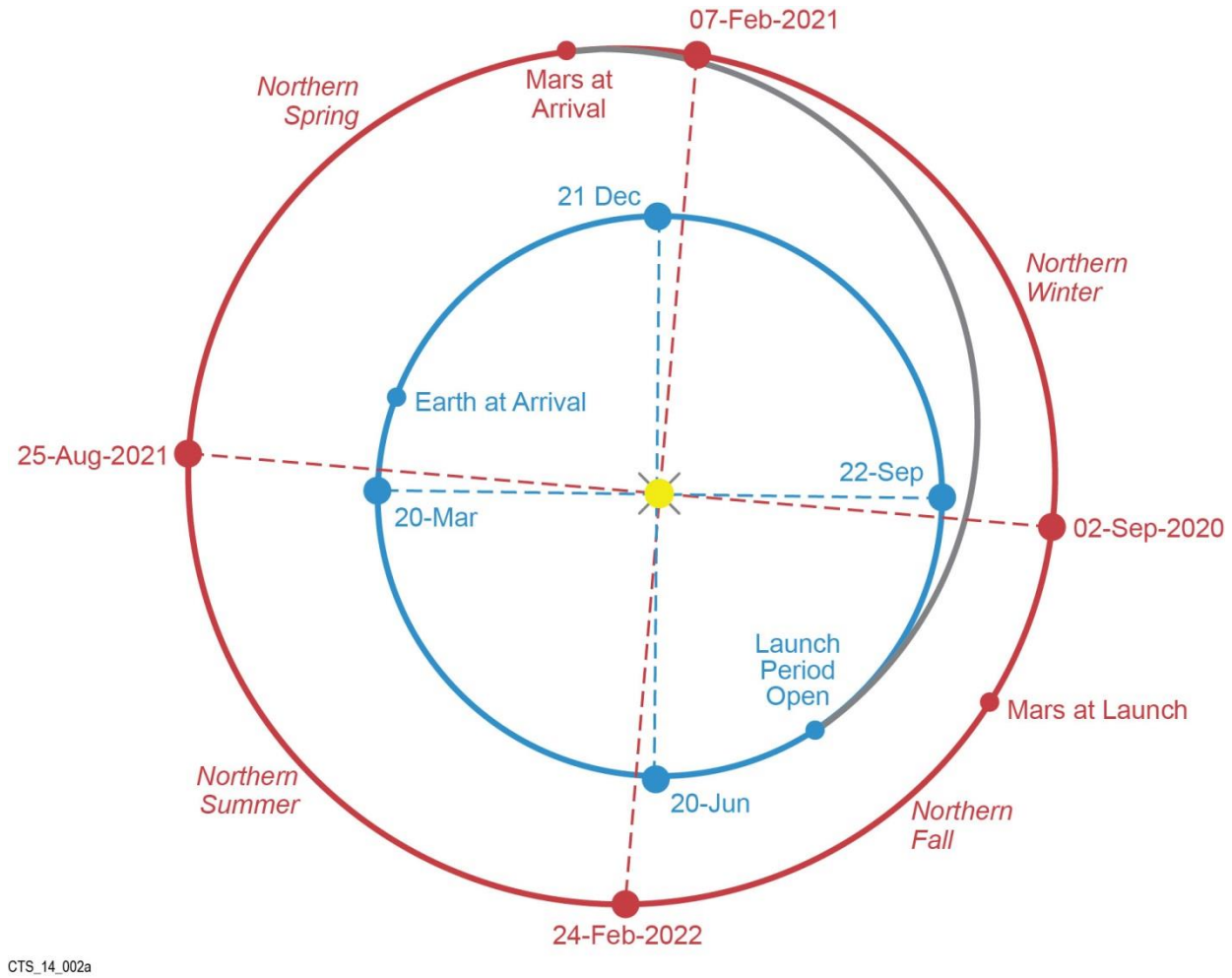
at Mars. The cruise phase would last approximately 7 months depending on the exact launch date, trajectory, and selected landing site.

The spacecraft's trajectory from Earth would be designed for a direct entry into the Martian atmosphere, without the spacecraft first entering into orbit around Mars. A final trajectory correction maneuver would be performed prior to separation of the cruise stage from the entry vehicle. Cruise stage separation would occur from 20 to 40 minutes before atmospheric entry. The cruise stage would enter the Martian atmosphere and would break apart and burn up from friction and heating.

The arrival date at Mars would range from January 2021 to March 2021. The arrival date at Mars is constrained by many factors including the need for real-time data transmission from the spacecraft during the critical entry, descent, and landing operations so that fault reconstruction could be developed should a failure occur. This capability would be implemented most efficiently during the Mars 2020 mission via high data rate communication. A high-rate communication link would allow real-time transmission of all critical engineering data (e.g., spacecraft position and orientation, and confirmation of deployment sequences).

For the Mars 2020 mission, this could only be achieved by using a pre-positioned Mars orbiting spacecraft to relay transmissions from the Mars 2020 flight system to Earth. Currently available orbiting spacecraft for entry, descent, and landing (EDL) communications and surface operations relay include the Mars Reconnaissance Orbiter (MRO), which entered Mars orbit in March 2006 and Mars Odyssey which entered orbit in October 2001. In addition, two planned future missions would provide an opportunity for additional Mars-orbiting spacecraft before the Mars 2020 mission arrives at Mars. These missions—MAVEN, which launched in November of 2013 with a planned arrival at Mars in 2014 and the 2016 ExoMars Trace Gas Orbiter (part of a European Space Agency mission with NASA support) with a planned arrival at Mars in 2016—would insert spacecraft with communications capabilities able to support the Mars 2020 mission. NASA would coordinate among these four missions to identify which would provide the optimal high data rate communication relay spacecraft for the Mars 2020 arrival event and for subsequent rover surface operations. The constraints on launch dates and arrival conditions during the 20-day launch period, including mutual visibility at arrival among the orbiting spacecraft and the Mars 2020 spacecraft, would limit arrival to specific dates between January 2021 and March 2021.

Figure 2-2 shows the positions of Earth and Mars as they orbit the sun and the seasons for Mars. The range of Mars 2020 proposed arrival dates would coincide with the transition from winter to spring in the northern hemisphere of Mars.



Source: JPL 2013

Note: Earth and its orbit are in blue; Mars and its orbit in red

Figure 2-2. Arrival Dates for the Proposed Mars 2020 Mission

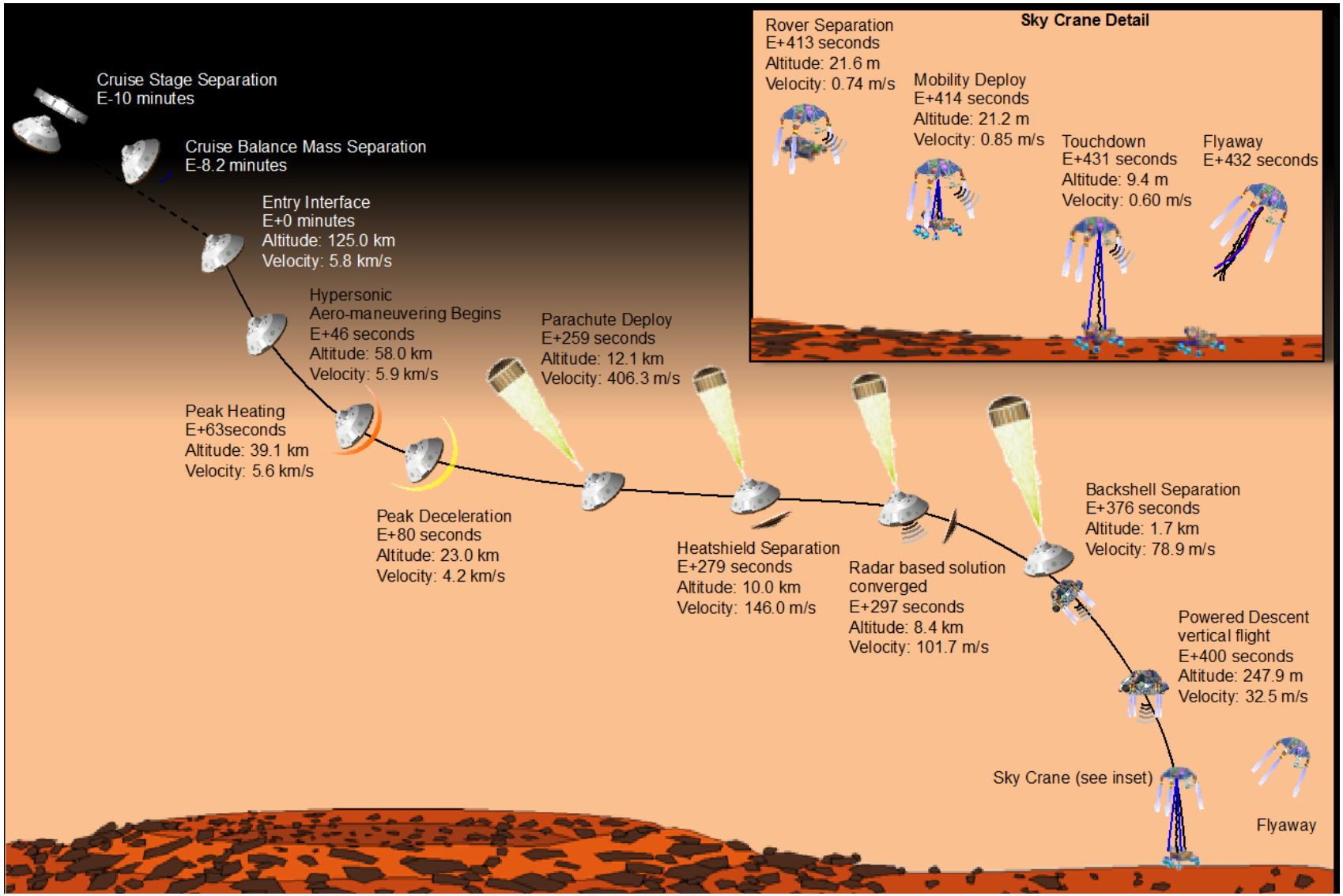
The exact landing site for the proposed Mars 2020 mission has not yet been selected. The location of the landing site would be restricted to between 30° north and 30° south latitudes as indicated in Table 2-1. It is anticipated that the landing site would be selected far enough in advance of the planned launch to allow sufficient time to determine the final details of the mission design (e.g., the specific launch trajectory). The site selection process would include a consensus recommendation by mission scientists, utilizing very detailed, high resolution images expected from the MRO mission and other available science data, on the most scientifically worthy location to land the rover. The selection process would also include NASA's engineering assessment of the rover's capabilities at the proposed site. NASA would then approve the selected site. The selected landing site would then factor into determination of the optimum launch and arrival dates for the mission, given the other constraints discussed above.

The EDL phase of the mission (Figure 2-3) would begin when the entry vehicle reaches an altitude of approximately 125 km (78 mi) above the surface of Mars, and would end with a soft touchdown of the rover on the Martian surface. The spacecraft would enter the Mars atmosphere directly from its interplanetary trajectory after a final trajectory correction maneuver and without entering orbit. The entry vehicle would maneuver during the early portion of atmospheric flight in order to reduce the landing site targeting errors that could result from pressure and density variations in the atmosphere.

Following parachute deployment at an altitude of about 12 km (7.5 mi), the heat shield would be released, the rover's mobility system deployed, and the landing radar initiated. The descent stage and rover would be released from the backshell about 1700 meters (m) (5,580 feet (ft)) above the surface and the terminal descent engines would be fired to slow the descending vehicle. At just over 20 m (66 ft) above the landing site, the rover would be lowered from the descent stage on tether/umbilical lines for a wheels-down soft landing on the Martian surface, called the "skycrane" phase of the landing sequence. The exact landing site is expected to be within a 25 km x 20 km (16 mi x 12 mi) elliptical area, although an improved EDL stage that would reduce the size of the landing area to an 18 km x 14 km (11 mi x 8.7 mi) elliptical area is being considered for the Mars 2020 mission. The tether/umbilical lines connecting the descent stage and the rover would be released, and the descent stage with the tether/umbilical lines attached would perform a fly-away maneuver to a hard landing a safe distance from the rover.

After landing on Mars, primary surface operations would commence and last for approximately one Martian year, which is 669 sols[4] or 687 Earth days. Under nominal initialization procedures, initial rover health checks would include calibration/checkout of the high gain antenna gimbal and the rover mast azimuth/elevation mechanism, removal of any engineering camera covers, and checkout of arm and mobility actuators. The rover would check the status of all major subsystems. Initial landed engineering camera and science instrument payload health checks would also occur during surface operations phase initialization, as well as a transition to the surface flight software load (i.e., a replacement of the onboard interplanetary cruise flight software with a flight software load tailored for the operation of a rover on the surface of a planet). A second phase of rover commissioning would include further checkout of mobility and arm functionality before the rover would be ready to start nominal science operations. In addition, first-time activities during nominal surface operations would require additional scrutiny. For example, first-time activities on the Mars Science Laboratory (MSL) Curiosity rover system included the first use of sample processing hardware and the first use of the corer. Mars 2020 would have comparable first-time activities to implement upon landing.

[4] 1 sol = 1 Martian day = 24 hours, 37 minutes = 1.026 Earth days.



Source: Mars 2020 Proposal Information Package (JPL)

Figure 2-3. Entry, Descent, and Landing Phase

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Surface operations are characterized by a long primary mission driven by an inherently interactive geological exploration and surveying process. The rover would have limited resources (power, mass storage, bandwidth, CPU, etc.) that require both flight- and ground-based management. The operations would be driven by a small set of repeating science scenarios. The general features of a typical surface operational scenario timeline can be divided into five main types of activities. This division is intended as an aid to understanding the Mars 2020 surface activities and scenario-dependent resource allocations, and is not intended to exclude any type of investigation that would be proposed through the Mars 2020 AO process. These scenarios are built of sol templates. Five different sol templates describe the expected building blocks of the surface mission operations plan: (1) traverse & approach, (2) site reconnaissance (remote sensing science), (3) arm manipulation & contact science, (4) coring/caching & contact science, and (5) recharge /telecom. The sol templates are used to help define resource usage for Mars 2020 planned activities to meet the mission and science objectives. The operations concept for the Mars 2020 mission, including team structures, uplink and downlink planning scenarios, daily operations timeline, and planned changes in operations approach over the course of the mission is derived from the experience and plans for Mars Exploration Rover (MER) and MSL flight operations.

Surface operations involve making decisions about how much time would be spent driving, how much time would be spent conducting fieldwork, and how much time would be spent collecting and caching samples. The amount of driving that might be required would depend greatly on where the rover has landed and where the highest-priority science targets might be located. *Fieldwork* is a term used here to encompass all of the effort expended to characterize the geology, assess habitability and preservation potential, identify possible biosignatures, and prepare any potential cores for caching. In particular for the Mars 2020 mission, fieldwork would include:

- acquisition and analysis of contextual imaging and mineralogy measurements,
- targeted contextual and fine-scale imaging and mineralogy observations,
- close-up elemental and organic detection measurements,
- preparation of rock surfaces by brushing and/or abrasion, and
- conduct of experiments in support of human exploration.

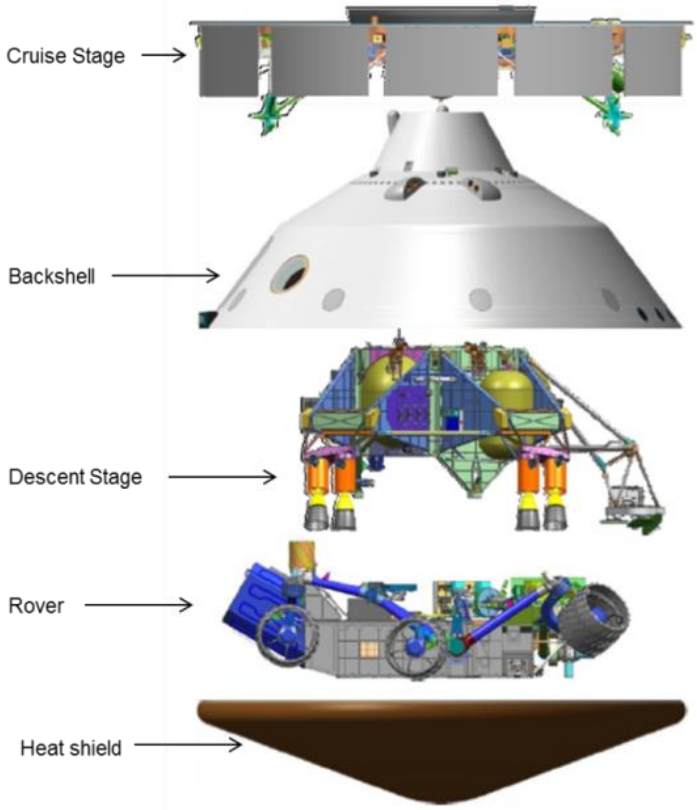
Fieldwork measurements would set the stage for selection of what to core, and which cores to cache for possible return to Earth. This effort would include the engineering interrogation of materials for their suitability to be cored. Decisions about the time spent on each of these activities would be governed by the strategic science objectives.

Scenarios for the rover's surface science operations are still being planned and evaluated by Mars 2020 mission scientists and engineers. The final details of the scenarios would depend upon factors such as the actual capabilities of the rover, when finally assembled and tested, and the selected landing site. Surface operations would also be adaptable to actual conditions on the surface of Mars and discoveries made during the course of the rover's mission. Best available information derived from the Mars 2020 AO documentation, from SDT mission objectives and SDT desired landing sites, are consistent with the mission operations scenarios of driving and fieldwork that have been used to estimate resource usage in order to accomplish surface mission

objectives for the Mars 2020 mission. Resource usage models to accomplish these objectives are based upon a high-heritage flight system implementation, as discussed in Section 2.1.2, using representative instrumentation "stand-ins" and payload elements that would accomplish the desired measurements as sought by the currently underway Mars 2020 competitive procurement process.

2.1.2 Spacecraft Description

The Mars 2020 spacecraft flight system is based upon the successful MSL design and would consist of a cruise stage, an entry vehicle, a descent stage, and the science rover. The flight system, illustrated in Figure 2-4, is currently estimated to weigh up to 4,050 kilograms (kg) (8,930 pounds (lb)).



Source: JPL 2013

Figure 2-4. Illustration of the Proposed Mars 2020 Flight System

The cruise stage, approximately 4.4 m (14.4 ft) in diameter, would provide the services necessary to support the trip to Mars. These services would include communications with Earth and provision of electrical power to the entry vehicle via a 6.8 square meter (73.2 square feet) solar array. Attitude control and trajectory correction maneuvers would be performed via a spin-stabilized hydrazine propellant system. Two titanium propellant tanks would contain approximately 70 kg (154 lb) of hydrazine.

The entry vehicle, approximately 4.5 m (14.8 ft) in diameter, would contain the systems that would safely enter the Martian atmosphere and deliver the rover to its designated landing site. The entry vehicle would include a heat shield and backshell, a supersonic parachute deployed by a mortar, and the stowed descent stage and rover.

The descent stage, illustrated in Figure 2-5, would provide the systems needed to guide, decelerate, hover, and lower the rover onto its designated landing site. The descent stage would contain five propulsion system tanks; three hydrazine tanks made of titanium and two helium pressure vessels made of composite material. The total propellant load for the descent stage would be about 390 kg (860 lb) of hydrazine.

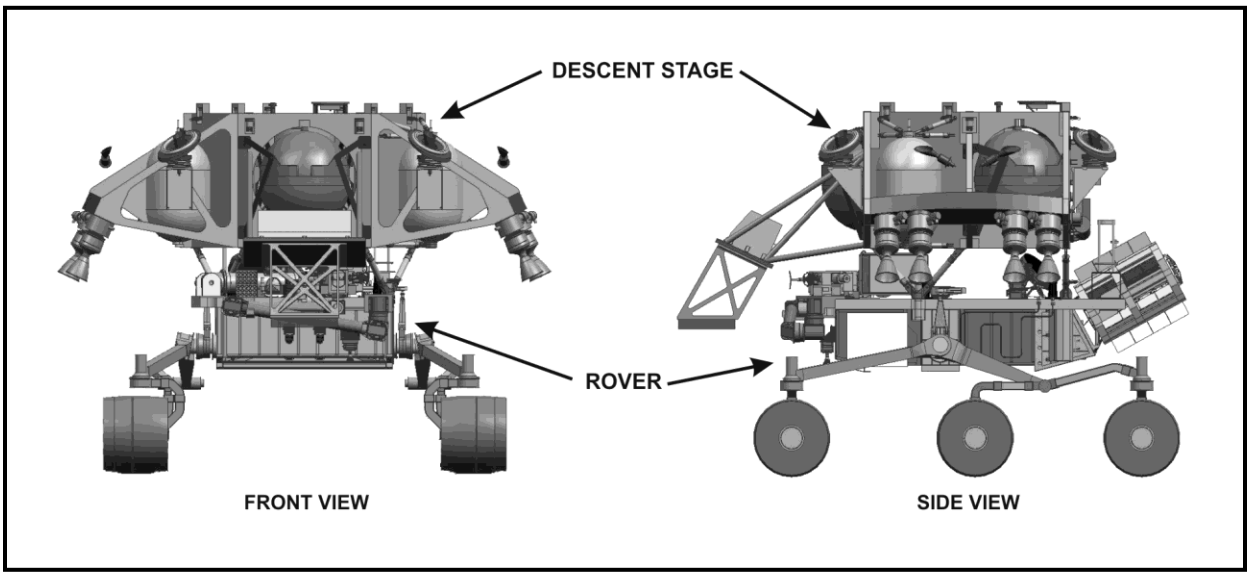
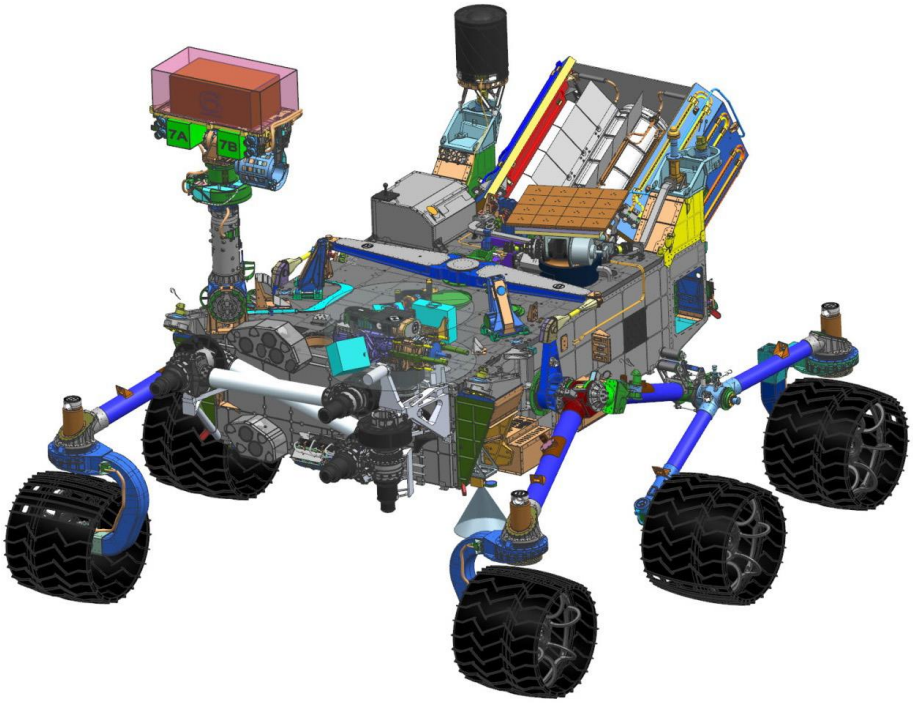


Figure 2-5. The Mars 2020 Descent Stage and Proposed Mars 2020 Rover

The preferred alternative rover, illustrated in Figure 2-6, would be made from an all-aluminum primary structure with machined panels. The thermal subsystem would include a heat exchange radiator system that allows use of the waste heat from the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) to keep the avionics and communication systems within thermal limits throughout Mars' daily and seasonal temperature variations. The mobility system would connect to the rover chassis. The rover would be designed to accommodate a payload module that would contain the body-mounted instruments and payload element, as well as the robotic arm. The rover would also support a remote sensing mast that would provide an elevated platform for critical engineering and scientific assets such as navigation imaging cameras, science imaging cameras, remote sensing instruments, and possibly meteorology instruments.

The payload instrumentation planned for the Mars 2020 mission would be selected by NASA through a competitive process (NASA 2013d) to meet the science objectives summarized in Chapter 1. The instrumentation solicited includes the science instrumentation used for investigating the surface of Mars (objectives A and B: to explore an astrobiologically relevant environment and to seek signs of life) and technology capabilities (objectives C and D: to make technical progress towards sample return and further preparation for human and robotic exploration). The selection of the instruments to be included on the Mars 2020 rover is the subject of a NASA Announcement of Opportunity published on September 24, 2013 to solicit proposals for the Mars 2020 surface-science investigations and exploration technology investigations. Following receipt and review of the proposals, NASA plans to select the suite of instruments in 2014. Pending the selection of the instruments for the Mars 2020 mission, the following discussion is based on the Mars 2020 mission SDT's assessment of the needs for the 2020 mission. The final selection of instruments would be based on the determination of the instruments that are best able to meet the goals of the Mars 2020 mission.



Source: JPL 2013

Figure 2-6. The Proposed Mars 2020 Rover

The SDT report identified two levels of scientific measurement for the Mars 2020 mission: a threshold level and a baseline level. The baseline level includes all of the measurements identified for the threshold level plus additional measurement capabilities and represents the capability to which the Mars 2020 science instrumentation would be designed. The types of measurements needed to meet the baseline science objectives for the Mars 2020 mission are summarized in Table 2-2, and the possible locations (the turret, mast, and internal rover volume) for the instruments on the rover are shown in Figure 2-7.

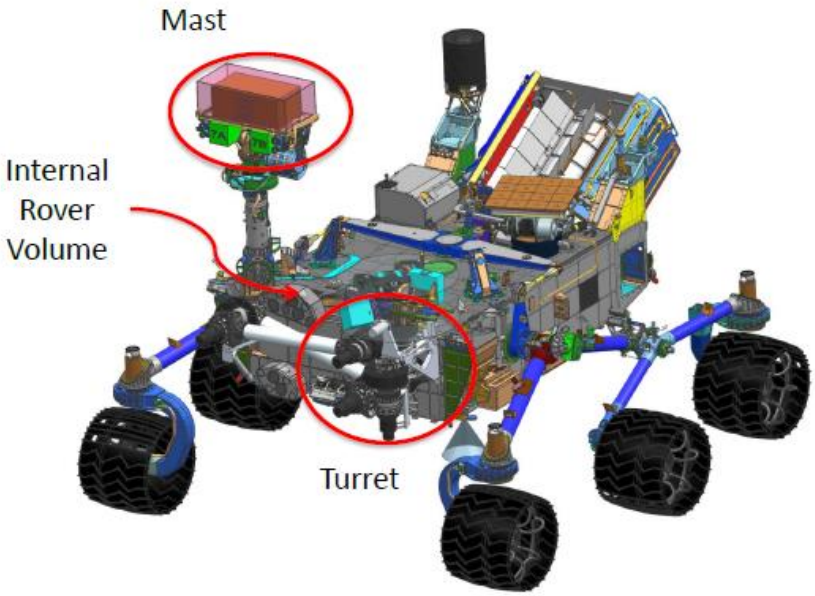
For objectives A, B, and C, five measurement types are threshold requirements to effectively and efficiently characterize the geology of a site, assess habitability, select samples, and document sample context.

Context Imaging. This measurement would image the terrain at a sufficient level of detail for navigational purposes (enabling the rover to travel at the required minimum distances per day), to characterize the geological context, to select (at a distance) locations for further in-depth analyses by close-up instruments and sampling, and to identify terrain that could support the assessment of past habitable environments and the potential for preservation of signs of life.

Table 2-2. Mars 2020 Science Measurements

Measurement	Objective A	Objective B	Objective C	Objective D
Context Imaging	√	√	√	
Fine-Scale Imaging	√	√	√	
Context Mineralogy	√	√	√	
Fine-Scale Elementary Chemistry	√	√	√	
Fine-Scale Mineralogy	√	√	√	
Subsurface Sensing	†			
Reduced/Organic Matter Detection		√		
Organic Matter Detection	†	†	†	
In Situ Resource Utilization				†
Entry, Descent, and Landing Data				†
Entry Descent, and Landing Precision				†
Surface Weather Monitoring				†
Biohazards to Astronauts				†

√ - Threshold
† - Baseline
Note: The total mass allocation for the science instruments is currently 28kg (62 lb) (NASA 2013d)



Source: JPL 2013

Figure 2-7. The Science Instrument Locations on the Proposed Mars 2020 Rover

Context Mineralogy. This measurement would serve a dual role in supplying reconnaissance information for possible drive targets and provide context for fine-scale measurements. Context mineralogy would identify, from afar, the presence of key mineral phases in surface targets to support the selection of specific outcrops, rocks, and soils to investigate in detail with other rover instrumentation, especially with respect to identifying potential areas that show signs of past habitable environments and the preservation of signs of life.

Fine-scale Imaging. The objectives of this measurement would be to characterize grain form and structure and the textural fabric of rocks and soils at a microscopic scale. Data from this investigation would: 1) contribute to the characterization of the rover site's geological environment; 2) illuminate details of local geologic history, such as crystallization of igneous rocks, deposition and conversion of sediment to rock, and weathering and erosion; and 3) assist in the search for structural signs of life, if preserved, in the rock record.

Fine-scale Mineralogy. The objectives of this investigation would be to detect and to measure the spatial distribution, at sub-millimeter scale, of the signatures of key minerals in outcrops, rocks, and soils. For objective B, a key purpose of the mineralogical measurement would be to detect potential biominerals and determine the mineral composition of other potential biosignatures and associated materials.

Fine-scale Elemental Chemistry. The objective of this investigation would be to measure the abundances of major and selected minor elements most indicative of igneous, alteration, and sedimentary processes. Among the science goals of these measurements would be to determine the fine-scale elemental chemistry of sedimentary, igneous and alteration features, and (for objective B) to detect potential chemical signs of life, determine the elemental composition of potential signs of life, and search for historical evidence of the activity of liquid water.

In addition to the five threshold investigations described above, baseline investigations would include organic detection investigation; both to provide contextual information on habitability and potential signs of life and to select, if possible, samples with preserved organic chemistry.

Organic Matter Detection. Organic matter detection would provide observations for assessing the processes that influence preservation of information about ancient environments. Detection of organic matter, via the identification of reduced carbon compounds in near-surface materials, could be used to help characterize meteoritic inputs, hydrothermal processes, atmospheric processes, and other potential processes that might form organic matter. Lastly, in order to identify the most desirable samples for possible return to Earth, detecting organic matter at a site would be valuable. The vast majority of spaceflight-compatible methods for detecting organic matter that might include potential organic signs of life can be categorized as types of mass spectrometry, chromatography, spectrophotometry, and binding assays or metabolic assays.

Subsurface Sensing. Techniques that sense subsurface structural continuity could provide contextual information complementary to that obtained by the envisaged threshold payload for surface exposures. Ground-penetrating radar and electromagnetic sounding are examples of relevant techniques that could provide information to better understand local stratigraphy.

Five demonstration payloads have been identified that meet the needs for Objective D; but these may not be the full set of demonstration payloads ultimately considered for the Mars 2020 mission. The first demonstration payload would be the demonstration of carbon dioxide (CO_2) capture and dust size characterization for atmospheric In Situ Resource Utilization (ISRU). This payload addresses two-high priority items:

demonstrating atmospheric ISRU and measuring dust properties. It would be an architecture enabling technology for human missions to Mars, which will likely depend on ISRU for producing the propellants needed for the return trip to Earth; ISRU can greatly reduce mass transported to the Martian surface. ISRU would demonstrate dust filtration and non-intrusive measurement during Mars CO_2 capture and subsequent CO_2 collection.

The second demonstration payload would be a flight of an enhanced EDL instrumentation payload to acquire temperature and pressure measurements on the heat shield and other parts of the spacecraft. The temperature and pressure measurements during atmospheric entry would be used to validate analytical models for designing future EDL systems. EDL systems capable of landing large payloads on Mars are an architecture enabling technology for human missions.

Another possible EDL technology demonstration would include technologies to improve EDL precision (reduce the size of the potential landing area or better ensure landing survival). Potential technologies include: a Range Trigger, improved technology for deployment of the parachute based on range to the landing site; Terrain Relative Navigation, navigation by matching visual images of the landing site taken during descent to images taken from orbit; and terminal hazard avoidance systems, a combination of landing site hazard identification and terminal guidance technologies.

The inclusion of a Surface Weather Station on the Mars 2020 payload would provide density for EDL and ascent profiles, plus validation data for global atmosphere models that would enable validation of global model extrapolations of surface pressure. It would also provide local-surface and near-surface validation data to validate regional and local model atmospheric conditions. Parameters monitored could include pressure, temperature, winds, humidity, and vertical temperature profiles. Additionally, total atmospheric aerosol content and aerosol profiles could be monitored. This set of instrumentation, plus the characterization of the dust properties provided as part of the ISRU demonstration, would address a number of climatological science questions and objectives.

A biohazards to astronauts technology would consist of a “biomarker detector” system which could not only examine the potential for contaminants to impact astronauts (and other species should the contaminant be returned to Earth), but could also assess the impact of terrestrial contaminants on Mars. Such a system could be used for extraterrestrial life detection by targeting universal biomarkers such as amino acids, polymers, polysaccharides, whole cells, and microbial spores; and also for planetary protection to monitor forward contamination during robotic/human operations in an extraterrestrial environment.

While the science instruments for the Mars 2020 rover are yet to be selected, it is reasonable to assume that at least some of them may contain small radioactive sources. These sources are typically used for calibration of the science instrument, or they could be a necessary part of the instruments investigative process. For example, the Mars Science Laboratory rover and the Mars Exploration Rovers (MERs) contained science instruments that contained radioactive sources used for instrument calibration or science experiments. The isotope and quantity of each source is listed below.

Mission	Instrument	Radioisotope	Activity, curies
MER	APXS	Curium-244	0.03
MER	Mossbauer Spectrometer	Cobalt-57	<0.35
MSL	APXS	Curium-244 Cadmium-109	0.06 0.105
MSL	DAN	Tritium (hydrogen-3)	2

Definitions: APXS – Alpha Particle X-ray Spectrometer; DAN – Dynamic Albedo of Neutrons

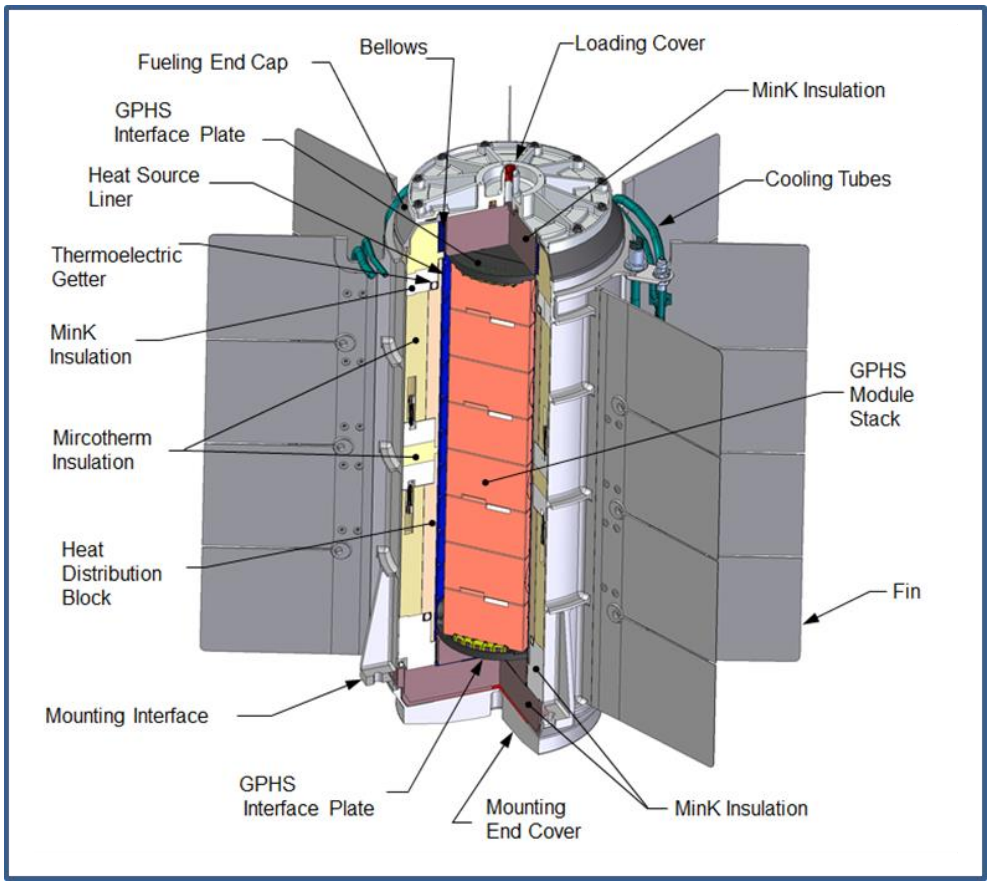
2.1.3 Rover Electrical Power

The proposed Mars 2020 rover would use a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), provided to NASA by the U.S. Department of Energy (DOE), as the source of electrical power for its engineering subsystems and science payload. This is the same power supply used by the MSL. The MMRTG would be the only radioisotope thermoelectric generator available for the Mars 2020 mission. NASA has pursued the development of both the MMRTG and an Advanced Stirling Radioisotope Generator (ASRG) (NASA 2006b). However, NASA recently announced that it has decided to end procurement of and discontinue work on the development of ASRG flight hardware. Therefore, an ASRG would not be available for the Mars 2020 mission.

An MMRTG (Figure 2-8) converts heat from the natural radioactive decay of plutonium (in a ceramic form called plutonium dioxide consisting mostly of plutonium-238) into usable electrical power. RTGs have been successfully used on 27 previously-flown United States space missions (Table 2-3), including six Apollo flights, and the Pioneer, Viking, Voyager, Galileo, Ulysses, Cassini, and New Horizons missions. The evolutionary development of radioisotope power systems has resulted in several RTG configurations, evolving from the Systems for Nuclear Auxiliary Power (SNAP)-3 RTG through the Multi-Hundred Watt (MHW)-RTG to the General Purpose Heat Source (GPHS)-RTG used for the New Horizons mission to Pluto. The MMRTG is designed for applications both in the vacuum of deep space and on the surface of bodies with an atmosphere, such as Mars.

Development of the MMRTG has been documented in NASA's Final Programmatic Environmental Impact Statement for the Development of Advanced Radioisotope Power Systems (NASA 2006b).

The heat source assembly of the MMRTG consists of eight GPHS modules, an isolation liner, and end components. Each GPHS module (Figure 2-9) has dimensions of approximately 9.3 by 10.0 by 5.8 centimeters (cm) (3.7 by 3.9 by 2.3 inches (in)), a mass of about 1.6 kg (3.5 lb), and would contain about 0.6 kg (1.3 lb) of plutonium dioxide (SNL 2014). A GPHS module consists of a graphite aeroshell, two carbon-bonded carbon fiber insulator sleeves, two graphite impact shells (GIS), and four iridium clads, with each clad containing a ceramic pellet of plutonium dioxide.



Source: SNL 2014

Figure 2-8. Components of a Multi-Mission Radioisotope Thermoelectric Generator

An MMRTG contains about 4.8 kg (10.6 lb) of plutonium dioxide with a total radiological activity of about 60,000 curies (Ci). Plutonium can exist in a number of different radioactive isotopic forms. The principal plutonium isotope in the fuel, in terms of mass and total activity, is Pu-238. Table 2-4 provides representative characteristics and the isotopic composition of the plutonium dioxide in the MMRTG (SNL 2014). Plutonium dioxide has a density of 9.6 grams per cubic centimeter (5.5 ounces per cubic inch), melts at 2,400 degrees Celsius (°C) (4,352 degrees Fahrenheit (°F)), and boils at 3,870°C (6,998°F).

The DOE designed the MMRTG to provide for containment of the plutonium dioxide fuel to the extent feasible during all mission phases, including ground handling, launch, and unplanned events such as reentry, impact, and post-impact situations including fires. Under normal, accident, and post-accident conditions the safety-related design features of the MMRTG to be used for the Mars 2020 mission are intended to:

- Prevent, to the extent possible, the release of plutonium dioxide from the iridium clad and GPHS
- minimize the release and dispersion of the plutonium dioxide fuel, especially small, respirable particles that could be hazardous to human health

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Table 2-3. U.S. Space Missions Using Radioisotope Power Sources (RPSs)

Power Source (number of RPSs)	Spacecraft	Mission Type	Launch Date	Status	Activity at Launch (curies)
SNAP-3B7 (1)	TRANSIT 4A	Navigational	Jun 29, 1961	Currently in Earth orbit	1,500 – 1,600
SNAP-3B8 (1)	TRANSIT 4B	Navigational	Nov 15, 1961	Currently in Earth orbit	1,500 – 1,600
SNAP-9A (1)	TRANSIT 5BN-1	Navigational	Sep 28, 1963	Currently in Earth orbit	17,000
SNAP-9A (1)	TRANSIT 5BN-2	Navigational	Dec 5, 1963	Currently in Earth orbit	17,000
SNAP-9A (1)	TRANSIT 5BN-3	Navigational	Apr 21, 1964	Mission aborted; RPS burned up on reentry as designed	17,000
SNAP-19B2 (2)	NIMBUS-B-1	Meteorological	May 18, 1968	Mission aborted; RPS retrieved intact	34,400
SNAP-19B2 (2)	NIMBUS III	Meteorological	Apr 14, 1969	Currently in Earth orbit	37,000
SNAP-27 (1)	APOLLO 12	Lunar	Nov 14, 1969	ALSEP [(a)] shut down and remains on lunar surface	44,500
SNAP-27 (1)	APOLLO 13	Lunar	Apr 11, 1970	Mission aborted on way to moon; ALSEP (in Lunar Module) was successfully targeted to the Tonga Trench in the Pacific Ocean for safe disposal	44,500
SNAP-27 (1)	APOLLO 14	Lunar	Jan 31, 1971	ALSEP shut down and remains on lunar surface	44,500
SNAP-27 (1)	APOLLO 15	Lunar	Jul 26, 1971	ALSEP shut down and remains on lunar surface	44,500
SNAP-19 (4)	PIONEER 10	Planetary	Mar 2, 1972	Successfully operated to Jupiter and beyond	80,000
SNAP-27 (1)	APOLLO 16	Lunar	Apr 16, 1972	ALSEP shut down and remains on lunar surface	44,500
TRANSIT-RTG (1)	TRIAD-01-1X	Navigational	Sep 2, 1972	Currently in Earth orbit	24,000
SNAP-27 (1)	APOLLO 17	Lunar	Dec 7, 1972	ALSEP shut down and remains on lunar surface	44,500
SNAP-19 (4)	PIONEER 11	Planetary	Apr 5, 1973	Successfully operated to Jupiter, Saturn and beyond	80,000
SNAP-19 (2)	VIKING 1	Planetary	Aug 20, 1975	Lander shut down and remains on surface of Mars	41,000
SNAP-19 (2)	VIKING 2	Planetary	Sep 9, 1975	Lander shut down and remains on surface of Mars	41,000
MHW-RTG (2)	LES 8	Communications	Mar 14, 1976	Successfully operating in Earth orbit	159,400
MHW-RTG (2)	LES 9	Communications	Mar 14, 1976	Successfully operating in Earth orbit	159,400
MHW-RTG (3)	VOYAGER 2	Planetary	Aug 20, 1977	Successfully operated to Neptune and beyond	240,000
MHW-RTG (3)	VOYAGER 1	Planetary	Sep 5, 1977	Successfully operated to Saturn and beyond	240,000
GPHS-RTG (2)	GALILEO	Planetary	Oct 18, 1989	Successfully operated in Jupiter orbit; after 8 years, spacecraft purposefully entered Jupiter's atmosphere	269,000 [(b)]
GPHS-RTG (1)	ULYSSES	Planetary	Oct 6, 1990	Successfully operating in heliocentric orbit	132,500
GPHS-RTG (3)	CASSINI	Planetary	Oct 15, 1997	Successfully operating in Saturn orbit	404,000 [(b)]
GPHS-RTG (1)	NEW HORIZONS	Planetary	Jan 19, 2006	Successfully operating in flight to Pluto	121,000
MMRTG (1)	MSL	Planetary	Nov 26, 2011	Successfully operating on the surface of Mars	58,700

(a) Apollo Lunar Surface Experiments Package.

(b) Includes inventory from Radioisotope Heater Units.

Note: The proposed Mars 2020 mission would use one MMRTG with approximately 60,000 curies.

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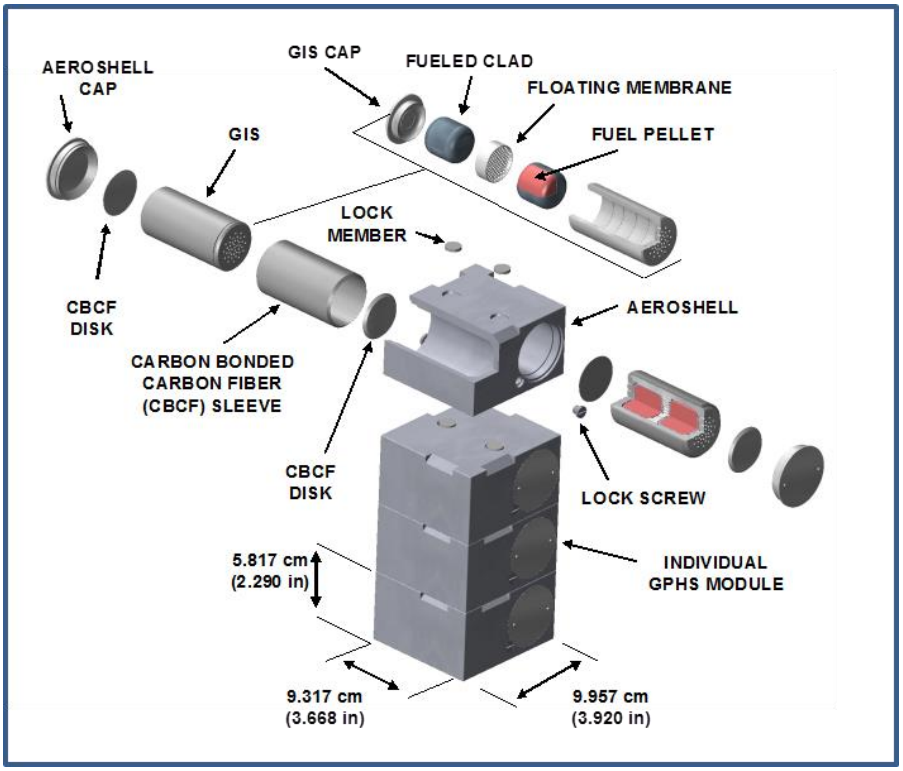


Source: SNL 2014

Figure 2-9. A General Purpose Heat Source Module

- reduce the likelihood that small respirable sized particles could be generated during an accident
- minimize any land, ocean and atmosphere contamination, particularly in populated areas; and,
- maximize the long-term immobilization of the plutonium dioxide fuel following postulated accidents so that it does not spread further and could be more effectively recovered.

The layered approach to the safety design features of the MMRTG and their response to potential accidents include the following elements.

- **Thermoelectric Converter/GPHS Design:** The MMRTG is designed to release the individual GPHS modules in case of inadvertent reentry into Earth's atmosphere after launch in order to minimize the terminal velocity of the modules and the potential for fuel release on Earth impact. The converter housing is made of aluminum alloy to ensure melting and breakup of the converter upon reentry, resulting in release of the modules.
- **GPHS Module, GIS, and related graphite components:** The GPHS module and its graphite components are designed to provide reentry and surface impact protection to the iridium fueled clad in case of accidental sub-orbital or orbital reentry. The aeroshell and GIS are composed of a rugged carbon-carbon Fine Weave Pierced Fabric, developed originally for reentry nose cone material. The

Table 2-4. Typical Isotopic Composition of an MMRTG

Fuel Component	Weight Percent	Half-Life, years	Specific Activity, curies/gram	Total Activity [(a)], curies
Plutonium (Pu)	85.99			
Pu–236	6×10^{-8}	2.851	531.3	0.0016
Pu–238	72.33	87.7	17.12	59,440
Pu–239	11.83	24,131	0.0620	17.6
Pu–240	1.70	6,569	0.2267	18.5
Pu–241	0.09	14.1	103.0	445
Pu–242	0.04	375,800	0.00393	0.0080
Actinide Impurities	0.97	NA	NA	24
Other Impurities	1.14	NA	NA	NA
Oxygen	11.9	NA	NA	NA
Total	**100.00**	**NA**	**NA**	**59,936**

Source: SNL 2014

(a) Based on 4.8 kg (10.6 lb) of PuO_2.
NA = Not Applicable

existing GPHS module is an evolution of a design that has worked with extreme reliability for the past three decades; to provide even greater protection, the broad face of the module and the face between the two shells are 20 percent thicker than the modules used in the GPHS-RTG in order to increase the module's strength and enhance its performance under impact and reentry conditions (SNL 2014).

- **Iridium Clads:** The iridium that encases each plutonium dioxide pellet is a strong, ductile metal that resists corrosion and does not react chemically with the radioisotope fuel. In the unlikely event of an accident involving an impact, the iridium cladding is designed to deform yet contain the fuel. Iridium is chemically compatible with the graphite components of the GPHS module and the plutonium dioxide fuel over the operating temperature range of the MMRTG, given its high melting temperature (2,443°C (4,430°F)) and excellent impact response.
- **Ceramic Form of Plutonium Dioxide:** The nuclear fuel used in an MMRTG is manufactured in a ceramic form. This form has material properties similar to a coffee cup: it tends to fracture in large, non-inhalable chunks and it is highly insoluble; this means that it does not easily mix or become easily transportable in water, nor does it react easily with other chemicals. Plutonium dioxide has a high melting temperature (2,400°C (4,352°F)).

DOE has over 30 years of experience in the engineering, fabrication, safety testing, and evaluation of GPHS modules, building on the experience gained from previous heat source development programs and an information base that has grown since the 1960s.

The GPHS modules were designed to prevent the release of fuel under a wide variety of accident scenarios, including high-speed impacts, projectiles, fires, and Earth re-entry.

Previous generations of heat source designs have survived two accidents: the heat sources on the Nimbus-B spacecraft (1968) protected the fuel from release during an early launch abort (with the fuel subsequently being re-used on a future mission), and the Apollo 13 lunar module (1970) carried a lunar surface science experiment package heat source that was similarly protected during its re-entry and ocean impact.

The MMRTG and enhanced GPHS module were successfully flown on the MSL mission that launched in November 2011 and is now operating as designed on Mars. Even though formal safety testing is ongoing, much insight has been gained by examining the safety testing performed on the earlier GPHS-RTG and its components. The GPHS-RTG with 18 GPHS modules has been used on the Galileo, Ulysses, Cassini, and New Horizons missions. Formal safety testing of both the MMRTG and GPHS-RTG components has established a database that allows prediction of responses in accident environments. These safety tests have covered responses to the following environments:

- impact from fragments,
- other mechanical impacts,
- thermal energy,
- explosive overpressure, and
- reentry conditions (i.e., aerodynamic loads and aerodynamic heating).

2.1.4 Operational Considerations

An MMRTG supplies sufficient power for the rover to perform operations at all times and at all possible landing sites between 30° north and 30° south latitudes. At no time would the rover be required to operate at less than 100% capability (constrained capacity), nor would it have to hibernate (cease all operations but maintain the rover temperature within limits needed to assure rover survival).

2.1.5 Spacecraft Processing

The Mars 2020 spacecraft would be designed, fabricated, integrated and tested at facilities of the spacecraft provider, the Jet Propulsion Laboratory (JPL), which is managed for NASA by the California Institute of Technology in Pasadena, CA. These facilities have been used extensively in the past for a broad variety of spacecraft, and no new facilities would be required for the Mars 2020 spacecraft. JPL would deliver the spacecraft to NASA's Kennedy Space Center (KSC) in Florida for further testing and integration with the MMRTG and with the launch vehicle.

The spacecraft would be received at the KSC Payload Hazardous Servicing Facility (PHSF). The spacecraft would be inspected and comprehensive tests would be performed, including flight and mission simulations. The DOE would deliver the MMRTG to a KSC storage facility. Once the spacecraft tests are completed, the MMRTG would be moved to the PHSF where it would be fitted to the rover for a pre-flight systems check. After completing these checks, the MMRTG would be returned to storage. The spacecraft would then be fueled with a total of about 460 kg (1,014 lb) of hydrazine (SNL 2013), the currently estimated propellant load capability for the cruise stage and descent stage.

A systems check and other tests would then be performed, after which the spacecraft would be enclosed within the launch vehicle payload fairing (PLF). The PLF, containing the spacecraft, would then be transported from the PHSF to the launch complex at KSC or CCAFS and would be attached to the vehicle's second stage. The aft end of the PLF would be sealed with a barrier and connected to an environmental control system to prevent contamination during transit.

After the Mars 2020 spacecraft and its launch vehicle have been integrated at KSC or CCAFS, the MMRTG would be transported to the launch complex where it would be installed on the rover through special access panels on both the launch vehicle PLF and the entry vehicle aeroshell (Lytal 2010). MMRTG handling at KSC and CCAFS would be performed under stringent conditions following all requirements governing the use of radioactive materials. Transportation of the MMRTG between KSC and CCAFS would be in accordance with applicable U.S. Department of Transportation and other federal, state, and local regulations (NASA 2001).

2.1.6 Representative Launch Vehicle Configurations for the Mars 2020 Mission

Early in the development process for the proposed Mars 2020 mission, NASA plans to issue a Request for Launch Service Proposal to all NASA Launch Service (NLS)-approved contractors. The Request for Launch Service Proposal would contain a statement of work and request that proposals be submitted to NASA for the Mars 2020 mission. Once the proposals are received from the NLS contractors, NASA's Launch Service Task Order (LSTO) board would evaluate them in accordance with LSTO procedures and previously determined technical evaluation criteria. Upon completion of the evaluation, NASA would identify the proposed configuration of the launch vehicle that would meet all the specified mission requirements and would present the best value to the government.

The evaluations of potential environmental consequences for this DEIS, summarized in Section 2.5 and presented in more detail in Chapter 4, were prepared before NASA selected the launch vehicle for the proposed Mars 2020 mission. These evaluations were based upon representative configurations of the Atlas V and Delta IV class vehicles (the Delta IV class vehicle representing the liquid fueled Delta IV and Falcon Heavy launch vehicles) that would have the performance capabilities necessary for the mission. The representative launch vehicle configurations are described in the following sections.

2.1.6.1. Description of the Atlas V Launch Vehicle

The Atlas family of launch vehicles, provided by United Launch Alliance (ULA) a joint venture of Lockheed Martin Corporation and The Boeing Company (a NLS-approved contractor), has evolved through various government and commercial programs from the first research and development flight in 1957 through the Atlas II, III, and V configurations. Versions of Atlas vehicles have been built specifically for both robotic and human space missions. The most recent version, the Atlas V, is currently available in 400 and 500 series configurations.

The Atlas V configurations being considered for the proposed Mars 2020 mission are the Atlas V 541 and 551, each of which would consist of a liquid propellant first stage with strap-on solid rocket boosters (SRBs), a liquid propellant Centaur second stage, the Mars 2020 spacecraft, and the PLF. The "541" designation denotes a 5-m PLF, four SRBs, and a single-engine Centaur second stage; the “551” has five SRBs. The SRBs are attached to the first stage and the Centaur is mounted on top of the first stage. The Mars 2020 spacecraft would be mounted atop the Centaur. The PLF encloses and protects the spacecraft. The Atlas V, depicted in Figure 2-10, is approximately 62.4 m (205 ft) in height (ULA 2010).

2.1.6.1.1. First Stage

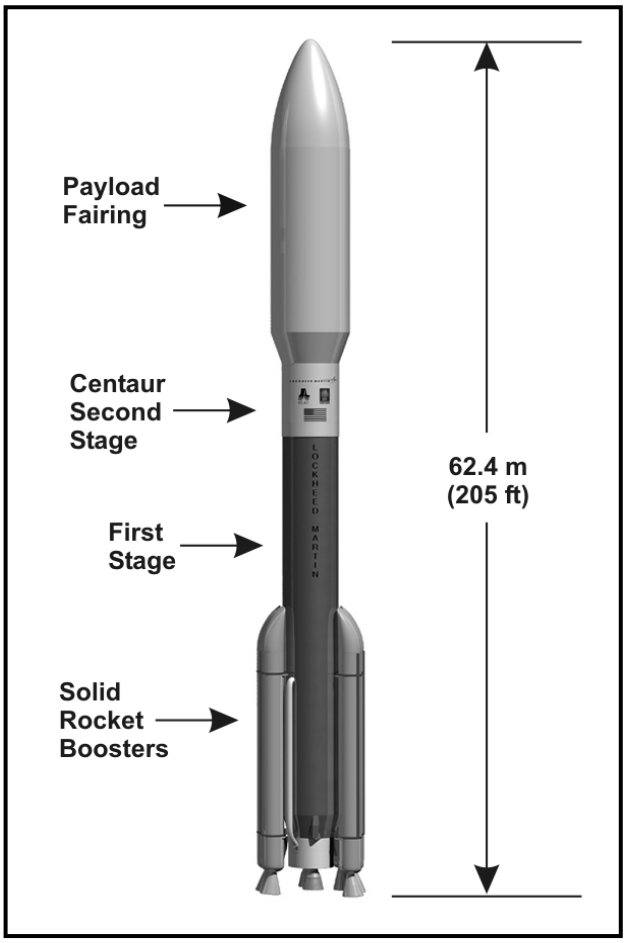
The Atlas V first stage is constructed mostly of aluminum and composite material, and is about 3.8 m (12.5 ft) in diameter and about 32.5 m (107 ft) in length. The first stage is powered by a liquid-fueled engine and contains about 284,089 kg (626,303 lb) of propellant. The fuel is rocket propellant-1 (RP-1), a thermally stable kerosene; and the oxidizer is liquid oxygen (LOx). Each SRB is 1.5 m (5 ft) in diameter, 20 m (66 ft) in length, and is fueled with about 43,000 kg (94,800 lb) of solid propellant (consisting of ammonium perchlorate, aluminum, and hydroxyl-terminated polybutadiene (HTPB) binder) for a total propellant mass of about 172,000 kg (379,000 lb) for the four SRBs, and about 215,000 kg (474,000 lb) for five SRBs (ULA 2010).

2.1.6.1.2. Centaur Second Stage

The Atlas V Centaur second stage is constructed of stainless steel and is about 3.1 m (10 ft) in diameter and about 12.7 m (42 ft) in length. The Centaur is powered by a single, cryogenic engine, and contains about 20,830 kg (45,922 lb) of propellant, consisting of liquid hydrogen (LH_2) as the fuel and LOx as the oxidizer (ULA 2010). The Centaur uses less than 91 kg (200 lb) of hydrazine for reaction control (USAF 2000).

2.1.6.1.3. Payload Fairing

The PLF for the Atlas V is about 5.4 m (18 ft) in diameter and about 20.7 m (68 ft) in length and is constructed of aluminum, carbon



Source: Adapted from, ULA 2010

Figure 2-10. An Atlas V Launch Vehicle with Solid Rocket Boosters

fiber, and composite materials. The PLF encloses and protects the spacecraft from thermal, acoustic, electromagnetic, and environmental conditions during ground operations and lift-off through atmospheric ascent (ULA 2010). Figure 2-11 depicts the spacecraft within the PLF envelope.

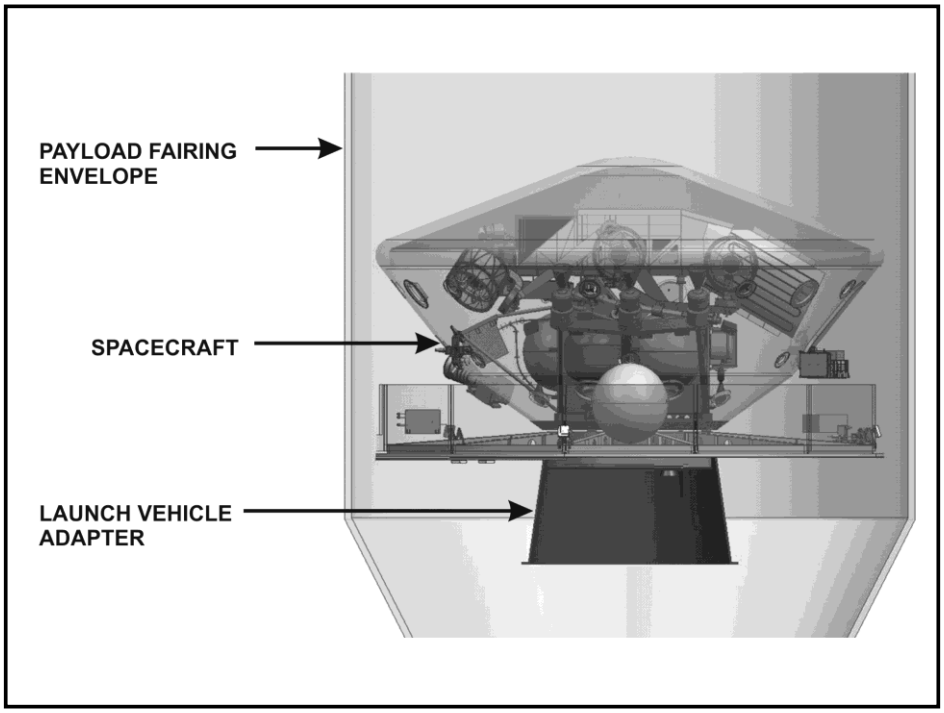


Figure 2-11. The Spacecraft Within the Payload Fairing Envelope

2.1.6.1.4. Atlas V Space Launch Complex-41

Space Launch Complex (SLC)-41 is located in the northernmost section of CCAFS. The launch complex consists of a launch pad, an umbilical mast, propellant and water storage areas, an exhaust flume, catch basins, security services, fences, support buildings, and facilities necessary to prepare, service, and launch Atlas V vehicles (USAF 1998, ULA 2010).

Security at SLC-41 is ensured by a perimeter fence, guards, and restricted access. Since all operations in the launch complex would involve or would be conducted in the vicinity of liquid or solid propellants and explosive devices, the number of personnel permitted in the area, safety clothing to be worn, the type of activity permitted, and equipment allowed would be strictly regulated. The airspace over the launch complex would be restricted at the time of launch.

2.1.6.1.5. Launch Vehicle Processing

Atlas launch vehicle preparation activities and procedures during and after launch have been previously documented (USAF 1998, ULA 2010). All NASA launches follow the current standard operating procedures.

The Atlas V launch vehicle components for the Mars 2020 mission would be received at CCAFS, where they would be inspected, stored, and processed at appropriate facilities.

When needed for launch, the components would be moved to the Vertical Integration Facility (VIF) at SLC-41, where the launch vehicle would be assembled, integrated, and tested. The PLF, containing the Mars 2020 spacecraft, would then be transported from the PHSF at KSC to the VIF and mated to the Centaur second stage. The Atlas V launch vehicle would then be moved via rail on a mobile launch platform (limited to a speed of 3.2 km/h (2 mph)) to the launch pad at SLC-41 for a rehearsal of loading the RP-1, LOx, and LH_2 liquid propellants, and then unloading the LOx and LH_2. The vehicle (with RP-1) would then be moved back to the VIF, where hydrazine would be loaded and final vehicle processing would be performed. The MMRTG would then be installed on the spacecraft. The launch vehicle would then be moved back to the pad for LOx and LH_2 loading, final systems tests, and launch (USAF 1998, USAF 2000, ULA 2010).

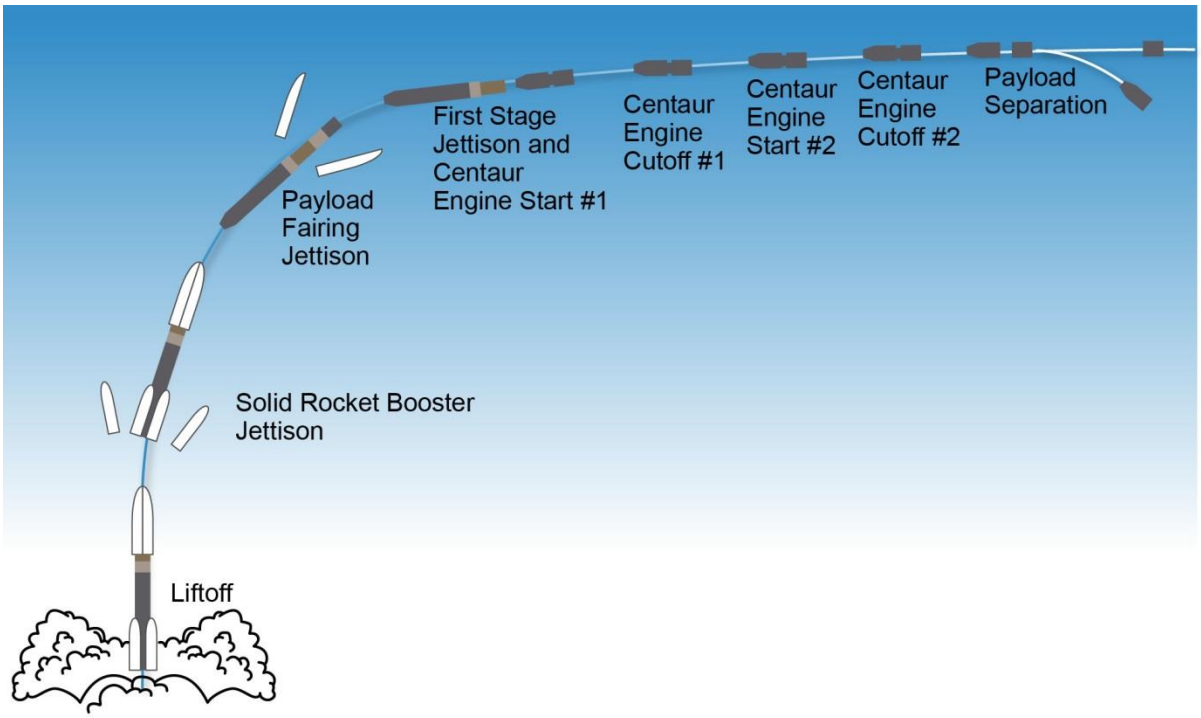
Processing activities for the Mars 2020 Atlas V vehicle would be similar to those routinely practiced for other Atlas launches from CCAFS. Effluents and solid or hazardous wastes that may be generated by these activities are subject to federal and state laws and regulations. NASA or its contractors would dispose of hazardous wastes. CCAFS has the necessary environmental permits and procedures for conducting launch vehicle processing activities (see Section 4.10).

2.1.6.1.6. Launch Profile

Launch of the Atlas V would begin with the ignition of the first stage main engine followed approximately 3 seconds[5] later by ignition of the four SRBs (Figure 2-12). The SRB casings would be jettisoned after propellant burnout. The first stage main engine would continue to thrust and the PLF would be jettisoned. The main engine cutoff sequence would be initiated when low propellant levels are detected by the first stage propellant sensors (ULA 2010). The first stage would then separate from the second stage. The SRB casings, the PLF, and the first stage would fall into the Atlantic Ocean in predetermined drop zones and would not be recovered (USAF 2000).

The Centaur second stage would be ignited shortly after separation from the first stage. Upon achieving Earth parking orbit, the Centaur engine thrust would be cut off via a timed command. After a brief, predetermined coast period in an Earth parking orbit, the Centaur engine would restart and the vehicle would accelerate to Earth escape velocity. After Centaur engine cutoff, the Mars 2020 spacecraft would separate from the Centaur and continue on its trajectory to Mars. The Centaur would continue separately into interplanetary space.

[5] The engine undergoes an automatic "health check" during this period. Should a malfunction be detected, the engine would be shut down and the launch would be aborted.



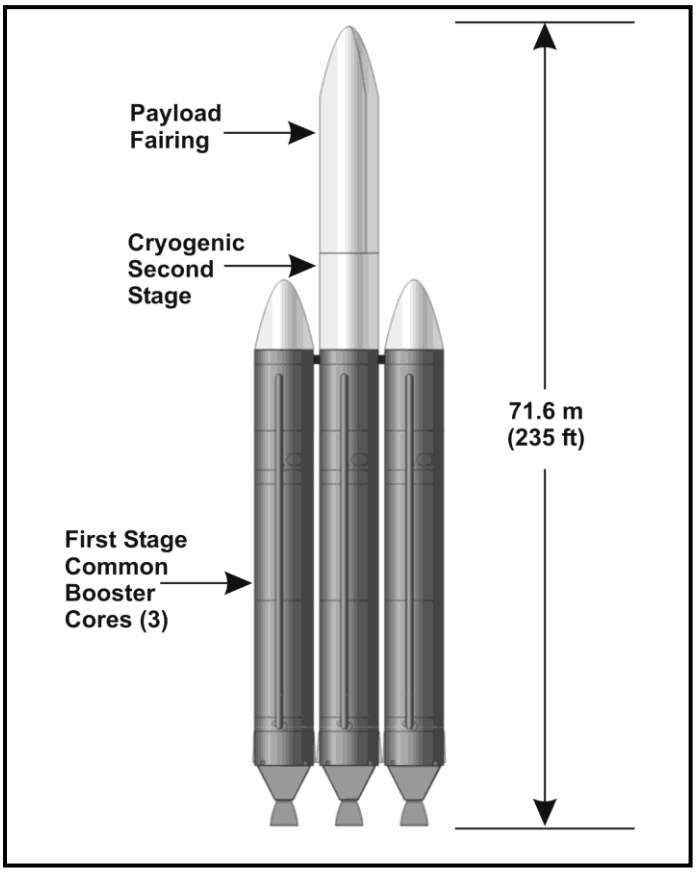
Source: Adapted from ULA 2010

Figure 2-12. Typical Atlas V Ascent Profile

2.1.6.2. Description of the Delta IV Heavy Launch Vehicle

The Delta launch vehicle program was initiated in the late 1950s by NASA with Douglas Aircraft (which then became McDonnell Douglas, which became part of The Boeing Company) and is now provided by ULA, a NLS-approved contractor. The Delta IV launch system, evolved from the Delta II and Delta III launch systems, is the latest generation in this nearly 50-year evolution. The Delta IV is currently available in Medium, Medium+, and Heavy configurations.

The representative Delta IV configuration for the proposed Mars 2020 mission is the Delta IV Heavy, which would consist of a liquid propellant first stage (called the common booster core (CBC)), two strap-on CBCs, a liquid propellant second stage, the Mars 2020 spacecraft, and a 5-m PLF. The additional CBCs are attached to the first stage, and the second stage is mounted atop the first stage. The Mars 2020 spacecraft would be mounted atop the second stage. The PLF encloses and protects the spacecraft. The Delta IV Heavy, depicted in Figure 2-13, is approximately 71.6 m (235 ft) in height (ULA 2013, ULA 2013).



Source: Adapted from ULA 2013

Figure 2-13. A Delta IV Heavy Launch Vehicle

2.1.6.2.1. First Stage

The Delta IV Heavy first stage CBCs are constructed mostly of aluminum and composite material. Each CBC is about 5 m (16.4 ft) in diameter and about 39.6 m (130 ft) in length. The CBCs are each powered by a cryogenic engine and each contains about 202,100 kg (445,600 lb) of propellant consisting of LH_2 as the fuel and LOx as the oxidizer for a total first stage propellant load of 606,300 kg (1,336,650 lb). A cylindrical interstage that encloses the second stage is mounted on the central CBC. Aerodynamic nosecones are mounted on the two strap-on CBCs in place of the interstage (ULA 2013, Freeman 2006).

2.1.6.2.2. Second Stage

The Delta IV second stage, constructed of aluminum and composite material, is about 5 m (16.4 ft) in diameter and about 13 m (42.7 ft) in length. The stage is powered by a single cryogenic engine and contains about 27,200 kg (60,000 lb) of propellant, consisting of LH_2 as the fuel and LOx as the oxidizer. The stage also uses about 154 kg (340 lb) of hydrazine for reaction control (Freeman 2006, ULA 2013).

2.1.6.2.3. Payload Fairing

The PLF for the Delta IV is about 5.1 m (16.8 ft) in diameter and about 19.1 m (62.7 ft) in length and constructed of composite materials. The PLF encloses and protects the spacecraft from thermal, acoustic, electromagnetic, and environmental conditions during ground operations and lift-off through atmospheric ascent (ULA 2013). Figure 2-11 depicts the Mars 2020 spacecraft within the PLF envelope.

2.1.6.2.4. Delta IV Space Launch Complex-37 (SLC-37)

SLC-37 is located in the northeastern section of CCAFS. The launch complex consists of a launch pad, a mobile service tower (MST), a fixed umbilical tower, propellant and water storage areas, an exhaust flume, catch basins, security services, fences, support buildings, and facilities necessary to prepare, service, and launch Delta IV vehicles (USAF 1998, ULA 2013).

Security at SLC-37 is ensured by a perimeter fence, guards, and restricted access. Since all operations in the launch complex would involve or be conducted in the vicinity of liquid or solid propellants and explosive devices, the number of personnel permitted in the area, safety clothing to be worn, the type of activity permitted, and equipment allowed would be strictly regulated. The airspace over the launch complex would be restricted at the time of launch.

2.1.6.2.5. Launch Vehicle Processing

Delta launch vehicle preparation activities and procedures during and after launch have been previously documented (USAF 1998, ULA 2013). All NASA launches follow the current standard operating procedures.

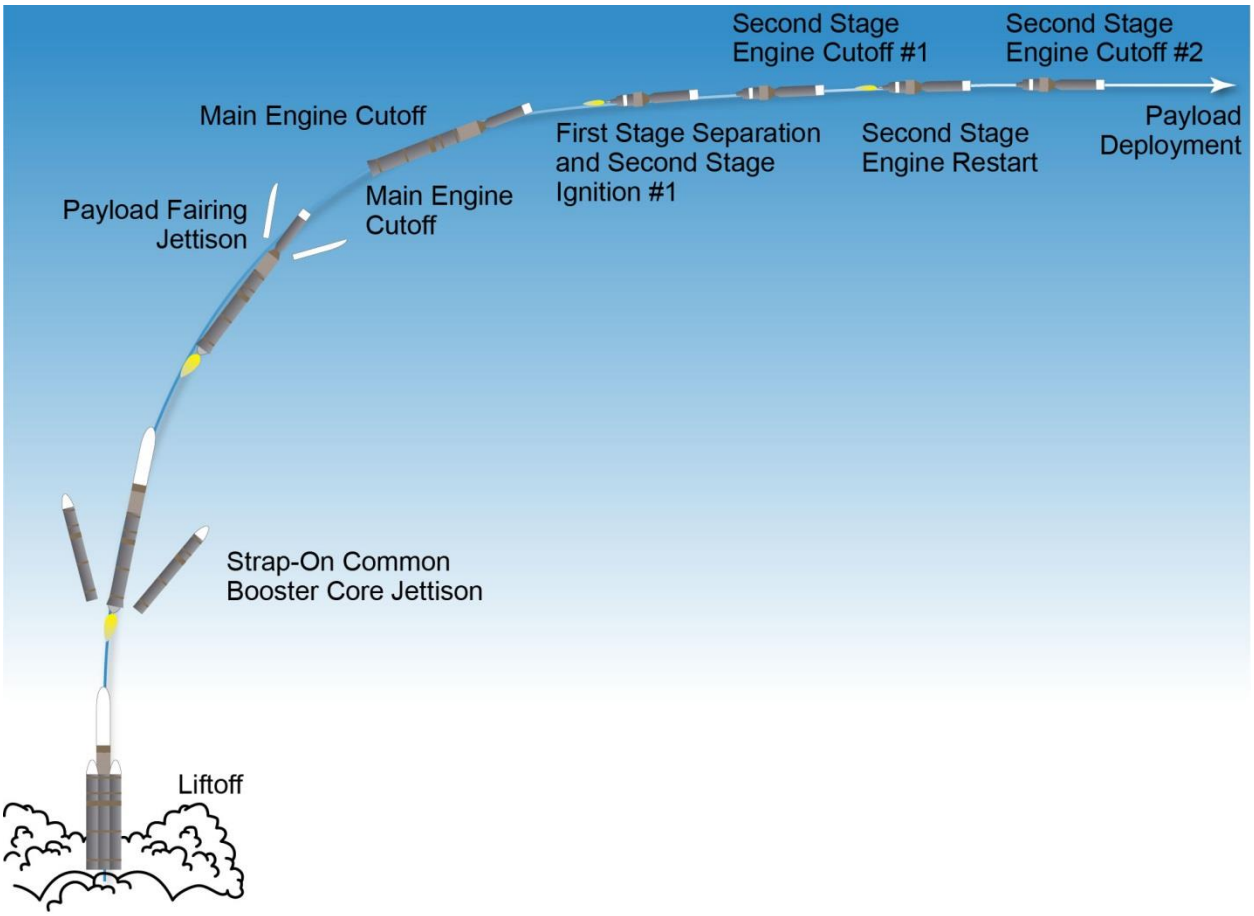
The Delta IV launch vehicle components for the Mars 2020 mission would be received at CCAFS, where they would be inspected, stored, and processed at appropriate facilities. When needed for launch, the components would be moved to the Horizontal Integration Facility at SLC-37, where the launch vehicle would be assembled, integrated, and tested. The Delta IV launch vehicle would then be moved via rail on the MST to the launch pad at SLC-37. The PLF, containing the Mars 2020 spacecraft, would then be transported from the PHSF at KSC directly to the launch pad at SLC-37 and mated to the second stage. The MMRTG would then be installed on the spacecraft. The vehicle would then be loaded with hydrazine and the LOx and LH_2 liquid propellants, and undergo final preparations for launch (ULA 2013).

Processing activities for the Mars 2020 Delta IV vehicle would be similar to those routinely practiced for other Delta launches from CCAFS. Effluents and solid or hazardous wastes that may be generated by these activities are subject to federal and state laws and regulations. NASA or its contractors would dispose of hazardous wastes. CCAFS has the necessary environmental permits and procedures for conducting launch vehicle processing activities (see Section 4.10).

2.1.6.2.6. Launch Profile

Launch of the Delta IV Heavy would begin with simultaneous ignition of the main engines[6] in the three first-stage CBCs (Figure 2-14). The two strap-on CBCs would thrust at a higher level than the central CBC, and their propellant would be depleted sooner. After engine cutoff, the strap-on CBCs would be jettisoned. The central CBC engine would continue to thrust until main engine cutoff, after which the first stage would separate from the second stage. The three depleted CBCs would fall into the Atlantic Ocean in predetermined drop zones and would not be recovered (USAF 2000).

[6] The engines undergo an automatic "health check" 5 seconds before liftoff. Should a malfunction be detected, the engines would be shut down and the launch would be aborted.



Source: Adapted from ULA 2013

Figure 2-14. Typical Delta IV Heavy Ascent Profile

The second stage would be ignited shortly after separation from the first stage. The PLF would then be jettisoned and would also fall into the Atlantic Ocean in predetermined drop zones and would not be recovered. Upon achieving Earth parking orbit, the second stage engine thrust would be cut off via a timed command. After a brief, predetermined coast period in an Earth parking orbit, the second stage engine would restart and the vehicle would accelerate to Earth escape velocity. After second stage engine cutoff, the Mars 2020 spacecraft would separate from the second stage and continue on its trajectory to Mars. The second stage would continue separately into interplanetary space.

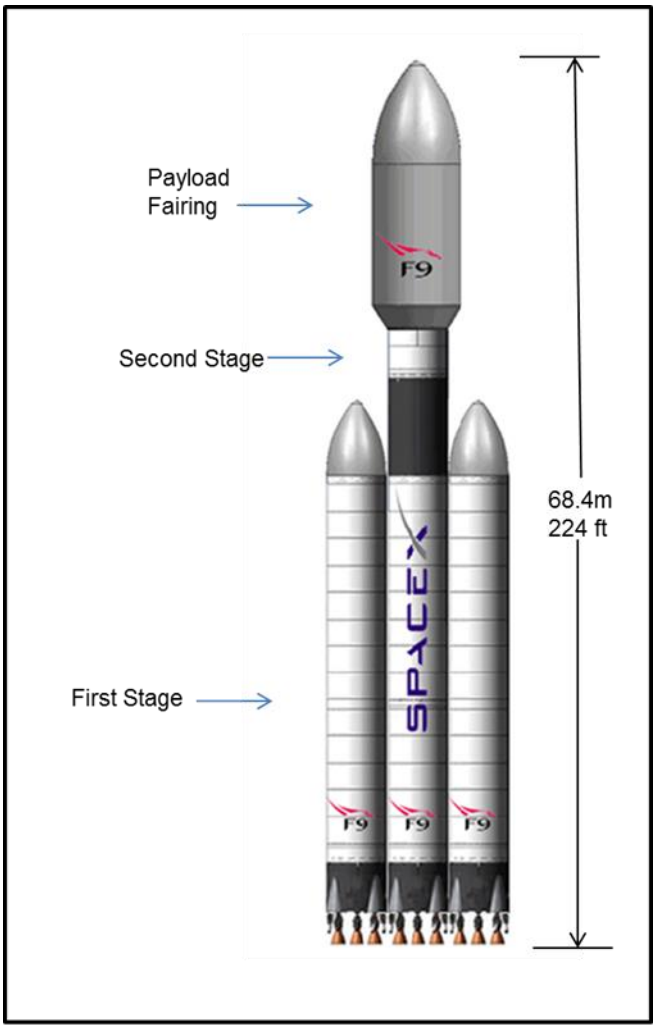
2.1.6.3. Description of the Falcon Heavy Launch Vehicle

The Falcon launch vehicle program was initiated in 2002 when SpaceX was launched as a commercial venture. The current launch vehicle is the Falcon 9. The proposed Falcon Heavy launch vehicle is an evolutionary version of the Falcon 9, with greater payload capability.

The representative Falcon Heavy configuration for the proposed Mars 2020 mission would consist of a liquid propellant first stage (similar to the first stage of the Falcon 9), and two boosters (also similar to the first stage of the Falcon 9), a liquid propellant second stage, the Mars 2020 spacecraft, and a 5-m PLF. The three first stage components are attached to each other, and the second stage is mounted atop the first stage. The Mars 2020 spacecraft would be mounted atop the second stage. The PLF encloses and protects the spacecraft. The Falcon Heavy, depicted in Figure 2-15, is approximately 68.4 m (224 ft) in height and is capable of delivering a 13,200 kg (29,100 lb) payload to Mars. Unlike the Atlas V and Delta IV vehicles, the first stages of the Falcon Heavy are designed to be reusable and could be recovered from the Atlantic Ocean (SpaceX 2013, SpaceX 2013b, USAF 2011).

2.1.6.3.1. First Stage

The Falcon Heavy first stage fuel tanks are constructed mostly of an aluminum and lithium alloy. Each Falcon 9 first stage is about 3.66 m (12 ft) in diameter and about 45.7 m (150 ft) in length. The Falcon 9 first stages are each powered by nine of SpaceX's Merlin engines (a Saturn V heritage engine) in an octagonal arrangement with one center engine. Each contains about 261,000 kg (576,000 lb) of propellant consisting of 81,600kg (180,000 lb) of RP-1 as the fuel, and 180,00 kg (397,000 lb) LOx[7] as the oxidizer for a total first stage propellant load of 245,000 kg (540,000 lb) of RP-1 and 539,000 kg (1,190,000 lb) of LOx. The Falcon Heavy utilizes a propellant cross-feed system; propellant is supplied from the two boosters to the center core so that fuel is preferentially drawn from the boosters first. This allows the central core to continue to maintain a significant portion of its initial fuel load and to operate well



Source: Adapted from FAA 2013

Figure 2-15. A Falcon Heavy Launch Vehicle

[7] Fuel quantities are for a Falcon 9. Falcon Heavy quantities may differ slightly from these amounts.

after the boosters are jettisoned. A cylindrical interstage that encloses the second stage is mounted on the central Falcon 9 first stage. Aerodynamic nosecones are mounted on the two Falcon 9 boosters in place of the interstage (SpaceX 2013; NASA 2011; FAA 2013).

2.1.6.3.2. Second Stage

The Falcon Heavy second stage is constructed of aluminum and composite material and is about 3.66 m (12 ft) in diameter and about 12.5 m (41 ft) in length. The stage is powered by a single Merlin engine, and contains about 49,000 kg (108,000 lb) of propellant, consisting of 15,100 kg (33,300 lb) of RP-1 as the fuel and 33,900 kg (74,700 lb) LOx as the oxidizer (NASA 2011**,** FAA 2013).

2.1.6.3.3. Payload Faring

The PLF for Falcon Heavy is about 5.2 m (17.1 ft) in diameter and about 15.2 m (50 ft) in length and is constructed of an aluminum core with carbon fiber face sheets. The PLF encloses and protects the spacecraft from thermal, acoustic, electromagnetic, and environmental conditions during ground operations and lift-off through atmospheric ascent (FAA 2013). Figure 2-11 depicts the Mars 2020 spacecraft within the PLF envelope.

2.1.6.3.4. Falcon Heavy Space Launch Complexes 39A and 40

Space X has launch privileges at both LC-39A and SLC-40. As currently configured, neither complex is capable of supporting the launch of the Falcon Heavy, although it is anticipated that LC-39A would be modified to support launch of the Falcon Heavy. Modifications to either launch complex to support this vehicle would be performed as part of the Falcon Heavy launch program and not specifically for the Mars 2020 mission.

LC-39, located on KSC, has been used as part of the Apollo program and for the Space Shuttle program. SpaceX recently won launch privileges from LC-39A, one of two launch pads within the launch complex. The launch complex is composed of, among other facilities, the two launch pads, the Vehicle Assembly Building, the Orbiter Processing Facility buildings, the Launch Control Center (which contains the firing rooms), and various logistical and operational support buildings.

2.1.6.3.5. Launch Vehicle Processing

All NASA launches follow the current standard operating procedures.

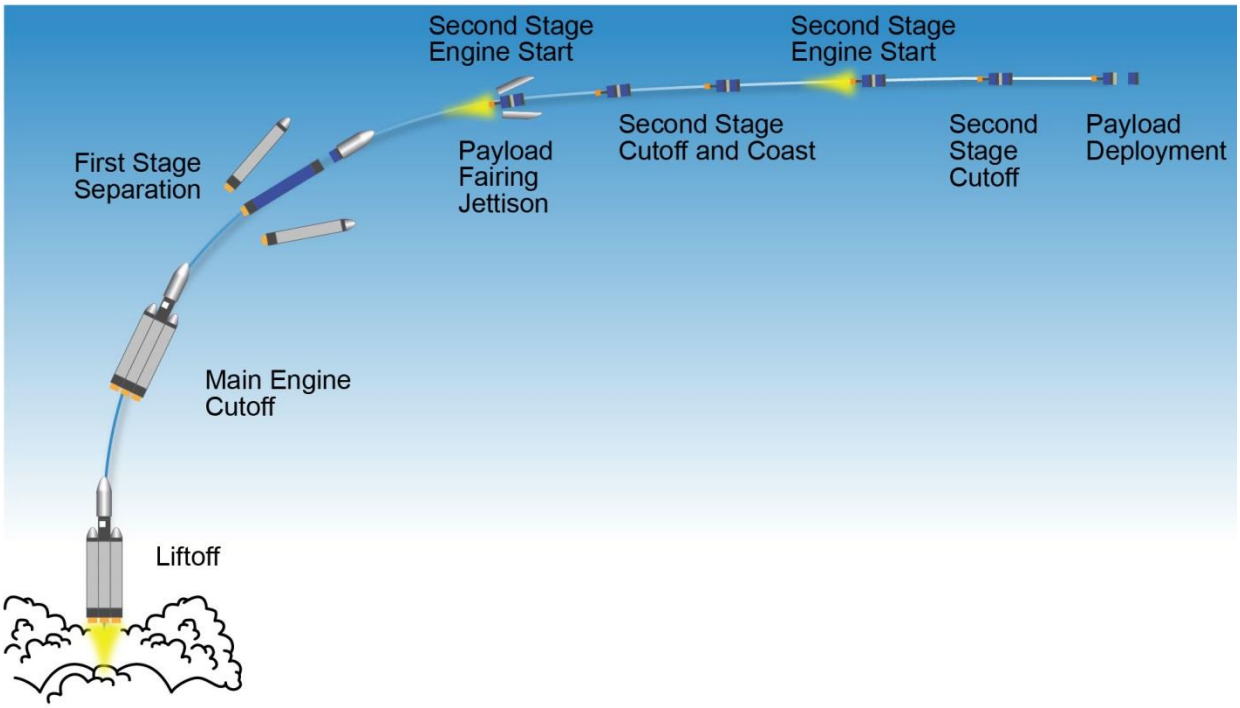
A Falcon Heavy has not been launched from KSC or CCAFS. The following descriptions are based on the process used for the Falcon 9. The Falcon Heavy launch vehicle components for the Mars 2020 mission would be received at KSC or CCAFS, where they would be inspected, stored, and processed at appropriate facilities. When needed for launch, the components would be moved to the Falcon 9 facility at LC-39A where the launch vehicle would be assembled, integrated, and tested. The PLF, containing the Mars 2020 spacecraft, would then be transported from the PHSF at KSC to the Falcon 9 facility at LC-39A and mated to the second stage. The MMRTG would then be installed on the spacecraft. The Falcon Heavy launch vehicle would then be moved via the vertical transporter-erector to the launch pad at LC-39A. The launch vehicle would be

transported in a horizontal position and raised to a vertical position at the launch pad. The vehicle would then be loaded with hydrazine and the LOx and RP-1 liquid propellants and undergo final preparations for launch (Univ 2011).

Processing activities for the Mars 2020 Falcon Heavy vehicle would be similar to those routinely practiced for other Falcon launches from CCAFS. Effluents and solid or hazardous wastes that may be generated by these activities are subject to federal and state laws and regulations. NASA, or its contractors, would dispose of hazardous wastes. CCAFS has the necessary environmental permits and procedures for conducting launch vehicle processing activities (see Section 4.10).

2.1.6.3.6. Launch Profile

Launch of the Falcon Heavy would begin with simultaneous ignition of the main engines in the core first stage and two first-stage boosters (Figure 2-16). The two boosters would be jettisoned when the booster fuel tanks (which have been supplying fuel to the core first stage and both boosters) are nearly depleted. The central core engines would continue to thrust until main engine cutoff, after which the first stage would separate from the second stage. The three depleted first-stage components would fall into the Atlantic Ocean in predetermined drop zones and could be recovered (SpaceX 2013).



Source: Adapted from Spacex 2013

Figure 2-16. Falcon Heavy Ascent Profile

The second stage would be ignited shortly after separation from the first stage. The PLF would then be jettisoned and would also fall into the Atlantic Ocean in predetermined drop zones and would not be recovered. Upon achieving Earth parking orbit, the second stage engine thrust would be cut off via a timed command. After a brief, predetermined

coast period in an Earth parking orbit, the second stage engine would restart and the vehicle would accelerate to Earth escape velocity. After second-stage engine cutoff, the Mars 2020 spacecraft would separate from the second stage and continue on its trajectory to Mars. The second stage would continue separately into interplanetary space.

2.1.6.4. Flight Termination System

Range Safety requires launch vehicles to be equipped with safety systems, collectively called the Flight Termination System (FTS), which are capable of causing destruction of the launch vehicle in the event of a major vehicle malfunction. Range Safety further specifies in the *Range Safety User Requirements Manual* (USAF 2004) that for any launch vehicle, the FTS reliability goal shall be a minimum of 0.999 at the 95 percent confidence level. The FTS for the Mars 2020 mission would provide the capability to destroy the launch vehicle either (1) autonomously after detecting an inadvertent breakup of the vehicle or unintentional separation of vehicle stages, or (2) by commands issued via secure radio links. The primary elements of the FTS, common for any of the candidate launch vehicles, would consist of an Automatic Destruct System (ADS) and a Command Destruct System (CDS). The FTS for the Atlas V would also include a Centaur Automatic Destruct System (CADS).

If inadvertent vehicle breakup or premature stage separation occurs, the ADS would automatically initiate ordnance components that split open all first- and second-stage propellant tanks to disperse the liquid propellants and split any strap-on solid rocket casings to terminate solid motor thrusting. Upon receipt of valid commands from Range Safety, the CDS would shut down the first stage or second stage main engines (depending on the timing of the event), and initiate destruction of the vehicle in the same manner as the ADS.

The FTS for all candidate LVs would be armed shortly before liftoff. Each major component of the FTS would be safed (automatically deactivated) at various times during the vehicle's ascent when the component would no longer be needed and to preclude its inadvertent activation. The ADS would be safed prior to separation of the first and second stages and the CDS would be safed immediately after the second stage with the Mars 2020 spacecraft has achieved Earth parking orbit.

For the Atlas V candidate LVs, an Inadvertent Separation Destruct System (ISDS) would be incorporated on each of the four SRBs. In the event of an inadvertent or premature separation of an SRB, the ISDS would initiate a linear-shaped charge to disable the SRB after a brief time delay to assure clearance from the Atlas V. The ISDS would be deactivated during a normal SRB separation event.

2.1.6.5. Range Safety Considerations

CCAFS has implemented range safety requirements (USAF 2004) that support launches from KSC and CCAFS. For the Mars 2020 mission, predetermined flight safety limits would be established for each day of the launch period. Wind criteria, impacts from fragments that could be produced in a launch accident, dispersion and reaction (e.g., toxic plumes, fire) of liquid and solid propellants, human reaction time, data delay

time, and other pertinent data would be considered when determining flight safety limits. The Mission Flight Control Officer would take any necessary actions, including destruction of the vehicle via the CDS, if the vehicle's trajectory indicates flight malfunctions (e.g., exceeding flight safety limits) (USAF 2004).

Range Safety at CCAFS uses models to predict launch hazards to the public and launch site personnel prior to a launch. These models calculate the risk of injury resulting from toxic exhaust gases from normal launches, and from potentially toxic concentrations due to a failed launch. The launch would be postponed if the predicted collective risk of injury from exposure to toxic gases exceeds established limits (USAF 2004). Range Safety monitors launch surveillance areas to ensure that risks to people, aircraft, and surface vessels are within acceptable limits. Controlled surveillance areas and airspace are closed to the public as required (USAF 2004).

2.1.6.6. Electromagnetic Environment

Launch vehicles may be subject to electromagnetic conditions such as lightning, powerful electromagnetic transmissions (e.g., radar, radio transmitters), and charging effects (i.e., electrical charges generated by friction and the resultant electrostatic discharges). NASA and the USAF address such conditions with respect to the design of the launch vehicle, as well as with ordnance (e.g., explosives, explosive detonators, and fuses), fuels, exposed surfaces of the vehicle, and critical electronic systems that must have highly reliable operations. A large body of technical literature exists on these subjects and has been used by NASA and the USAF in designing safeguards (see, for example, USAF 2004). The launch vehicle, the Mars 2020 spacecraft, and the launch support systems would be designed and tested to withstand these environments in accordance with requirements specified in USAF 2004.

2.1.7 Radiological Emergency Response Planning

Prior to launch of the Mars 2020 mission, a comprehensive set of plans would be developed by NASA to ensure that any launch accident could be met with a well-developed and tested response. NASA's plans would be developed in accordance with the National Response Framework (NRF) (DHS 2013) and the NRF Nuclear/ Radiological Incident Annex (DHS 2008) with the combined efforts of the U.S. Department of Homeland Security (DHS), DHS's Federal Emergency Management Agency (FEMA), DOE, the U.S. Department of Defense (DoD), the U.S. Department of State (DOS), the U.S. Environmental Protection Agency (EPA), the state of Florida, Brevard County, and local governmental organizations. These organizations and other federal agencies, as appropriate, could be involved in response to a radiological emergency. The radiological contingency planning and implementation for a Mars 2020 mission would be expected to be similar to the process used for the 2011 MSL mission launch (Scott 2012).

The radiological emergency response plan would be exercised prior to launch to verify that the response interfaces, command channels, and field response organizations would be prepared to respond in the unlikely event of a launch accident. Thus, in the event of a declaration of an *Incident of National Significance* (e.g., launch accident) whose impact is within United States jurisdiction, NASA, as the coordinating agency,

would work with the DHS to coordinate the entire federal response. Should a release of radioactive material occur in the launch area, NASA would provide information on the estimated release and its recommendations to the state of Florida, Brevard County, and local governments who, in turn, would determine an appropriate course of action (such as sheltering in place, evacuation, exclusion of people from contaminated land areas, or no action required), and with full access to the coordinated federal response. For accidents outside United States' jurisdiction and defined as *Incidents of National Significance*, NASA and DHS would assist the DOS in coordinating the United States' response via diplomatic channels and deploy federal resources as requested.

To manage the radiological contingency response, NASA would establish a radiological emergency response capability that would include a radiological assessment and command center as well as field monitoring assets that would be deployed prior to launch both onsite and offsite. The assessment and command center would be the focal point for NASA and DHS coordination efforts. This center would also be used to coordinate the initial federal response to a radiological contingency until the Mars 2020 spacecraft has left Earth orbit. Pre-deployed assets to support a response to a potential launch accident would include representation from NASA, DHS, DOE, DoD, DOS, EPA, USAF, the National Oceanic and Atmospheric Administration (NOAA), the state of Florida, and Brevard County. If measureable amounts of plutonium are detected after a launch vehicle accident, the center would issue appropriate direction to KSC/CCAFS personnel as well as the public to ensure minimal or no potential exposures.

If impact occurs in the ocean following an accident, NASA would coordinate with the DHS, the U.S. Coast Guard, the U.S. Navy, and DOE to initiate security measures and assess the feasibility of search and retrieval operations. Efforts to recover the MMRTG or its components would be based on technical feasibility and in consideration of any potential health hazards presented to recovery personnel and potential environmental impacts.

2.2 DESCRIPTION OF ALTERNATIVE 2

The mission and spacecraft for Alternative 2 would be designed and developed, to the extent practicable, to meet the operational capabilities summarized in Table 2-1. In Alternative 2, the MMRTG power source would be replaced by a solar power array. The rover used in this alternative would rely on the power generated by solar arrays to generate electricity to operate the rover's scientific instrumentation and communication equipment and provide motive power. Power from the solar arrays would also power electric heaters to maintain the thermal environment required to ensure the survival of the rover's engineering subsystems and science payload. The descriptions presented in this section for Alternative 2 are based on the information available at the time this DEIS was prepared, as presented in the *Mars 2020 Solar Feasibility Study* (JPL 2014). Should NASA make changes in Alternative 2 that are relevant to environmental concerns, NASA would evaluate the need for additional environmental analysis documentation.

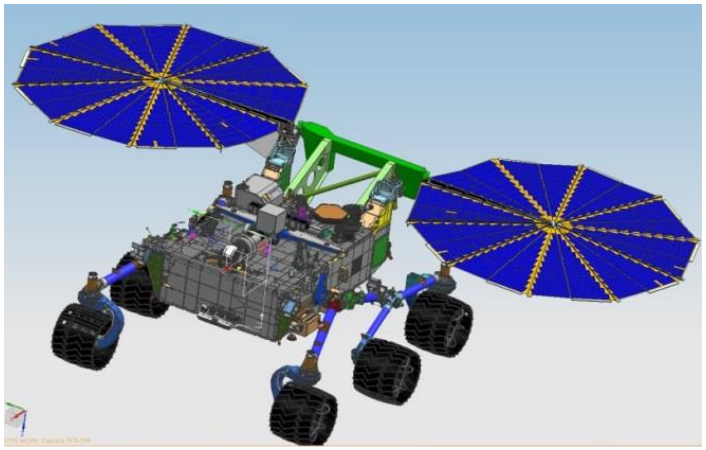
2.2.1 Mission and Spacecraft Description

Many of the technical aspects of the mission and spacecraft designs for Alternative 2 would be similar to those described in Section 2.1 for the Proposed Action (Alternative 1). These would include the following major features.

- The Mars 2020 spacecraft would be launched from KSC or CCAFS onboard an expendable launch vehicle from the Atlas V, Delta IV, or Falcon Heavy class of vehicles (see Section 2.1.5 for representative descriptions of these vehicles).
- The mission design would be as described in Section 2.1.1, including a launch opportunity in July to August of 2020, with a backup opportunity in August to September 2022, and an Earth-Mars trajectory leading to direct entry of the spacecraft into the Martian atmosphere.
- The Mars 2020 flight system would consist of a high-heritage MSL cruise stage, entry vehicle, and descent stage (as described in Section 2.1.2), and a science rover.
- The rover's science instrument payload would be as described in Table 2-2. Planning for the rover science mission would be based upon an operational timeline similar to that described in Section 2.1.1.

2.2.1.1. Solar Power Supply System

The Mars 2020 rover for Alternative 2 would use a solar array as the source of electrical power for its engineering subsystems and science payload (JPL 2014). The size of the array would be limited by the volume constraints of the rover in its stowed configuration within the descent stage inside the entry vehicle, which in turn is limited in size by the diameter of the launch vehicle payload fairing (see Figure 2-11). Use of a solar array would be expected to increase the mass of power supply systems for the rover by less than 10 kg (22 lb) compared to the use of the MMRTG (JPL 2014). The solar array would attach to the back section of the rover and would be folded for stowage inside the entry vehicle. The array would be deployed after the rover has landed on the surface of Mars. A representative deployed array configuration is illustrated in Figure 2-17.



Source: Adapted from JPL 2014

Figure 2-17. A Representative Solar-Powered Alternative 2 Mars 2020 Rover

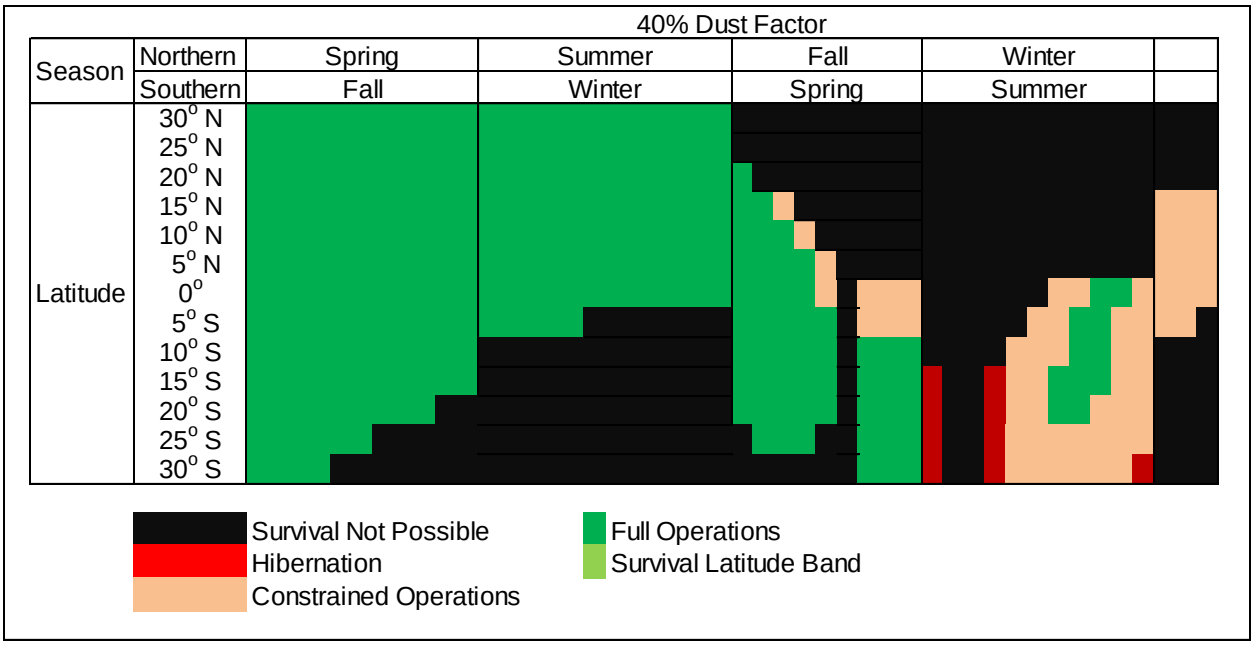
After landing, the solar array would be deployed into two separate panels and would be in a fixed position parallel with the upper surface of the rover chassis. The deployed array of two panels would have an active cell surface area of approximately 7.4 square meters (80 square feet). The array would consist of the same type of multi-junction solar cells as were used on the Mars Exploration Rovers (MERs), which landed on Mars in January 2004. At the atmospheric temperatures of the MER landing sites near the equator of Mars, this array would have a conversion efficiency of about 26 percent.

2.2.2 Solar Power Availability

The available electrical power produced by the solar array described in Section 2.2.1.1 would be a function of several factors (JPL 2014). The most important of these are the landing site latitude and time of year on Mars, which affect the incidence angle of the sunlight shining on the array and the amount of time sunlight is available per sol. Low incidence angles at high latitudes, reduced solar intensity near Mars aphelion, and short periods of daylight during a Martian Winter would reduce the available amount of electrical power produced by the solar array. Other factors affecting array output would include shadowing of the array from the masts and antennas, the amount of dust in the Martian atmosphere, and dust deposition and accumulation on the array.

All of the energy that this solar array would generate per sol could not be used exclusively to perform science operations. The rover would need to maintain its thermal health and mechanical functionality so that it could communicate with Earth and drive to specified science locations. The solar energy required to maintain the rover's thermal health would vary with latitude (i.e., landing site) and time of year. During the Martian Winter there would be a higher demand for heat to maintain the rover's components within acceptable thermal limits, but there would be less total energy available from the solar array for the reasons discussed above.

Of the available energy per sol, approximately 100 to 600 watt-hours would be needed to perform science operations, which would include driving to science locations, site reconnaissance, and acquiring and analyzing samples and other scientific data (JPL 2013). The remainder of the available energy would be needed for the rover's engineering functions, including communications and thermal control. Figure 2-18 illustrates locations on the surface of Mars where the baseline solar array configuration would provide sufficient power for the rover to perform science operations and maintain its health and functionality as a function of latitude over the course of one Mars year.



Note: The expected arrival date for the Mars 2020 mission would coincide with the transition from winter to spring in the northern hemisphere of Mars. This date appears on the far left of this figure.

Source: Adapted from JPL 2014

Figure 2-18. Mars 2020 Solar-Powered Rover Operability (40% Dust Factor)

As shown in the figure, one of the factors that affects the feasibility of using solar power is the dust factor. This factor is a measure of the remaining electric power output from the solar arrays when some energy is blocked due to the accumulation of dust on the surface of the arrays panels. The dust factor is the percentage of the effective array surface that remains clean, and is roughly equivalent to the total power still available given the accumulation of dust—the lower the dust factor, the lower the amount of electrical energy produced. A 40% dust factor[8] means that 40% of the array surface area is clean and the electrical output of the solar arrays is reduced proportionally. Higher dust factors, may be achievable only with the use of active dust mitigation technology or with the assumption of more frequent environmental cleaning events.

For Alternative 2, sufficient solar power for one Mars year is not available at any latitude assuming a dust factor of 40% (the solar array remains at least 40% dust free). With more frequent dust cleaning or mitigation resulting in a dust factor of at least 70% (the solar array remaining at least 70% dust free), the rover could operate for one Mars year only at approximately 5° south latitude.

[8] The 40% dust factor is based upon the dust accumulation rates on the MER solar arrays. The accumulation of dust is limited by naturally occurring cleaning events. The 70% dust factor relies upon more frequent cleaning events or active dust mitigation technology. Dust mitigation technology may improve the dust factor to beyond 70%, but these technologies have not been demonstrated to function in Martian environmental conditions.

The solar feasibility assessment (JPL 2014), which developed these estimates of rover operability, was performed with sufficient detail to develop estimates for a representative solar-powered rover configuration. Should NASA select Alternative 2, the solar-powered rover design would be finalized, but any changes would likely not change the fundamental results presented in the solar feasibility assessment.

2.2.3 Operational Considerations

As shown in Figure 2-18, for all latitudes between 30° south and 30° north, the survival of the rover for a full Martian year would not be expected. There are times when the rover would have to operate at less than full capabilities (Constrained Operations), times when the rover would have to cease scientific operations and operate in a mode where only functions needed for rover survival—primarily maintaining an acceptable thermal environment—are performed (Hibernation), and times the rover would not survive. These periods of reduced science operability impact the amount of science investigation that can be performed at the various landing sites which adversely impacts the ability of the rover to reach all of the baseline goals for the mission.

Table 2-5 shows the estimated operational lifetime of the solar-powered Mars 2020 rover as a function of landing site latitude for the anticipated arrival dates. The MMRTG power option, which is capable of full operations for an entire Mars year, is included for comparison purposes. This table reflects the fact that the solar power alternative with a 40% dust factor is not capable of surviving for a full Mars year, although science operations could be performed for parts of the year. The ability of the rover to survive longer in the northern latitudes is a result of the mission arrival dates coinciding with spring in the northern Martian latitudes while these arrival dates are in the fall in the southern Martian latitudes.

A larger dust factor (70%) would extend the operational lifetime of the rover and would allow for full year operation between 5° south latitude and 0° and would marginally extend the operational lifetime of the rover at some latitudes, thereby increasing the amount of science that could be performed.

The science capabilities associated with partial-year operation are provided in Table 2-6. These capabilities are expressed in terms of the percentage of the samples that could be obtained given a full year of operation with no limitations (constrained operations or hibernation).

For comparison, Alternative 1 provides 100% capability. Given the assumptions for initial checkout and rover movement (driving from site to site) any landing site with an operational lifetime of 40% or less would not provide the opportunity to perform any sampling activities unless the rover movement was curtailed.

Table 2-5. Operational Lifetime for a Solar-Powered Rover

Option		Operational Lifetime[a]	
		Solar	MMRTG
Latitude	30° N	50%	100%
	25° N	50%	100%
	20° N	50%	100%
	15° N	55%	100%
	10° N	60%	100%
	5° N	60%	100%
	0°	60%	100%
	5° S	35%	100%
	10° S	25%	100%
	15° S	25%	100%
	20° S	20%	100%
	25° S	15%	100%
	30° S	10%	100%

Source: Adapted from JPL 2014

(a) Lifetime expressed in terms of a full Martian year. Lifetime assuming a 40% dust factor (solar cells remain 40% clean)

Rover operates for less than a full Martian year

Rover operates for a full Martian year

Table 2-6. Science Capability

Operational Lifetime in Mars Years[(a)]	Percent of Mars Year Assumed for Initial Checkout and Driving[(a)]	Percent of Mars Year Available For Sampling Activities[(a)]	Percent of Sampling Activities Available on an MMRTG Mission[(b)]
50%	40%	10%	17%
60%	40%	20%	33%
70%	40%	30%	50%
100%	40%	60%	100%

(a) These values are in terms of a full Martian year (689 Earth days). For example, 40% of a Martian year is 276 Earth days.

(b) The fourth column represents the expected sampling capability, expressed as a percentage of the capabilities associated with unconstrained operation for a full year.

2.3 DESCRIPTION OF ALTERNATIVE 3

The mission and spacecraft for Alternative 3 would be designed and developed, to the extent practicable, to meet the operational capabilities summarized in Table 2-1. The descriptions presented in this section for Alternative 3 are based on the information available at the time this DEIS was prepared, as presented in the *Mars 2020 Solar Feasibility Study* (JPL 2014). In Alternative 3, the MMRTG would be replaced and the rover would be powered by solar power arrays, similar to that proposed in Alternative 2. The rover used in this alternative would rely on the power generated by solar arrays to

generate electricity to operate the rover's scientific instrumentation, communication equipment, and to provide motive power. In addition to the solar arrays, the rover in this alternative would incorporate up to 71 LWRHUs as a heat source. Power from the solar arrays would also power electric heaters to augment the LWRHUs to help maintain the thermal environment required to ensure the survival of the rover's engineering subsystems and science payload. As described in the following sections, the additional thermal power from the LWRHUs extends the operational capabilities of the rover to include an expanded selection of landing sites and an increased science return capability. Should NASA make changes in Alternative 3 that are relevant to environmental concerns, NASA would evaluate the need for additional environmental analysis and documentation.

2.3.1 Mission and Spacecraft Description

Many of the technical aspects of the mission and spacecraft designs for Alternative 3 would be similar to those described in Section 2.1 for Proposed Action (Alternative 1). These would include the following major features.

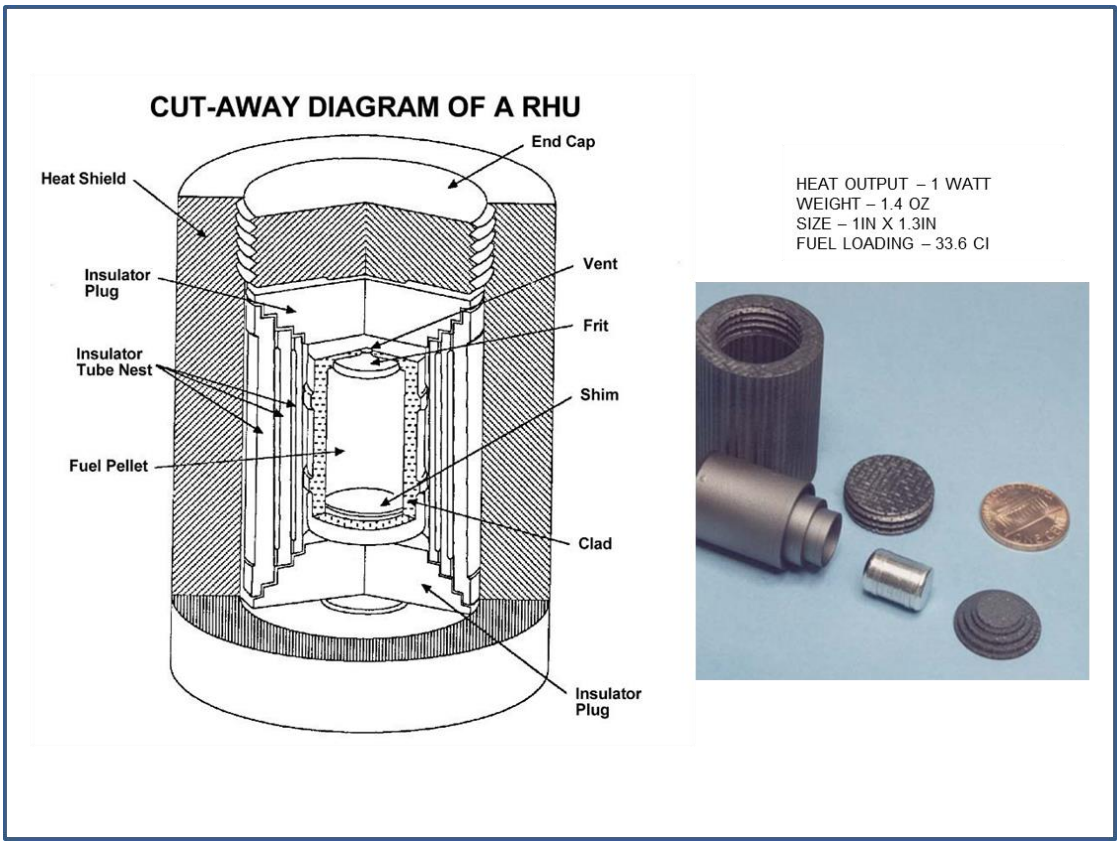
- The Mars 2020 spacecraft would be launched from KSC or CCAFS onboard an expendable launch vehicle from the Atlas V, Delta IV, or Falcon Heavy class of vehicles (see Section 2.1.5 for representative descriptions of these vehicles).
- The mission design would be as described in Section 2.1.1, including a launch opportunity in July to August of 2020, with a backup opportunity in August to September 2022, and an Earth-Mars trajectory leading to direct entry of the spacecraft into the Martian atmosphere.
- The Mars 2020 flight system would consist of a high-heritage MSL cruise stage, entry vehicle, and descent stage as described in Section 2.1.2, and a science rover.
- The rover's science instrument payload would be as described in Table 2-2. Planning for the rover science mission would be based upon an operational timeline similar to that described in Section 2.1.1.

2.3.1.1. Solar Power Supply System

The solar power system that would be used for Alternative 3 is the same system described in Section 2.2.1.1 above for Alternative 2.

2.3.1.2. Radioisotope Heater Units

The Mars 2020 rover could use a combination of LWRHUs and electric heaters to maintain internal temperature during periods of extreme cold. Alternative 3 considers the use of up to 71 such LWRHUs (JPL 2014). Each LWRHU (see Figure 2-19) would produce about 1 thermal watt of heat derived from the radioactive decay of 2.7 grams (g) (0.095 ounce (oz)) of plutonium (mostly plutonium-238) in the form of a ceramic of plutonium dioxide. Each LWRHU would contribute approximately 33.2 Ci for a total plutonium inventory of up to 2,360 Ci. Table 2-7 provides the typical radionuclide composition of a LWRHU's fuel. The exterior dimensions of a LWRHU are 2.6 cm (1.03 in) in diameter by 3.2cm (1.26 in) in length. Each LWRHU has a mass of about 40g (1.4 oz).



Source: Adapted from SNL 2014

Figure 2-19. Principal Features of a Light-Weight Radioisotope Heater Unit (LWRHU)

LWRHUs are designed to contain the plutonium dioxide during normal operations and under a wide range of accident environments. The integrity and durability of LWRHUs have been well documented by the U.S. Department of Energy (SNL 2014). The plutonium dioxide ceramic is encapsulated in a 70% platinum and 30% rhodium alloy clad. A fine weave pierced fabric of carbon graphite used as a heat shield provides protection against high-temperature accident environments, and a series of concentric pyrolitic graphite[9] sleeves and end plugs thermally insulate the encapsulated radioactive material. The LWRHU's plutonium dioxide is principally protected from ground or debris impact by the alloy clad. The heat shield and inner pyrolitic graphite insulators provide additional protection.

[9] Pyrolitic graphite is a man-made form of graphite, created by heating graphite and allowing it to cool into a crystalline form. This type of graphite has enhanced thermal conduction properties compared to ordinary graphite.

Table 2-7. Typical Radionuclide Composition of a LWRHU Fuel Pellet

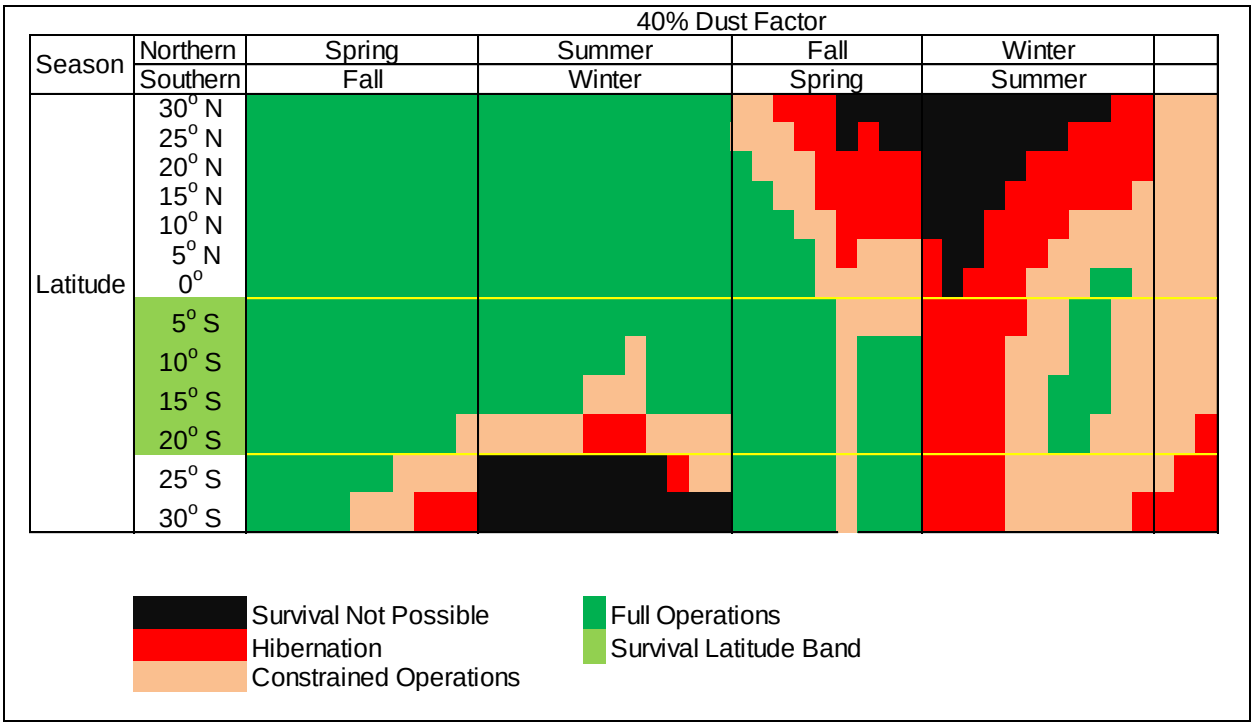
Fuel Component	Weight Percent	Half-Life (yrs)	Specific Activity (Ci/g of Fuel Component)a	Total Activity (Ci)
Plutonium (Pu)	85.735			
Pu-236	0.0000010	2.851	531.3	0.00001
Pu-238	70.810	87.7	17.12	32.7312
Pu-239	12.859	24.131	0.0620	0.02153
Pu-240	1.787	6.569	0.2267	0.01094
Pu-241	0.168	14.4	103.0	0.4672
Pu-242	0.111	375,800	0.00393	0.00001
Actinide impurities	2.413	NA	NA	NA
Oxygen	11.852	NA	NA	NA
Total	**100**	**NA**	**NA**	**33.2312**

2.3.2 Solar Power Availability

The factors affecting the ability of a solar-powered rover to operate on the surface of Mars were discussed in Section 2.2.2 and 2.2.3 for Alternative 2, and are applicable to this alternative as well. Figure 2-20 illustrates the locations on the surface of Mars where there would be sufficient solar power (augmented by the thermal output of the LWRHUs) for the rover to perform science operations and maintain its health and functionality as a function of latitude over the course of one Mars year. The analysis of this alternative assumes the same dust factors as assumed in the analysis of Alternative 2.

For Alternative 3, sufficient solar power for one Mars year of operation (although the rover would be required to hibernate for at least part of the winter) is available between 20° south and 5° south latitudes assuming a dust factor of 40%. With improved dust cleaning or mitigation resulting in a dust factor of 70%, the rover could operate for one Mars year between 20° south and 15° north latitudes.

The solar feasibility assessment (JPL 2014), which developed these estimates of rover operability, was performed with sufficient detail to develop estimates for a representative solar-powered rover configuration. Should NASA select Alternative 3, the solar-powered rover design would be finalized, but any changes would likely not change the fundamental results presented in the solar feasibility assessment.



Note: The expected arrival date for the Mars 2020 mission would coincide with the transition from winter to spring in the northern hemisphere of Mars. This date appears on the far left of this figure.

Source: Adapted from JPL 2014

Figure 2-20. Mars 2020 Solar-Powered (with LWRHUs) Rover Operability with 40% Dust Factor

2.3.3 Operational Considerations

As shown in Figure 2-20, for all latitudes between 30° south and 30° north, the ability of the rover to fully perform for a full year is restricted. There are times when the rover would have to operate at less than full capability (Constrained Operations), times when the rover would have to cease scientific operations and operate in a mode where only functions needed for rover survival—primarily maintaining an acceptable thermal environment—are performed (Hibernation), and times the rover would not survive. Full year survival is only possible between 20° and 5° south latitudes. The periods of reduced science operability impact the amount of science investigation that can be performed at the various landing sites which adversely impacts the ability of the rover to reach all of the baseline goals for the mission.

Table 2-8 shows the estimated operational lifetime of the solar-powered Mars 2020 rover as a function of landing site latitude for the anticipated arrival dates. The MMRTG power option, which is capable of full operations for an entire Mars year, is included for comparison purposes. The numbers shown for a partial-year operation are indicative of how long the rover would be expected to survive before failing due to cold weather. The ability to survive longer in the northern latitudes is a result of the mission arrival dates coinciding with spring in the northern Martian latitudes, while these arrival dates are in the fall in the southern Martian latitudes.

Table 2-8. Operational Lifetime for a Solar-Powered Rover with LWRHUs

Operational Lifetime[a]			
	Option	Solar plus LWRHUs[b]	MMRTG
Latitude	30° N	50%	100%
	25° N	55%	100%
	20° N	60%	100%
	15° N	60%	100%
	10° N	60%	100%
	5° N	65%	100%
	0°	70%	100%
	5° S	100%	100%
	10° S	100%	100%
	15° S	100%	100%
	20° S	100%	100%
	25° S	25%	100%
	30° S	15%	100%

Source: Adapted from JPL 2014

(a) Lifetime expressed in terms of a full Martian year
(b) Lifetime assuming a 40% dust factor (solar cells remain 40% clean)

Rover operates for less than a full Martian year
Rover operates for a full Martian year

Larger dust factors would improve the operational capabilities of the rover; however, even with a dust factor of 70%, a full year of rover operation is possible only between 20° south and 15° north latitudes. The improvement in survivability would result in an increase in the amount of science that could be performed and an increase in the range of locations and, therefore, the number of potential landing sites.

The science capabilities associated with a partial-year operation are provided in Table 2-6. These capabilities are expressed in terms of the percentage of the samples that could be obtained given a full year of operation with no limitations (constrained operations or hibernation). For comparison, Alternative 1 provides 100% capability. Although the rover would be expected to survive for an entire year at latitudes between 20° and 5° south, it would not be able to operate at full capacity for the entire year (Figure 2-20). The limited operational capability during the winter (constrained operation and hibernation) limit the amount of science that can be performed to 60 to 70% of that possible during a full year of unrestricted operations. Given the assumptions for initial checkout and rover movement (driving from site to site) any landing site with an operational lifetime of 40% or less would not provide the opportunity to perform any sampling activities unless rover movement was curtailed.

2.4 DESCRIPTION OF THE NO ACTION ALTERNATIVE

Under the No Action Alternative, NASA would discontinue preparations for the Mars 2020 mission. The next step in NASA's Mars Exploration Program following the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission in 2014 would not be conducted as currently envisioned (excluding the joint NASA – European Space Agency ExoMars missions), and NASA would need to reevaluate its programmatic options for the 2020 launch opportunity to Mars and beyond.

Without development and implementation of a large mobile science platform, such as the rover planned for the Mars 2020 mission, NASA's ability to meet the highest recommendation of the National Research Council's Planetary Science Decadal Survey—to acquire detailed scientific information on the habitability and biosignature potential of Mars—would be severely limited, and the advancements in technological and operational capabilities necessary for the future exploration of Mars may not be achieved.

2.5 ALTERNATIVES CONSIDERED BUT NOT EVALUATED FURTHER

There were no alternatives considered but not evaluated further. Alternative radioisotope power sources to the MMRTG were considered in previous environmental impact statements (NASA 2005b, NASA 2006). These alternatives were not considered here since no new information has been developed that would indicate that these power sources would present a viable alternative to the MMRTG.

2.6 COMPARISON OF ALTERNATIVES INCLUDING THE PROPOSED ACTION

For the purpose of the evaluations presented in this DEIS, the primary difference between the baseline Mars 2020 mission described in the Proposed Action (Alternative 1) and the Mars 2020 mission described in Alternatives 2 and 3 is the source of electrical power that would be used for the Mars 2020 rover. For the Proposed Action, the rover power source would be an MMRTG, described in Section 2.1.3; whereas, for Alternative 2, the rover power source would be a solar array, described in Section 2.2.1; and for Alternative 3, the power source would be a solar array augmented by up to 71 LWRHUs, described in Section 2.3.1.

2.6.1 Comparison of Mission Science Capabilities

Since the Mars 2020 rover designs in the Proposed Action (Alternative 1), Alternative 2, and Alternative 3 would carry the same science instruments, any of these three alternatives could conduct the same set of experiments. The estimated science capability for these alternatives, expressed in terms of the percentage of the full science return that could be attained at a given latitude on Mars, is summarized in Table 2-9.

Alternative 1. The MMRTG-powered rover would be capable of achieving all of the target operational capabilities (100% science return) as summarized in Table 2-1, including landing at a scientifically interesting location between 30° south and 30° north latitude, and operating and conducting science for at least one Mars year.

Table 2-9. Estimated Science Capability Comparison of the Mars 2020 Mission Alternatives

Rover Power Alternative	Landing Site Latitude Range	Operational Capability	Percentage of Science Achieved at Landing Site Latitude
MMRTG (Alternative 1)	30°S to 30°N	100%	100%
Solar Array (Alternative 2) (40% dust factor[a])	0° to 30°N	Unable to Operate for Full Year Maximum Operational Lifetime[b] 60%	20-30%
	30°S to 0°	Unable to Operate for Full Year Maximum Operational Lifetime 35%	a few percent
Solar Array with LWRHUs (Alternative 3) (40% dust factor)	30°S to 20°S	Unable to Operate for Full Year Maximum Operational Lifetime 25%	a few percent
	20°S to 5°S	Constrained Operations (up to 28%) Hibernation (up to 9%)	60-70%
	5°S to 30°N	Unable to Operate for Full Year Maximum Operational Lifetime 70%	20-40%

Notes:

a)The MER Opportunity dust factor has always stayed above 40%, but the MER Spirit dust factor fell below 25% (more than 2 Mars years into the mission). The factors controlling dust accumulation are not well known, so there is a risk that a solar-powered mission without dust mitigation technology assuming a minimum dust factor of 40% may fail if the actual dust accumulation exceeds that seen on Opportunity and is closer to that seen on Spirit late in its mission. Meeting a 70% dust factor (i.e., the loss of power from the solar arrays due to accumulated dust is limited to 30%) while promising greater science return would require development of dust removal technology.

b) For each latittude range, the Maximum Operational Lifetime represents the longest time the rover would be expected to survive before failing due to environmental conditions. It is expressed in terms of a full Martian year.

All values are approximate. N = North Latitude; S = South Latitude.

Source JPL 2014

Alternative 2. At most latitudes on Mars, the amount of time that a solar-powered rover could perform science operations would be limited by the ability of the solar array to generate sufficient power for the rover to survive the extreme thermal environment. A solar-powered rover with arrays stowable in the available volume would not be able to survive for a full Martian year at any latitude assuming the solar arrays remain at least 40% dust free. Partial-year operation with reduced science capability is possible over a range of latitudes from 0° to 30°north. More favorable dust factors would result in an increase in the operational range of the rover, expanding the latitudes at which a partial year operation would be possible, with a full year of operation possible only at latitudes ranging from 0° to 5° north. Operations would be limited (constrained operations or hibernation) for parts of the year.

Alternative 3. At most latitudes on Mars, the amount of time that a solar-powered rover, with additional thermal power from LWRHUs, could perform science operations would be limited by the ability of the solar array and LWRHUs to generate sufficient power for the rover to survive the extreme thermal environment. A solar-powered rover with LWRHUs (solar arrays 40% dust free) would have sufficient power to operate for a full Martian year at latitudes on Mars between 20° south and 5° south. Partial-year

operation with further reduced science capability is possible over a wider range of latitudes. This solar/RHU-powered rover could operate for at least one Mars year at latitudes ranging from 20° south to 15° north, if a more favorable solar array dust factor of 70% is assumed.

Alternative 1, 2, and 3: 2022 Launch Opportunity. Should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022. The science potential associated with Alternatives 1, 2, and 3 with a 2022 launch would be similar to those projected for each alternative with a 2020 launch. Under all circumstances, an MMRTG-powered rover would provide more power for science activities.

No Action Alternative. The No Action Alternate would not accomplish any science on the surface of Mars; this does not fulfill the purpose and need for the Mars 2020 mission as discussed in Chapter 1 of this DEIS.

2.6.2 Comparison of Potential Environmental Impacts

This section summarizes and compares the potential environmental impacts of the Proposed Action (Alternative 1), Alternative 2, Alternative 3, and the No Action Alternative. The anticipated impacts associated with nominal or normal implementation of Alternatives 1, 2, and 3 are considered first (Section 2.6.2.1). This is followed by a summary of the non-radiological impacts that could occur due to a potential launch accident with Alternatives1, 2, and 3 (Section 2.6.2.2); and finally a summary of potential radiological consequences and risks from a launch accident associated with each of the Alternatives (Section 2.6.2.3). Details of these results are addressed in Chapter 4.

As noted in Section 2.1.5, the evaluations presented in this DEIS, based on representative configurations of the possible launch vehicles, were completed prior to NASA’s selection of the mission launch vehicle. NASA considers these evaluations to adequately bound the potential environmental consequences of the alternatives described in this DEIS. Should NASA's continuing evaluations produce results that differ substantially from the information presented in this DEIS, NASA would consider the new information, and determine the need, if any, for additional environmental analysis and documentation

2.6.2.1. Environmental Impacts of a Normal Launch

Table 2-10 provides a summary comparison of the anticipated environmental impacts associated with normal implementation of Alternatives 1, 2, and 3, and the No Action Alternative.

Alternatives 1, 2, and 3. The impacts associated with a successful launch were addressed in the *Final Environmental Assessment for Launch of NASA Routine Payloads on Expendable Launch Vehicles* (Routine Payload EA) (NASA 2011) for all candidate launch vehicles. These impacts were determined to have no significant impacts, as detailed in the Finding of No Significant Impact (FONSI) for the Routine Payloads EA.

Table 2-10. Summary of Anticipated Environmental Impacts of the Mars 2020 Mission Alternatives

Impact Category	Mars 2020 Mission Alternatives	
	Normal Implementation of the Proposed Action and Alternatives 2 and 3	No Action Alternative
Land Use	Consistent with designated land uses at KSC and CCAFS; no adverse impacts on non-launch-related land uses at KSC and CCAFS would be expected.	No change in baseline condition.
Air Quality	High levels of solid propellant combustion products occur within the exhaust cloud for a launch vehicle using solid rockets boosters (e.g., the Atlas V). The exhaust cloud would rise and begin to disperse near the launch complex. Some short-term local ozone impacts. No long-term adverse air quality impacts would be expected in the region.	No change in baseline condition.
Noise and Sonic Boom	Sound exposure levels during launch are estimated to be within OSHA and EPA regulations/guidelines for affected workers and the public.	No change in baseline condition.
Geology and Soils	Some deposition of Al_2O_3 particulates and HCl near the launch complex for a launch vehicle using solid rockets boosters. No long-term adverse impacts would be expected.	No change in baseline condition.
Water Quality	Water used for pre-launch fire protection, heat suppression, acoustic damping, and post-launch wash down is recovered and treated if necessary. No long-term adverse impacts to groundwater or surface water would be expected; short-term increase in the acidity of nearby surface waters would be expected.	No change in baseline condition.
Offshore Environment	The offshore environments at KSC or CCAFS would be impacted by the jettisoned launch vehicle sections in pre-approved drop zones. Small amounts of residual propellants would be released to the surrounding water. Toxic concentrations would be unlikely because of the slow rate of the corrosion process and the large volume of ocean water available for dilution.	No change in baseline condition.
Biological Resources	Biota near the launch complex could be damaged or killed during launch, although no animal mortality has been observed that could be attributed to previous Delta and Atlas launches. Possible acidification of nearby surface waters from solid propellant exhaust products is not expected to cause any mortality of aquatic biota. No long-term adverse effects would be expected. No short-term or long-term impacts would be expected to threatened or endangered species. No long-term impacts would be expected to critical habitat.	No change in baseline condition.
Socioeconomics	No adverse impacts to socioeconomic factors such as demography, employment, transportation, and public or emergency services.	No change in baseline condition.
Environmental Justice	No disproportionately high and adverse impacts would be expected.	No change in baseline condition.
Cultural/Historical/ Archaeological Resources	No impacts would be expected.	No change in baseline condition.
Global Environment	Not anticipated to adversely affect global climate change. Temporary localized decrease in stratospheric ozone with rapid recovery would be anticipated along the launch vehicle's flight path.	No change in baseline condition.

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The environmental impacts associated with implementing the Proposed Action (Alternative 1), Alternative 2, or Alternative 3 would center largely on the exhaust products emitted from the launch vehicle's strap-on solid rockets and the short-term impacts of those emissions, should a vehicle that uses solid rockets (i.e., one of the Atlas V configurations) be selected. High concentrations of solid rocket motor exhaust products, principally aluminum oxide (Al_2O_3) particulates, carbon monoxide (CO), hydrogen chloride (HCl), nitrogen (N_2), and water (H_2O), would occur in the exhaust cloud that would form at the launch complex. CO would be quickly oxidized to carbon dioxide (CO_2); and at the high exhaust plume temperatures, N_2 may react with oxygen to form nitrogen oxides (NO_X). Due to the relatively high gas temperatures, this exhaust cloud would be buoyant and would rise quickly and begin to disperse near the launch pad. High concentrations of HCl would not be expected, so prolonged acidification of nearby water bodies and long-term or cumulative damage to vegetation should not occur. First-stage liquid propellant engines that use RP-1 and LOx, such as the Atlas V and Falcon Heavy, would primarily produce CO, CO_2, and water vapor as combustion products. First-stage liquid propellant engines that use LH_2 and LOx, such as the Delta IV, would produce water vapor. For either launch vehicle, no adverse impacts to local air quality would be expected.

If rain were to occur shortly after launch, some short-term acidification of nearby water bodies could occur with the accompanying potential for some mortality of aquatic biota. Biota that happened to be in the path of the exhaust could be damaged or killed. Threatened or endangered species would not be jeopardized nor would critical habitats be affected at KSC or CCAFS. As the launch vehicle gains altitude, a portion of the solid rocket motor exhaust (specifically, HCl, Al_2O_3, and NO_X) would be deposited in the stratosphere, resulting in a short-term reduction in ozone along the launch vehicle’s flight path. Recovery, however, would be rapid and cumulative impacts would not be expected.

Noise and sonic booms would be associated with the launch. However, neither launch site workers nor the public would be adversely affected. Increased noise levels, anticipated to be below Occupational Safety and Health Administration (OSHA) regulations for unprotected workers, would occur for only a short period during the launch vehicle's early ascent, and would diminish rapidly as the vehicle gains altitude and moves downrange. No impacts to cultural, historical or archaeological resources would be expected from a normal launch. The Mars 2020 mission launch would not be expected to disproportionately impact either minority or low-income populations.

No Action Alternative. Under the No Action Alternative, NASA would discontinue preparations for the Mars 2020 mission, and the spacecraft would not be developed and launched. Thus, none of the anticipated impacts associated with a normal launch would occur.

2.6.2.2. Potential Non-radiological Environmental Impacts of Launch Accidents

Alternatives 1, 2, and 3. As with the impacts associated with a successful launch, these impacts were addressed in the *Final Environmental Assessment for Launch of NASA Routine Payloads on Expendable Launch Vehicles* (Routine Payload EA) (NASA

2011) for all candidate launch vehicles. These impacts were determined to have no significant impact and described in the FONSI for the Routine Payload EA.

Non-radiological accidents could occur during preparation for and launch of the Mars 2020 spacecraft at KSC or CCAFS. The two most significant non-radiological accidents would be a liquid propellant spill associate with fuel loading operations and a launch vehicle accident.

The potential for environmental consequences would be limited primarily to liquid propellant spills of RP-1, LH_2, LOx, and hydrazine (depending on the propellants used in the selected launch vehicle); during fueling operations; and a launch accident at or near the launch pad. USAF safety requirements (USAF 2004) specify detailed policies and procedures to be followed to ensure worker and public safety during liquid propellant fueling operations. Propellant spills or releases of RP-1, LH_2, and LOx would be minimized through remotely operated actions that close applicable valves and safe the propellant loading system. Workers performing propellant loading (e.g., RP-1 and hydrazine) would be equipped with protective clothing and breathing apparatus, and uninvolved workers would be excluded from the area during propellant loading. Propellant loading would occur only shortly before launch, further minimizing the potential for accidents.

A launch vehicle accident on or near the launch area during the first few seconds of flight could result in the release of the propellants (solid and liquid) onboard the launch vehicle and the spacecraft. A launch vehicle accident would result in the prompt combustion of a portion of the liquid propellants, depending on the degree of mixing and ignition sources associated with the accident, and somewhat slower burning of the solid propellant fragments, should a vehicle that uses solid rockets be selected. The resulting emissions would resemble those from a normal launch, consisting principally of CO, CO_2, HCl, NO_X, and Al_2O_3 from the combusted propellants, and depending on the propellants used in the selected launch vehicle. Falling debris would be expected to land on or near the launch pad resulting in potential secondary ground-level explosions and localized fires. After the launch vehicle clears land, debris from an accident would be expected to fall over the Atlantic Ocean. Modeling of accident consequences with meteorological parameters that would result in the greatest concentrations of emissions over land areas indicates that the emissions would not reach levels threatening public health. Some burning solid and liquid propellants could enter surface water bodies and the ocean resulting in short-term, localized degradation of water quality and conditions toxic to aquatic life. Such chemicals entering the ocean would be dispersed and buffered, resulting in little long-term impact on water quality and resident biota.

For suborbital, orbital, and reentry debris, standard safety review processes require that NASA missions comply with the re-entry requirements of NASA Standard 8719.14, *Process for Limiting Orbital Debris*. This NASA Standard (i.e., Requirement 4.7.1) limits the risk of human casualty from reentry debris to 1 in 10,000 and requires that missions be designed to assure that in both controlled and uncontrolled entries, domestic and foreign landmasses are avoided.

The environmental impact of objects falling into the ocean would depend on the physical properties of the materials (e.g., size, composition, quantity, and solubility) and the

marine environment of the impact region. Based on past analyses of other space components, it is expected that the environmental impact of reentering orbital debris would be negligible (NASA 2005b; USAF 1998). NASA has studied the potential risks associated with reentry and Earth impact of spacecraft propellant tanks, including those used on prior science missions to the surface of Mars. Specifically, for the MSL spacecraft, an analysis showed that under certain launch accident conditions, there was a small probability the spacecraft with a full propellant load (475 kg) could reenter prior to achieving orbit and impact land in southern Africa or Madagascar. The probability of such an accident occurring and leading to a land impact was determined to be on the order of 1 in 20,000. The overall risk of an individual injury resulting from the land impact of a spacecraft and exposure to hydrazine was determined to be less than 1 in 100,000 (NASA 2010b).

In accident scenarios occurring after achievement of the park orbit, analysis for the MSL spacecraft determined it would be extremely unlikely that there would be any residual hydrazine remaining inside the propellant tanks at the point of ground impact (NASA 2010b).

No Action Alternative. Under the No Action Alternative, a launch would not occur, therefore there would be no potential for either type of accident to occur.

2.6.2.3. Potential Radiological Environmental Impacts of Launch Accidents

This section presents a summary of DOE's *Nuclear Risk Assessment for the Mars 2020 Mission Environmental Impact Statement* (SNL 2014) for the Proposed Action (Alternative 1), Alternative 2, and Alternative 3 as described in this DEIS. More detailed presentations can be found in Sections 4.1.4, 4.1.5, and 4.3.4.

Alternative 1: Figure 2-21 presents summaries of launch-related probabilities for Alternative 1 for the proposed Mars 2020 mission. These probability summaries were derived by combining the estimated failure probabilities from Mars 2020 Representative Data Book (NASA 2013), and DOE's estimated release probabilities (SNL 2014). As such, the estimated probabilities summarized in Figure 2-21 do not reflect the reliability of any single launch vehicle.

The most likely outcome of implementing the proposed Mars 2020 mission, with over a 97% probability, is a successful launch to Mars. The unsuccessful launches (about a 2.5 % probability) would result from either a malfunction or a launch accident. Most malfunctions would involve trajectory control malfunctions, which would occur late in the ascent profile. This type of malfunction would place the spacecraft on an incorrect trajectory escaping from Earth but leading to failure of the spacecraft to reach Mars. Most launch accidents result in destruction of the launch vehicle but would not result in damage to the MMRTG sufficient to cause a release of some plutonium dioxide. The analysis estimates that for less than 0.04% of the time (a probability of 1 in 2,600), a launch could result in an accident with the release of plutonium dioxide, but typically not in a quantity large enough to result in discernible radiological consequences (see Section 2.6.2.3.2).

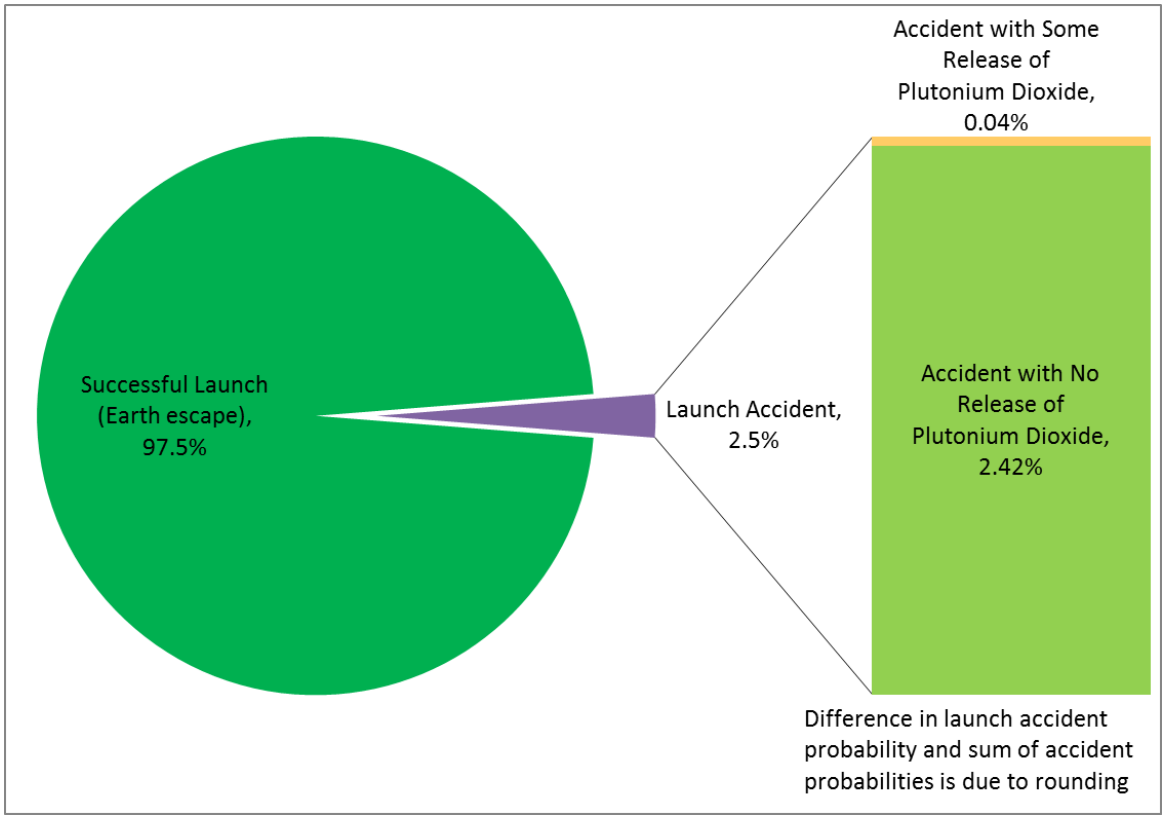

Figure 2-21: Alternative 1 - MMRTG Accident Probabilities

The rover may incorporate science instruments with a small quantity of radioactive sources. NASA has not yet identified the specific instruments that would be used on the Mars 2020 mission. However, DOE has performed a risk assessment using a representative instrument radioisotope source. The results of the instrument source analysis are provided in the following sections and provide a perspective on their relative risks compared to that from the MMRTG or LWRHUs. One significant difference between the small quantity radioactive sources and the plutonium dioxide in the MMRTG is the likelihood of a release following a launch accident. Considering all launch accidents, there is a slightly less than 50% chance that the accident would result in the release of radioactive material from the small quantity of certain radioactive sources. The risks associated with these source terms would be applicable to all three rover configurations (Alternatives 1, 2, and 3).

Alternative 2: For Alternative 2, the rover would rely solely on the power from the solar arrays to provide electric power for rover operations and heat to maintain an acceptable thermal environment for rover equipment and instrumentation. There would be no radioactive material other than the small quantity radioactive sources that may be contained in science instruments that are incorporated into the rover.

Alternative 3: For Alternative 3 the rover would rely upon power from the solar arrays to provide electric power for rover operations and heat to maintain an acceptable thermal environment for rover equipment and instrumentation and incorporate up to 71

LWRHUs[10] as an additional heat source. As with alternatives 1 and 2, Alternative 3 may incorporate science instruments with small quantity radioactive sources.

Figure 2-22 presents summaries of launch-related probabilities for Alternative 3 of the proposed Mars 2020 mission. These probability summaries were derived by combining the estimated failure probabilities from *Mars 2020 Representative Data Book* (NASA 2013), and DOE's estimated release probabilities (SNL 2014). As such, the estimated probabilities summarized in Figure 2-22 do not reflect the reliability of any single launch vehicle.

The differences between the three rover configurations (MMRTG powered, solar-powered with no LWRHUs, and solar-powered with LWRHUs) do not significantly impact the accident probability for the mission. However, the probability of an accident with a release of plutonium dioxide is smaller, 0.006% (1 in 15,000), for the solar-powered rover with LWRHUs configuration, than for the MMRTG powered rover. The amount of material released is typically not large enough to result in discernible radiological consequences. (See Section 2.6.2.3.2)

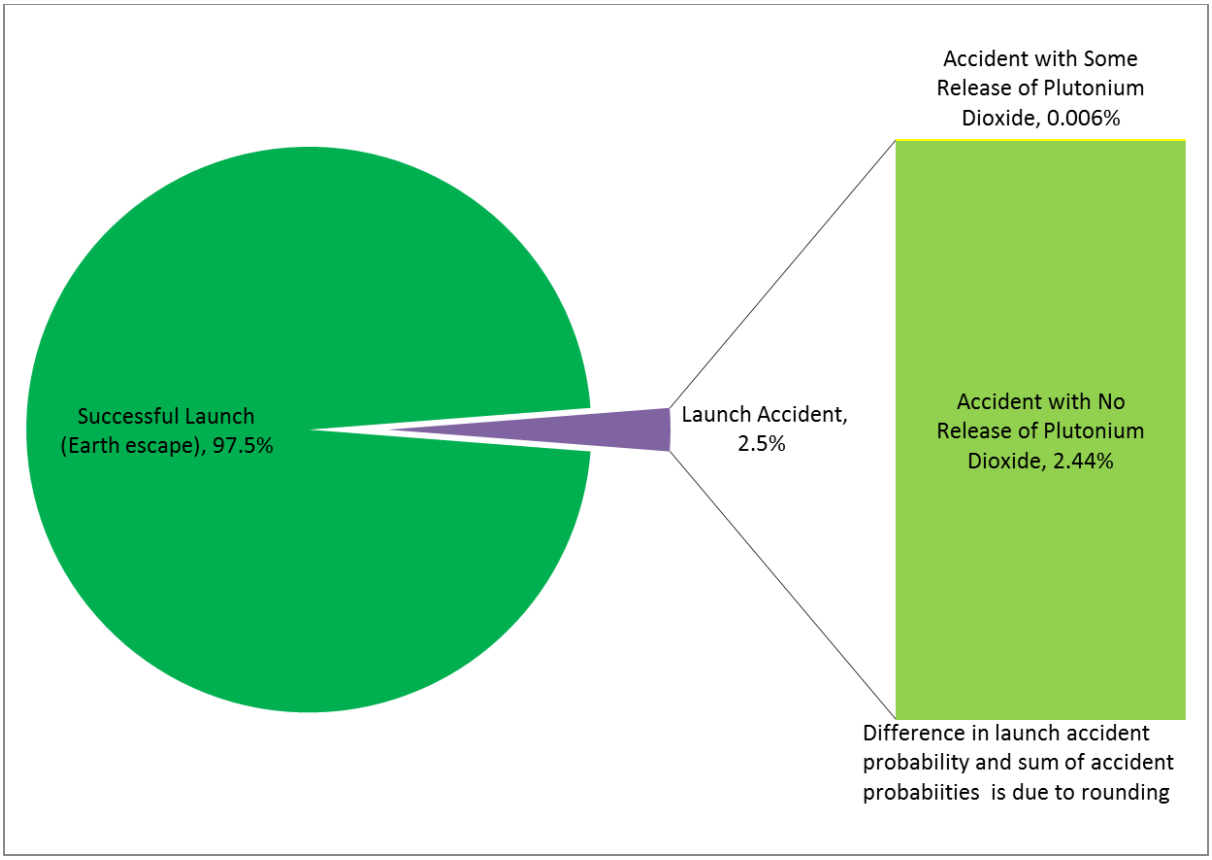

Figure 2-22: Alternative 3 - LWRHU Accident Probabilities

[10] For the purposes of the risk analysis, DOE assumed the rover could include up to 80 LWRHUs

2.6.2.3.1. The DEIS Nuclear Risk Assessment

The nuclear risk assessment for the proposed Mars 2020 mission considers (1) potential accidents associated with the launch and their probabilities and accident environments; (2) the response of the MMRTG and LWRHUs to such accidents in terms of the amount of radioactive materials released and their probabilities; and (3) the radiological consequences and mission risks associated with such releases. The risk assessment was based on a typical MMRTG radioactive material inventory of about 60,000 Ci of primarily plutonium-238 (an alpha-emitter with an 87.7 year half-life).

DOE's risk assessment was developed when the candidate launch vehicles being considered by NASA for the Mars 2020 mission were the Atlas V 541 and 551, the Delta IV Heavy, and the Falcon Heavy. A composite approach was taken in DOE's nuclear risk assessment (SNL 2014) for accident probabilities, potential releases of plutonium dioxide in case of an accident (called source terms), radiological consequences, and mission risks. The composite approach taken in the risk assessment and reported in this DEIS reflects the state of knowledge at this early stage in the mission with respect to the candidate launch vehicles.

The risk assessment for the Mars 2020 mission began with the identification of the initial launch vehicle system malfunctions or failures and the subsequent chain of accident events that could ultimately lead to the accident environments (e.g., explosive overpressures, fragments, fire) that could threaten the MMRTG or LWRHUs. These launch vehicle system failures were based on launch vehicle system reliabilities and estimated failure probabilities (NASA 2013).

Failure of the launch vehicle has the potential to create accident environments that could damage the MMRTG or LWRHUs and result in the release of plutonium dioxide. Based on analyses performed for earlier missions that carried radioisotope devices (RTGs and LWRHUs), DOE identified the specific accident environments that could potentially threaten these devices. DOE then determined the response of the MMRTG, MMRTG components, and LWRHUs to these accident environments and estimated the amount of radioactive material that could be released.

For this risk assessment, the Mars 2020 mission was divided into mission phases, which reflect principal launch events.

- **Phase 0 (Pre-Launch) and Phase 1 (Early Launch):** A launch-related accident during these periods could result in ground impact in the launch area.
- **Phase 2 (Late Launch):** A launch accident during this period would lead to impact of debris in the Atlantic Ocean.
- **Phase 3 (Sub Orbital):** A launch accident during this period prior to reaching Earth parking orbit could lead to prompt sub-orbital reentry within minutes.
- **Phase 4 (Orbital) and Phase 5 (Long-Term Reentry):** A launch accident that occurs after attaining parking orbit could result in orbital decay reentries from minutes to years after the accident.

2.6.2.3.2. Accident Probabilities and Consequences

Section 4.1.4 provides a detailed quantitative discussion of the accident probabilities and associated potential consequences for the proposed Mars 2020 mission.

The radiological consequences of a given accident that results in a release of radioactive material have been calculated in terms of radiation doses, potential health effects, and land area contaminated at or above specified levels. The radiological consequences have been determined from atmospheric transport and dispersion simulations incorporating both worldwide and launch-site specific meteorological and population data.

Sections 4.1.4 and 4.1.5 (Alternative 1), and 4.3.4 (Alternative 3) describe the risk assessment in greater detail, with the results presented for both mean and 99th percentile values. For the purposes of this summary, the accident consequences and associated risks are presented only in terms of the mean.

Consequences of Radiological Release on Human Health

Human health consequences are expressed in terms of maximum individual dose, collective dose to the potentially exposed population, and the associated health effects. The maximum individual dose is the maximum dose, typically expressed in units of rem (Roentgen equivalent in man), delivered to a single individual assumed to be outside during the time of radiological exposure for each accident. Collective dose (also called a population dose) is the sum of the radiation dose received by all individuals exposed to radiation from a given release. Health effects represent statistically estimated additional latent cancer fatalities resulting from an exposure over a 50-year period to a release of radioactive material, and are determined based on Interagency Steering Committee on Radiation Standards (ISCORS) health effects estimators (DOE 2002). The estimated radiological consequences by mission phase and for the overall mission are summarized below.

Alternative 1: For alternative 1, an accident resulting in the release of plutonium dioxide from the MMRTG occurs with a probability of 1 in 2,600. The mean mission human health consequences are:

- maximum dose received by an individual would have a mean of 0.016 rem which is equivalent to about 5% of the natural annual background dose received by each member of the population of the United States during a year[11]
- a mean collective dose resulting in about 0.076 additional latent cancer fatalities within the entire group of potentially exposed individuals.

For individual phases of the mission, the maximum dose received by an individual ranges from 0.000016 to 0.060 rem, and the additional latent cancer fatalities range

[11] An average of about 0.3 rem per year is received by an individual in the United States from natural sources. The dose from man-made sources, such as medical diagnosis and therapy, could be as high as an additional 0.3 rem. See Section 3.2.6 for further information.

from 0.000078 to 0.29. The largest values are both associated with accidents with releases that occur during the Early Launch Phase (Phase 1).

Alternative 3. For alternative 3, an accident resulting in the release of plutonium dioxide from the LWRHUs occurs with a probability of 1 in 15,000. The mean mission human health consequences are:

- maximum dose received by an individual would have a mean of 0.0041 rem which is equivalent to about 1% of the natural annual background dose received by each member of the population of the United States during a year
- a mean collective dose resulting in about 0.020 additional latent cancer fatalities within the entire group of potentially exposed individuals.

For individual phases of the mission in which accidents can result in a plutonium dioxide release, the maximum dose received by an individual ranges from 0.0013 to 0.0042 rem. and the additional latent cancer fatalities range from 0.006 to 0.020. Accidents occurring during phases 2, 4, and 5 are not expected to release any plutonium dioxide. The largest values are both associated with accidents with releases that occur during the Early Launch Phase (Phase 1).

Alternatives 1, 2, and 3. For alternatives 1, 2, and 3, the probability of an accident resulting in the release of some of the instrumentation radioisotope is about 1 in 87. The mean mission human health consequences are:

- maximum dose received by an individual would have a mean of 0.00003 rem which is equivalent to about one-hundredth of 1% of the natural annual background dose received by each member of the population of the United States during a year,
- a mean collective dose resulting in about 0.00014 additional latent cancer fatalities within the entire group of potentially exposed individuals.

For individual phases of the mission, the maximum dose received by an individual ranges from of 0.000011 to of 0.000061 rem and the additional latent cancer fatalities range from of 0.000053 to 0.00029. The largest values are both associated with accidents with releases that occur during the long-term reentry phase (Phase 5).

In summary, for accidents in and near the launch area (Phases 0 and 1), as well as Phase 3 and Phase 4 accidents, the mean health effects are estimated to be small within the potentially exposed population. This estimate assumes no intervention (mitigation), such as sheltering and exclusion of people from contaminated land areas.

Also, the predicted mean maximum radiological dose to an individual within the exposed population (i.e., the maximally exposed individual) ranges from very small to less than a rem for all accidents with a release. None of these potential exposures would lead to short-term radiological effects, only to a statistical increase in the likelihood of cancer.

Table 2-11 provides a summary of the human health consequences for all mission phases for each alternative.

Should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022. Since this launch period is in a similar season as the 2020 launch period, the projected radiological impacts would be similar, with only a small increase in population impacts due to population growth. Thus, within the overall uncertainties, the radiological impacts associated with a 2022 launch would be the same as those for the proposed 2020 launch.

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Table 2-11. Summary of Estimated Mean Radiological Health Consequences

Consequence Contributing Source		Launch Area Accidents		Accidents Beyond The Launch Area				Overall Mission Accidents
		Pre Launch	Early Launch	Late Launch	Sub-Orbital	Orbital	Long-term reentry	
Alternative 1 - MMRTG	Probability of an Accident with a Release	1 in 93,000	1 in 11,000	1 in 130,000	1 in 67,000	1 in 3,800	1 in 11,000,000	1 in 2,600
	Maximum Individual Dose, rem	0.00029	0.06	0.000016	0.043	0.0005	0.0008	0.016
	Latent Cancer Fatalities[(a)]	0.0014	0.29	0.000078	0.20	0.0026	0.0038	0.076
Alternative 3 - LWRHUs	Probability of an Accident with a Release	1 in 3,200,000	1 in 16,000	0[(b)]	1 in 430,000	0[(b)]	0[(b)]	1 in 15,000
	Maximum Individual Dose, rem	0.0030	0.0042	-	0.0013	-	-	0.0041
	Latent Cancer Fatalities	0.015	0.020	-	0.0060	-	-	0.020
Alternatives 1, 2 and 3 – Instrumentation Source	Probability of an Accident with a Release	1 in 550,000	1 in 1,700	1 in 8,500	1 in 150	1 in 240	1 in 1,000,000	1 in 87
	Maximum Individual Dose, rem	0.000034	0.000011	0.000031	0.000031	0.000031	0.000061	0.000030
	Latent Cancer Fatalities	0.00016	0.000053	0.00015	0.00015	0.00015	0.00029	0.00014

(a) A latent cancer fatality of less than 1.0 can be interpreted as the probability of the occurrence of one or more latent cancer fatalities. For example, a value of 0.25 would be a one in four chance that the accident would result in one or more latent cancer fatalities.

(b) The multiple protective layers of the LWRHUs would be sufficient to prevent the release of fuel under all circumstances during these types of launch accidents. Therefore, the release probability is 0.0 and there are no associated radiological consequences as indicated by the "-."

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Impacts of Radiological Releases on the Environment

In addition to the potential human health consequences of launch accidents that could result in a release of plutonium dioxide, environmental impacts could also include contamination of natural vegetation, wetlands, agricultural land, cultural, archaeological and historic sites, urban areas, inland water, and the ocean, as well as impacts on wildlife.

Potential environmental contamination was evaluated in terms of areas exceeding various screening levels and dose-rate-related criteria considered in evaluating the need for land cleanup following radioactive contamination. In the risk assessment for this DEIS, land areas which could be contaminated at or above a level of 0.2 microcuries per square meter (μCi/m^2) have been identified. This is a screening level used in prior NASA environmental documentation (e.g., NASA 1989, NASA 1997, NASA 2005b, NASA 2006 (MSL EIS)) to identify areas potentially needing further action, such as monitoring or cleanup. The results for the mean land area contaminated at or above a level of 0.2 μCi/m^2 are summarized in Table 2-12.

Table 2-12. Mars 2020 Mission Alternatives: Land Contamination

Phase	MMRTG (Alternative 1)		LWRHU (Alternative 3)		Science Sources (Alternatives 1, 2, & 3)	
	Release Probability[a]	Land Contamination	Release Probability [a]	Land Contamination	Release Probability[a]	Land Contamination
Pre-launch	1 in 93,000	0.035 km^2 (0.014 mi^2)	1in 3.3 million	0.37 km^2 (0.14 mi^2)	1in 550,000	0.0041 km^2 (0.0016 mi^2)
Early launch	1 in 11,000	7.4 km^2 (2.9 mi^2)	1 in 16,000	0.51 km^2 (0.20 mi^2)	1 in 1,700	0.0014 km^2 (0.0005 mi^2)
Late launch	1 in 130,000	0.0020 km^2 (0.00077mi^2)	0	----	1 in 8,500	0.0038 km^2 (0.0015 mi^2)
Sub-Orbital	1 in 68,000	5.2 km^2 (2.0 mi^2)	1 in 430,000	0.15 km^2 (0.058 mi^2)	1 in 152	0.0038 km^2 (0.0015 mi^2)
Orbital	1 in 3,800	0.066 km^2 (0.025 mi^2)	0	----	1 in 240	0.0038 km^2 (0.0015 mi^2)
Long-term Reentry	1 in 11 million	0.097 km^2 (0.037 mi^2)	0	----	1 in 1 million	0.0075 km^2 (0.0029 mi^2)
Overall Mission	1 in 2,600	1.94 km^2 (0.75 mi^2)	1 in 15,000	0.50 km^2 (0.19 mi^2)	1 in 87	0.0036 km^2 (0.0014 mi^2)

a) Probability of an accident with a radionuclide release. A value of '0' indicates that there are no accidents that result in a release and therefore no corresponding land contamination (---); the multiple protective layers of the LWRHUs would be sufficient to prevent the release of fuel under all circumstances during these types of launch accidents.

For alternatives 1, 2, and 3, costs associated with potential characterization and cleanup, should decontamination be required, could vary widely ($110 million to $600 million per km^2 or about $285 million to $1.6 billion per mi^2) depending upon the characteristics and size of the contaminated area. The Price-Anderson Act of 1957, as amended (42 U.S.C. 2210), governs liability and compensation in the event of a nuclear incident arising out of the activities of the DOE. In the case of the Mars 2020 mission, DOE retains responsibility for the MMRTG or LWRHUs. The MMRTG or LWRHUs

would, therefore, be subject to Price-Anderson Act provisions. In the unlikely event that an accident were to occur resulting in release of plutonium dioxide, affected property owners within or outside the United States would be eligible for reimbursement for loss of property due to contamination.

In addition to the potential direct costs of radiological surveys, monitoring, and potential cleanup following an accident, there are potential secondary societal costs associated with the decontamination and mitigation activities due to launch area accidents. Those costs may include: temporary or longer term relocation of residents; temporary or longer term loss of employment; destruction or quarantine of agricultural products, including citrus crops; land use restrictions; restriction or bans on commercial fishing; and public health effects and medical care.

The areas that could be contaminated to the extent that these secondary costs would be incurred are not necessarily the same as the area contaminated above 0.2 $\mu Ci/m^2$. For example, the Food and Drug Administration has provided guidelines for crop contamination intended to ensure contaminated foodstuffs would not endanger the health and safety of the public. These guidelines, in the form of Derived Intervention Levels (DILs) identify the level of contamination above which some action (decontamination, destruction, quarantine, etc.) is required. For potential launch area accidents, DOE has estimated that the crop area contaminated above the DIL would be over 50 times smaller than the area contaminated above 0.2 $\mu Ci/m^2$.

2.6.2.3.3. Mission Risks

To place the estimates of potential health effects due to launch accidents for the proposed Mars 2020 mission into a perspective that can be compared with other human undertakings and events, it is useful to use the concept of risk. Risk is commonly viewed as the possibility of harm or damage. For the Mars 2020 mission, public risk is characterized in terms of the expectation of health effects in a statistical sense. The risk for each mission phase and for the overall mission is estimated by multiplying the total probability of a release by the health effects resulting from that release. Risk calculated in this manner can also be interpreted as the probability of one or more health effects occurring in the exposed population.

Population Risks

For Alternative 1 of the Mars 2020 mission, overall population health effects risk from the release of plutonium dioxide is estimated to be about 1 in 34,000—that is, one chance in 34,000 of an additional health effect. For accidents that may occur in the launch area, not everyone within 100 km (62 mi) of the launch site would be potentially exposed. Who would be potentially exposed is dependent upon several factors, including the weather conditions at the time of the accident. The total probability of a health effect within the regional population is about 1 in 61,000, or about 57% of the total risk for the overall mission. For the global population (excluding those exposed in the launch area region) the risk would be due to the potential for accidental release occurring from pre-Launch through Mars trajectory insertion and was estimated to be about 1 in 79,000, or about 43% of the total risk for the mission.

For Alternative 3 of the Mars 2020 mission, overall population health effects risk from the release of plutonium dioxide is estimated to be about 1 in 790,000. For accidents that may occur in the launch area, only a portion of the total population within 100 km (62 mi) of the launch site would be potentially exposed. The total probability of a health effect within the regional population is about 1 in 1,200,000, or about 64% of the total risk for the overall mission. For the global population (excluding those exposed in the launch area region) the risk would be due to the potential for accidental release occurring from pre-Launch through Mars trajectory insertion and was estimated to be about 1 in 2,200,000, or about 36% of the total risk for the mission.

Alternatives 1, 2, and 3 may include science instrumentation that could include small radioactive sources. The results discussed above include only the risks due to the plutonium dioxide in either the MMRTG or in LWRHUs and do not include the risks associated with these small sources. As stated previously, the science instruments have not been selected for a Mars 2020 mission; however, DOE performed a risk assessment for a representative small radioactive source.

The overall radiological risk from the instrument small source radioisotopes for the Mars 2020 mission is estimated to be about 1 in 610,000. The global risks due to accidents in all mission phases would be over 98% of the total risk. The contribution to risk within 100 km (62 mi) of the launch site would be about 1.4% of the total risk for the mission.

For Alternative 1, this would increase the overall mission risk to 1 in 33,000, and for Alternative 3 to 1 in 340,000.

Individual Risks (Maximum Individual Risks)

Those individuals within the population that might receive the highest radiation exposures, such as those very close to the launch area, would face very small risks. The risk to the maximally exposed individual within the regional population is estimated to be less than 1 in several million for all alternatives considered for the Mars 2020 mission. Most people in the potentially exposed population would have much lower risks.

These risk estimates are small compared to other risks. Annual fatality statistics indicate that in the year 2010 the average individual risk of accidental death in the United States was about 1 in 2,600 per year, while the average individual risk of death due to any disease, including cancer, was about 1 in 130 (see Section 4.1.4.7 of this DEIS for additional details).

2.6.3 Summary Comparison of the Alternatives

Table 2-13 presents a summary comparison of the Proposed Action (Alternative 1), Alternative 2, Alternative 3, and the No Action Alternative in terms of each alternative's capabilities for operating and conducting science on the surface of Mars, the anticipated environmental impacts of normal implementation (i.e., a successful launch to Mars) of each alternative, and the potential environmental impacts in the event of an unlikely launch accident for each alternative.

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Table 2-13. Summary Comparison of the Mars 2020 Mission Alternatives

	Proposed Action (Alternative 1)	Alternative 2	Alternative 3	No Action Alternative
Rover Power Alternative	MMRTG	Solar Array no LWRHUs	Solar Array with LWRHUs	Not applicable
Functional Capability	Capable of operating for at least one Mars year at landing sites between 30° north and 30° south latitudes on Mars	Unable to operate for a full year at any latitude[(a)]	Limited lifetime capability for operating at landing sites between 20° south and 5° south latitudes on Mars[(a)]	Not applicable
Science Capability (detailed comparison in Table 2-9)	Capable of accomplishing all science objectives at any scientifically desirable landing site between 30° north and 30° south latitudes	Capable of accomplishing up to 33% of science objectives during partial year operation[(b)]	Capable of accomplishing up to 70% of science objectives due to constrained operations during winter.[(b)]	No science achieved
Anticipated Environmental Impacts	Short-term impacts associated with exhaust emissions from the launch vehicle during a normal launch	Short-term impacts associated with exhaust emissions from the launch vehicle during a normal launch	Short-term impacts associated with exhaust emissions from the launch vehicle during a normal launch	No impacts
Potential Environmental Impacts in the Event of a Launch Accident (detail comparison in Tables 2-11 and 2-12)	Potential impacts associated with combustion of released propellants and falling debris Potential radiological impacts associated with release of small quantity radioisotopes from science instruments and release of some of the PuO_2 from the MMRTG	Potential impacts associated with combustion of released propellants and falling debris Potential radiological impacts associated with release of small quantity radioisotopes from science instruments	Potential impacts associated with combustion of released propellants and falling debris Potential radiological impacts associated with release of small quantity radioisotopes from science instruments and release of some of the PuO_2 from the LWRHUs	No potential impacts

(a) These numbers assume a dust factor of 40%. Assuming dust mitigation technology improvements on the MER solar array performance, the rover (without LWRHUs) is predicted to survive for a full year at latitudes between 0° and 5° south and, with LWRHUs, is predicted to survive for a full year at latitudes between 20° south and 15° north.

(b) Improved solar array performance from dust mitigation technology would result in a corresponding increase in science capability, expanding the range of latitudes the rover could operate for a full year.

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In terms of operational capabilities, the major difference between the Proposed Action (Alternative 1), Alternative 2, and Alternative 3 is the length of time the rover would be expected to survive and successfully operate and conduct science experiments at a selected landing site. The capability to operate the rover within a broad range of latitudes is important because doing so maintains NASA's flexibility to select the most scientifically interesting location on the surface and fulfill the purpose and need for the Mars 2020 mission as discussed in Chapter 1 of this DEIS. The No Action Alternative would not fulfill the purpose and need for the Mars 2020 mission.

In terms of environmental impacts, normal implementation of either the Proposed Action (Alternative 1) or Alternative 2 or 3 would primarily yield short-term impacts to air quality from the launch vehicle's exhaust (see Section 2.6.2.1). Should an unlikely launch accident occur for either of these alternatives, potential environmental impacts would be primarily associated with combustion products from released propellants and from falling debris (see Section 2.6.2.2). For the Proposed Action (Alternative 1), an unlikely launch accident could result in a release of some of the plutonium dioxide from the MMRTG, which could potentially result in consequences to human health and the environment (see Section 2.5.2.3). Similarly in Alternative 3, plutonium dioxide could be released from LWRHUs (see Section 2.6.2.3). For Alternative 1, 2, and 3, during these accidents, releases of the small quantity source terms could also result in consequences to human health and the environment. With the No Action Alternative, no environmental impacts would occur since there would be no launch, but none of the planned science would be achieved.

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3. DESCRIPTION OF THE AFFECTED ENVIRONMENT

This chapter of the Draft Environmental Impact Statement (DEIS) for the Mars 2020 mission briefly discusses the local and global areas that could be affected by implementing the Proposed Action (Alternative 1), Alternative 2, Alternative 3, and the No Action Alternative as described in Chapter 2. This document is a Tier 2 mission-specific DEIS under NASA's *Final Programmatic Environmental Impact Statement for the Mars Exploration Program* (PEIS MEP) (NASA 2005a). The PEIS MEP addressed, in general, the regional area surrounding Cape Canaveral Air Force Station (CCAFS) and the Kennedy Space Center (KSC), Florida, and the global environment that could be affected if any of the alternatives in the PEIS were implemented. As a tiered document, the Mars 2020 DEIS supplements that discussion. Implementing the No Action Alternative (i.e., discontinue the Mars 2020 mission) would result in no impacts to the existing environment. Launch of the Mars 2020 mission would take place at CCAFS or KSC, Brevard County, Florida, during the summer of 2020 launch opportunity. The next launch opportunity for this mission would occur during the summer of 2022.

The PEIS MEP used other National Environmental Policy Act (NEPA) documentation such as the U.S. Air Force's (USAF) *Final Environmental Impact Statement for the Evolved Expendable Launch Vehicle Program* (USAF 1998), *Final Supplemental Environmental Impact Statement for the Evolved Expendable Launch Vehicle Program* (USAF 2000), and institutional documents as principal sources of information to describe the affected environment. Where relevant, these documents are summarized in this chapter with the exception where updated documents are noted.

Section 3.1 describes the affected environment at CCAFS and KSC and includes consideration of the resource areas of Land Use, Air Quality, Noise, Geology and Soils, Water Quality, Biological and Natural Resources, Socioeconomics, Historical and Cultural Resources, Hazardous Materials and Hazardous Waste, Health and Safety, Environmental Justice and Aesthetics. Section 3.2 provides a general discussion of areas of the global environment that may be affected by the proposed action.

3.1 CAPE CANAVERAL AIR FORCE STATION AND KENNEDY SPACE CENTER LOCATION DESCRIPTION

CCAFS is located on the east coast of Florida in Brevard County on a barrier island called the Canaveral Peninsula. CCAFS is bounded on the west by the Banana River, on the north by KSC, on the east by the Atlantic Ocean, and on the south by Port Canaveral. CCAFS encompasses an area of approximately 15,800 acres (63.9 square kilometers, 24.7 square miles).

KSC is located on the east coast of Florida in Brevard County on the north end of Merritt Island adjacent to Cape Canaveral. KSC is bordered on the west by the Indian River and on the east by the Atlantic Ocean and CCAFS. The northernmost end of the Banana River lies between Merritt Island and CCAFS 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 across Mosquito Lagoon in Volusia County. The Indian River, Banana River, and the Mosquito

Lagoon collectively make up the Indian River Lagoon system. The land and lagoon areas encompass approximately 139,400 acres (564.1 square kilometers, 217.8 square miles) (NASA 2010). The CCAFS and KSC area are illustrated in Figure 3-1.

Figure 3-1. CCAFS and NASA/KSC Locations

3.1.1 Land Use

NASA has devised eleven land use categories to describe the regions within which various types of operational or support activities are conducted. These land use categories are Launch, Launch Support, Airfield Operations, Spaceport Management, Research and Development, Public Outreach, Seaport, Recreation, Conservation, Agriculture, and Open Space.

Only a very small part of the total acreage of KSC has been developed or designated for NASA operational and industrial use. Merritt Island consists of prime habitat for unique and endangered wildlife; therefore, in 1972 NASA entered into an agreement with the U.S. Fish and Wildlife Service (USFWS) to establish a wildlife preserve, known as the Merritt Island National Wildlife Refuge (MINWR), within the boundaries of KSC. Public Law 93-626 created the Canaveral National Seashore (CNS); thereby, an agreement with the Department of the Interior (DOI) was also entered into in 1975 due to the location of CNS within KSC boundaries (NASA 2010).

Land use is carefully planned and managed at KSC to provide required support for missions and to maximize protection of the environment. NASA maintains operational control of approximately 4,212 acres (17.0 square kilometers, 6.6 square miles) at KSC and this area comprises the functional area dedicated to NASA operations. NASA's two primary developed areas at KSC are Launch Complex (LC)-39 in the north and the centrally located Industrial Area. Approximately 70 percent of the NASA operational control area is developed land dedicated as facility sites, roads, lawns and right-of way. The remaining undeveloped areas are dedicated safety zones or are held in reserve for planned and future expansion (NASA 2010).

Land uses at CCAFS include launch operations, launch and range support, airfield, port operations, station support area, and open space. The launch operations land use category is present along the Atlantic Ocean shoreline and includes the active and inactive launch sites and support facilities. The launch and range support area is west of the launch operations area and is divided into two sections by the airfield. The airfield includes a single runway, taxiways, and apron, and is in the central part of the station. The port operations area is in the southern part of the station and includes facilities for commercial and industrial activities. The major industrial area is located in the center of the western portion of the station. This area also includes administration, recreation, and range-support facilities. Open space is dispersed throughout the station. There are no public beaches located on CCAFS. All land uses at CCAFS are under the operational control of the USAF 45th SW, located at Patrick Air Force Base (PAFB) (NASA 2011).

The proposed Mars 2020 mission would be launched either on a Delta IV launch vehicle from SLC-37 located on the northeastern section of CCAFS; an Atlas V launch vehicle from SLC-41 located in the northernmost section of CCAFS; or a Falcon Heavy launch vehicle from LC-39 located on the north end of Cape Canaveral at the Shuttle launch complex.

3.1.2 Air Resources

3.1.2.1. Climate

The climate of CCAFS and KSC is subtropical with short, mild winters and hot, humid summers, with no recognizable spring or fall seasons. Summer weather usually begins in April and prevails for about nine months of the year. During this period, dawns are normally slightly cloudy or hazy, with little wind and temperatures near 70 degrees Fahrenheit (°F). During the day, the temperature rises into the 80s and 90s °F. A typical day is mostly sunny, with scattered white clouds. Thundershowers tend to lower the local temperatures, followed by an ocean breeze. The dominant weather pattern (May to October) is characterized by southeast winds, which travel clockwise around the Bermuda High. The southeast wind brings moisture and warm air, which helps produce almost daily thundershowers creating a wet season. Approximately 70 percent of the average annual rainfall occurs during this period. Occasional cool days occur in November, with winter weather starting in January and extending through February and March. These last two months are usually windy with temperatures ranging from about 40°F at night to 75°F during the day. Weather patterns in the dry season (November to April) are influenced by cold continental air masses. Rains occur when these masses move over the Florida peninsula and meet warmer air. In contrast to localized, heavy thundershowers in the wet season, rains are light and tend to be uniform in distribution in the dry season (NASA 1979).

The main factors influencing climate at CCAFS and KSC are latitude and proximity to the Atlantic Ocean and the Indian and Banana Rivers, which moderate temperature fluctuations (NASA Technical Memorandum 1990). Results of the Cape Atmospheric Boundary Layer Experiment found that wind direction, especially the sea breeze front, is controlled by thermal differences between the Atlantic Ocean, Banana River, Indian River, and Cape Canaveral's land mass. Heat is gained and lost more rapidly from land than water. During a 24-hour period, water may be warmer and again cooler than adjacent land. Cool air replaces rising warm air creating offshore (from land to ocean) breezes in the night and onshore (from ocean to land) breezes in the day. These sea breezes have been recorded at altitudes of 3,281 feet (1000 m) and higher, and reach further inland during the wet season. Seasonal wind directions are primarily influenced by continental temperature changes. In general, the fall winds occur predominantly from the east to northeast. Winter winds occur from the north to northwest shifting to the southeast in the spring and then to the south in the summer months (NASA 1979).

3.1.2.2. Air Quality

CCAFS and KSC are located in an area classified as in attainment for all the Federal and state criteria pollutants listed in Table 3-1.

Table 3-1. State and Federal Ambient Air Quality Standards

Pollutant	Average Time	State of Florida Standard	Federal Primary NAAQS	Federal Secondary NAAQS
Carbon Monoxide	8-hour[a] 1-hour[a]	9 ppm 35 ppm	9 ppm 35 ppm	N/A N/A
Lead	Quarterly 3-Month	1.5 µg/m3 1.5 µg/m3	1.5 µg/m3 0.15 µg/m3[b]	1.5 µg/m3 0.15 µg/m3
Nitrogen Dioxide	Annual 1-hour[d]	0.053 ppm 0.10 ppm	0.053 ppm 0.10 ppm	0.053 ppm 0.10 ppm
Ozone	8-hour[h] 1-hour[i]	0.075 ppm N/A	0.075 ppm 0.12 ppm	0.075 ppm 0.12 ppm
Particulate Matter (PM10)	24-hour[e]	15 µg/m3	150 µg/m3	150 µg/m3
Particulate Matter (PM2.5)	Annual[f] 24-hour[g]	15 µg/m3 N/A	15 µg/m3 35 µg/m3	15 µg/m3 35 µg/m3
Sulfur Dioxide	Annual 24-hour[a] 1-hour[j] 3-hour	0.02 ppm 0.10 ppm N/A 0.5 ppm	0.03 ppm 0.14 ppm 0.075 ppm N/A	0.5 ppm 0.14 ppm N/A 0.5 ppm

Source: NASA 2010, NASA 2011, KSC 2013.

a. Not to be exceeded more than once per year. b. Final rule signed October 15, 2008. c. Annual mean. d. 98th percentile averaged over 3 years. e. Annual 4th highest daily maximum 8-hour concentration averaged over 3 years. f. Not to be exceeded more than once per year on average over 3 years. g. Annual mean averaged over 3 years. h. 99th percentile of 1-hour daily maximum concentrations averaged over 3 years. i. EPA revoked the 1-hour ozone standard in all areas, although some areas have continuing obligations under that standard ("anti-backsliding"); the standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is <1. j. The 3-year average of 99th percentile of daily maximum 1-hour average must not exceed 75 ppb.

3.1.2.3. Ozone Depleting Substances

The Clean Air Act amendments established a deadline of 2000 for the phase-out of the production of the Class I Ozone Depleting Substances (ODS) chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and 2002 for methyl chloroform. Under the Montreal Protocol, the U.S. must also phase-out its use of Class II ODS (hydrochlorofluorocarbons) by 2030.

In 1993, Executive Order 12843 directed Federal agencies to minimize the procurement of products containing ODS. The NASA policy requires that NASA minimize the procurement of ODS in anticipation of the phase-out of ODS production.

3.1.2.4. Risk Management Program 40 CFR 68

At KSC, monomethyl hydrazine (MMH) is the only listed regulated substance for accidental release prevention under its Risk Management Program (NASA 2010).

3.1.3 Noise

Ambient noise levels at CCAFS and KSC range from quiet (40 dBA) in isolated areas to 75 dBA or more due to infrequent launch activities, aircraft movement, and other support-related activities (NASA 1998). Noise generated at CCAFS and KSC by day-to-day operations, space vehicle launches, and Orbiter landings can be attributed to six general sources: (1) Orbiter re-entry sonic booms, (2) launches, (3) aircraft movements, (4) industrial operations, (5) construction, and (6) traffic noise (NASA 2010). The closest residential areas to CCAFS are to the south, in the cities of Cape Canaveral and Cocoa Beach. The closest residential area to LC-39 at KSC is to the west, in the city of Titusville. Infrequent aircraft fly-over and rocket launches from CCAFS and KSC would be expected to increase noise levels for short periods of time. The highest recorded levels were produced by launches of the Space Shuttle, which in the launch vicinity could exceed 160 dBA. Sonic booms produced during vehicle ascent typically occur over the Atlantic Ocean and are directed in front of the vehicle and do not impact land areas (USAF 1998, NASA 2011).

3.1.4 Soils and Geology

3.1.4.1. Soils

The KSC and CCAFS soil pattern is complex and not all of the same age. Soils on Cape Canaveral, False Cape, and the barrier island section on the east side of Mosquito Lagoon are younger than those of Merritt Island, and therefore have had less time to weather. Well-drained soil series (e.g., Palm Beach, Canaveral) in these areas still retain shell fragments in the upper layers, while those inland on Merritt Island (e.g., Paola, Pomello) do not. The presence of shell fragments influences soil nutrient levels, particularly calcium and magnesium, and pH.

Differences in age and parent material account for some soil differences, but on landscapes of Merritt Island with similar age, topography has a dramatic effect on soil formation. Relatively small elevation changes cause dramatic differences in the position of the water table that, in turn, affect leaching, accumulation of organic matter, and formation of soil horizons. In addition, proximity to the lagoon systems influences soil salinity.

Soils at CCAFS/KSC are highly permeable and allow water to quickly percolate into the ground and have a high buffering capacity (NASA 1998). No prime or unique farmland is present at CCAFS/KSC (USAF 1998).

3.1.4.2. Geology

The eastern edge of Merritt Island at its contact with the Mosquito Lagoon and the Banana River forms a relict cape aligned with False Cape. Multiple dune ridges represent successive stages in this growth. It is suggested that the geologic history of the Merritt Island-Cape Canaveral barrier island was complex. The western portion of

Merritt Island is substantially older than the east and erosion has reduced the western side to a nearly level plain (NASA 2010).

3.1.4.3. Seismology

Seismological investigations of the Cape Canaveral area include refraction surveys and well logs. Investigations, conducted by the Seismological Branch of the U.S. Coast and Geodetic Survey, showed that the Cape Canaveral underground structure is normal and free of voids or anomalies. The Florida Platform exhibits high seismologic stability with very few confirmed earthquakes (NASA 2010).

3.1.5 Water Quality

3.1.5.1. Surface Water Classification

The major water bodies surrounding KSC and CCAFS include the Atlantic Ocean and the inland estuary consisting of the Indian River, the Banana River, and the Mosquito Lagoon. The inland estuary has been designated as an Estuary of National Significance, and contains Outstanding Florida Waters (OFW) and Aquatic Preserves. Freshwater inputs to the estuary include direct precipitation, storm water runoff, discharges from impoundments, and groundwater seepage (NASA 2010).

Surface drainage within CCAFS launch areas is generally westward toward the Banana River. CCAFS/KSC launch areas do not lie within the 100-year floodplain and are not within a wetland (USAF 2002). LC-39A is also outside the 500-year floodplain (KSC 2013). There are no National or state-designated wild or scenic rivers on or near KSC or CCAFS (NPS 2005, FS 258.501).

3.1.5.2. Surface Water Quality

Surface water quality at CCAFS/KSC is considered to be generally good. Historically, the best areas of water quality are adjacent to the undeveloped areas of the lagoon, such as the north Banana River, Mosquito Lagoon, and the northernmost portion of the Indian River. However, since 2011, the overall water quality of the waters surrounding KSC has been markedly impacted. The likely cause for these impacts is related to the presence of two large and persistent algal blooms in the area. The first bloom occurred from early spring through late fall of 2011. This bloom covered a large portion of the northern Indian River Lagoon basin, mainly the Indian River lagoon proper and Banana River, and included the waters surrounding KSC. The second large bloom occurred during the summer of 2012. Unlike the bloom of 2011, which began in the Banana River Lagoon before spreading to the northern Indian River Lagoon and Mosquito Lagoon, the 2012 bloom started in the southern Mosquito Lagoon in July, then spread into the northern Indian River Lagoon. These blooms decreased water clarity and overall quality, which negatively impacted seagrass growth and distribution. The marked decline of seagrass (approximately 90%) during this bloom has been documented for much of the central Indian River and the majority of the Banana River, including the KSC long-term monitoring sites and the St John’s River Water Management District long-term seagrass sites (KSC 2013).

The Florida Department of Environmental Protection (FDEP), in compliance with the

Environmental Protection Agency (EPA) Numeric Criteria Standards for pollutants, has set total maximum daily loadings (TMDLs) for many impaired waters in the State. The following waters within the boundary or adjoining KSC are identified as impaired:

- Atlantic Ocean (Brevard County, Volusia County): mercury in fish tissue
- Indian River (Brevard County): mercury in fish tissue, copper, nickel, and nutrients
- Banana River (Brevard County): mercury in fish tissue and nutrients
- Mosquito Lagoon (Brevard County, Volusia County): mercury in fish tissue.

Basin Management Action Plans (BMAPs) addressing the first five years of a 15 year restoration period, for the Banana River Lagoon, and the North Indian River Lagoon have been developed and adopted. These BMAPs address nutrient and dissolved oxygen impairment (KSC 2013). In addition, a statewide TMDL for mercury has been adopted by the state of Florida and approved by the U.S. EPA (Gao 2014).

3.1.5.3. Groundwater Sources

There are three aquifer systems underlying CCAFS and KSC: the surficial aquifer system, the intermediate aquifer system, and the Floridan aquifer system. The surficial aquifer system, which is generally comprised of sand and marl, is under unconfined conditions and is approximately 21 m (68.9 ft) thick. The water table in the aquifer is generally 1 m (3.3 ft) or less below the ground surface. A confining unit composed of clays, sands, and limestone separates the surface aquifer from the underlying Floridan aquifer. The Floridan aquifer is the primary source of potable water in central Florida. These two main aquifers are separated by nearly impermeable confining units and contain three shallow aquifers referred to as the intermediate aquifer system. Groundwater in the Floridan aquifer at CCAFS and KSC is highly mineralized. CCAFS and KSC receive their potable water from the city of Cocoa, which utilizes water from the Floridan aquifer (USAF 1998).

3.1.5.4. Coastal Zone Management

NASA is responsible for making consistency determinations and obtaining concurrence from the respective state coastal zone management agency for NASA-approved or funded actions within the coastal zone. The USAF is responsible for making the coastal zone consistency determinations for its activities within the state. The Florida Department of Community Affairs reviews the coastal zone consistency determination (USAF 1998). The state of Florida's coastal zone includes the area encompassed by all of the state's 67 counties and its territorial seas.

Activities at CCAFS/KSC, which are likely to require consistency determinations with the state's Coastal Zone Management Program include: any project subject to state or Federal dredge and fill permitting review; any point or new non-point source discharge to surface waters; and major industrial expansion or development projects. Consistency review is typically addressed in NEPA documentation and submitted to the Governor's

Office for review via the Intergovernmental Coordination and Review Process (NASA 2010).

3.1.6 Biological and Natural Resources

Biological resources include native and introduced plants and animals within an area potentially affected by the proposed activity. These are divided into vegetation, wildlife, threatened or endangered species, and sensitive habitats. Sensitive habitats include, but are not limited to, wetlands, plant communities that are unusual or of limited distribution, and important seasonal use areas for wildlife. They also include critical habitat as protected by the Endangered Species Act and sensitive ecological areas as designated by state or federal rulings.

Because CCAFS and KSC are located near the coastline, the Marine Mammal Protection Act (MMPA) applies. The MMPA prohibits, with certain exceptions, the “take” of marine mammals in U.S. waters and by U.S. citizens on the high seas, and importation of marine mammals and marine mammal products into the United States. The term “take” means to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal (NASA 2011).

CCAFS and KSC occupy a combined total of about 62,753 hectares (ha) (155,066 ac) of coastal habitat on a barrier island complex that parallels Florida’s mid-Atlantic coast. The area of interest for biological resources consists of CCAFS and KSC, the adjacent Atlantic Ocean, and three major inland water bodies including the Banana and Indian Rivers and Mosquito Lagoon. The region has several terrestrial and aquatic conservation and special designation areas (e.g., wildlife management areas and aquatic preserves). These areas serve as wildlife habitat and occupy about 25 percent (about 405,000 ha (1,000,000 ac)) of the total land and water area within the region.

3.1.6.1. Vegetation, Wetland, and Wildlife Resources

At CCAFS/KSC, coastal scrub and associated woodlands provide habitat for mammals, including the white-tailed deer, armadillo, bobcat, feral hog, raccoon, long-tailed weasel, round-tailed muskrat, and the Florida mouse (a state species of special concern). Resident and migrating bird species include numerous common land and shore birds.

The most common types of wetlands and open water areas at CCAFS/KSC are mangrove wetlands, salt marshes, freshwater wetlands, brackish water impoundments, borrow pits, and drainage canal systems (USAF 2008).

Amphibians observed at CCAFS and KSC include the spade-foot and eastern narrow-mouth toads, squirrel and southern leopard frogs, and green tree frogs. Reptiles observed include the American alligator, the Florida box turtle, the gopher tortoise, the Florida softshell turtle, the green anole lizard, the six-lined racerunner lizard, the broadhead skink lizard, the southern ringneck snake, the everglades racer snake, the eastern coachwhip snake, and the mangrove salt marsh snake (NASA 2011).

3.1.6.2. Aquatic Resources

The aquatic environment surrounding CCAFS and KSC provides diverse fish habitat, which supports many shore bird species, and sport, commercial, and recreational

fishing. The Atlantic beaches at CCAFS, KSC, and the CNS are important to nesting sea turtles. The Mosquito Lagoon is considered one of the best oyster and clam harvesting areas on the east coast.

Marine mammals populate the coastal and lagoon waters, including the bottlenose dolphin, the spotted dolphin, and the manatee. The seagrass beds in the northern Indian River system provide important nursery areas, shelter, and foraging habitat for a wide variety of fish, invertebrates, and manatees. The inland rivers and lagoons provide habitat for marine worms, mollusks, and crustaceans. The Mosquito Lagoon is an important shrimp nursery area.

A number of saltwater fish species can be found within the Indian and Banana River systems, including the bay anchovy, pipefish, goby, silver perch, lined sole, spotted sea trout, and oyster toadfish. The small freshwater habitats found on CCAFS and KSC contain bluegill, garfish, largemouth bass, killifishes, sailfin molly, and top minnow (USAF 1998).

The Magnuson-Stevens Fishery Conservation and Management Act of 1976, as amended, mandates the conservation of essential fish habitat (EFH). Ocean waters off KSC have several areas designated as EFH that are of particular importance to sharks and other game fish, as well as several species of lobsters, shrimp, and crabs. These habitats include: sandy shoals of capes and offshore bars, high profile rocky bottom and barrier island ocean-side waters from the surf to the shelf break zone and from the Gulf Stream shoreward, including areas containing Sargassum plant species. In addition, the northern boundary of Oculina Bank, a unique strip of coral reefs not duplicated elsewhere on Earth, is located approximately 37 km (23 mi) off of Cape Canaveral. The entire reef is 145 km (90 mi) long. There are restrictions on many types of fishing in most of the area and fishing for snapper and grouper species is prohibited in part of the area (KSC 2013).

Regional Fishery Management Officials (FMOs) are responsible for designating EFH in their management plans for all managed species within the Exclusive Economic Zone (EEZ), which is a managed fisheries area that extends from the shoreline to 200 miles offshore along the coastline of U.S. waters. For the marine area surrounding CCAFS and PAFB, the South Atlantic Fishery Management Council (SAFMC) is the managing body. The SAFMC currently manages several types of organisms in the vicinity of Cape Canaveral and PAFB: the South Atlantic Snapper-Grouper complex, South Atlantic shrimps, Coastal Migratory Pelagic species, Highly Migratory species, Red Drum, Spiny Lobster, Golden Crab, Calico Scallop, and Sargassum. The National Marine Fisheries Service (NMFS) defines EFH for highly migratory species under its jurisdiction. Habitat Areas of Particular Concern (HAPCs) have also been designated within EFH areas; these are localized areas that are vulnerable to degradation or are especially important ecologically. HAPCs are located within the estuary systems of PAFB and CCAFS for penaid shrimp. The Oculina Bank near Cape Canaveral also serves as a HAPC for nursery habitat and refuge for rock shrimp (USAF 2008).

The USAF has a programmatic consultation in place with the NMFS on EFH regarding Atlas V and Delta IV launches from CCAFS (USAF 2000). Similar consultations for

commercial Falcon Heavy launches would be expected to be in place before a possible Mars 2020 launch.

3.1.6.3. Threatened and Endangered Species

The USFWS currently recognizes 112 endangered or threatened and 22 candidate animal and plant species in the state of Florida (FWS 2014). The state of Florida considers 118 animal species as threatened, endangered, or of special concern (FFWCC 2014) and 55 plant species as threatened or endangered (FDACS 2014) for the state. Table 3-2 provides a list of Threatened, Endangered and Candidate Species Occurring on or Around CCAFS and KSC.

CCAFS and KSC have management plans in place for conservation of threatened or endangered species (e.g., Scrub Jay Operational Management Plan, Sea Turtle Operational Management Plan, exterior lighting management plans to minimize impacts from nighttime lights on sea turtle nesting beaches, designated manatee refuges, and sanctuaries in selected inland waterways) (USAF 2001, USAF 2008). In addition to protection under the Endangered Species Act, the wood stork, piping plover, roseate tern, and Florida scrub jay receive protection under the Migratory Bird Treaty Act (MBTA) (NASA 2010).

Table 3-2. Threatened, Endangered, and Candidate Species Occurring or Potentially Occurring on or Around CCAFS and KSC, Florida

Common Name	Scientific Name	Federal Status	State Status
Plants			
Beach-star[a]	*Remirea maritima*	–	E
Coastal mock vervain[a]	*Glandulareia maritima*	–	E
Curtiss' milkweed[a]	*Asclepias curtissii*	–	E
Florida lantana[a]	*Lantana depressa var. floridana*	–	E
Hand fern[a]	*Ophioglossum palmatum*	–	E
Scaevola Inkberry[a]	*Scaevola plumieri*	–	T
Nakedwood, Simpson's Stopper[a]	*Myrcianthes fragrans*	–	T
Nodding pinweed[a]	*Lechea cernua*	–	T
Sand dune spurge[a]	*Chamaesyce cumulicola*	–	E
Satin-leaf[a]	*Chrysophyllum oliviforme*	–	E
Sea lavender[a]	*Argusia gnaphalodes*	–	E
Shell mound prickly-pear cactus[a]	*Opuntia stricta*	–	T
Reptiles and Amphibians			
American alligator	*Alligator mississippiensis*	T(S/A)	T(S/A)
Atlantic (Kemp's) Ridley sea turtle[*]	*Lepidochelys kempi*	E	E
Atlantic green turtle	*Chelonia mydas*	E	E
Atlantic saltmarsh snake[b]	*Nerodia clarkia taeniata*		T
Eastern indigo snake	*Drymarchon corais couperi*	T	T
Florida gopher frog	*Lithobates capito aesopus*	–	SSC
Florida pine snake	*Pituophis melanoleucus mugitus*	–	SSC
Gopher tortoise	*Gopherus polyphemus*	C	T

Common Name	Scientific Name	Federal Status	State Status
Hawksbill sea turtle*	*Eretmochelys imbricata*	E	E
Leatherback sea turtle	*Dermochelys coriacea*	E	E
Atlantic loggerhead sea turtle	*Caretta caretta*	T	T
Alligator Snapping Turtle[a]	*Macrochelys temminckii*		SSC
Birds			
American oystercatcher[a]	*Haematopus palliatus*	–	SSC
Black skimmer	*Rynchops niger*	–	SSC
Brown pelican	*Pelecanus occidentalis*	–	SSC
Florida scrub jay	*Aphelocoma coerulescens*	T	T
Least tern	*Sterna antillarum*	–	T
Little blue heron	*Egretta caerulea*	–	SSC
Piping plover	*Charadrius melodus*	T	T
Reddish egret	*Egretta rufescens*	–	SSC
Roseate spoonbill	*Ajaia ajaja*	–	SSC
Roseate tern[a]	*Sterna dougallii dougallii*	T	T
Snowy egret	*Egretta thula*	–	SSC
Southeastern American kestrel	*Falco sparverius paulus*	–	T
Tricolored heron	*Egretta tricolor*	–	SSC
White ibis	*Eudocimus albus*	–	SSC
Wood stork	*Mycteria americana*	E	E
Audubon's Crested Caracara[a]	*Poyborus plancus audubonii*		T
Snowy Plover[a]	*Charadrius alexandrinus*		T
Bald Eagle[b]	*Haliaeetus leucocephalus*	P	
Mammals			
Florida mouse	*Podomys floridanus*	–	SSC
Northern right whale*	*Eubalaena glacialis*	E	E
Southeastern beach mouse	*Peromyscus polionotus niveiventris*	T	T
West Indian manatee	*Trichechus manatus latirostris*	E	E
Fish			
Smalltooth Sawfish*	*Pristis pectinata*	E	E

Sources: NASA 2010; USAF 2007, Dankert 2014a

a. Only found at CCAFS.

b Not observed at CCAFS.

c Not observed at CCAFS, but known to occur in vicinity.

* Does not occur on CCAFS property but occurs in waters adjacent to and required to consult for potential impacts to these species from CCAFS actions.

Key: C = candidate for Federal listing; CCAFS = Cape Canaveral Air Force Station; E = endangered; SSC = State species of special concern; (S/A) = similarity of appearance to a listed species; T = threatened; P = Protected under the Bald and Golden Eagle Protection Act.

3.1.6.4. Sensitive Habitats

Sensitive habitats on CCAFS and KSC include wetlands, critical habitats for threatened and endangered species as defined by the Endangered Species Act, and the nearby CNS and MINWR. The MINWR contains a large number of manatees. Manatee critical

habitat, located in the Banana River system, includes the entire inland sections of the Indian and Banana rivers, and most of the waterways between the two rivers.

Legally designated critical habitat for the northern right whale (*Eubalaena glacialis*) is located along the CCAFS/KSC coast and extends east for 9.3 km (5.8 mi); right whales are occasionally observed between December and March (KSC 2013).

Threatened or endangered species that inhabit the scrubby flatwoods of Merritt Island include the Florida scrub jay and the eastern indigo snake. The southern bald eagle, a federally protected species under the MBTA, the Bald and Golden Eagle Protection Act and the Lacey Act, is also known to occur in this area (KSC 2013).

The Indian River Lagoon area (Indian River, Banana River, and Mosquito Lagoon) is home to more than 5,300 kinds of plants and animals. The lagoon has a gradation of brackish water to salt water where it opens to the ocean. It is listed as an Estuary of National Significance and contains more species than any other estuary in North America (2,965 animals, 1,350 plants, 700 fish, and 310 birds). It also provides important migratory bird habitat. The lagoon contains one of the highest densities of nesting turtles in the western hemisphere, is a rich fishery, and is used by up to one third of the United States' manatee population (USAF 1998).

The Atlantic beaches are important to nesting sea turtles. Disorientation of marine turtles related to lighting from nighttime space operations has occurred at CCAFS and KSC in the past; however, CCAFS and KSC both have a light management plan that addresses mitigation of impacts to nesting sea turtles during nighttime launches (USAF 2001, KSC 2013).

3.1.7 Socioeconomics and Children's Environmental Health and Safety

The surrounding counties of CCAFS and KSC include Brevard County, Flagler County, Indian River County, Lake County, Orange County, Osceola County, Polk Seminole County, and Volusia County. The socioeconomic resources in this region include the population, economy, transportation system, public and emergency services, and recreational opportunities. Under EO 13045, Protection of Children from Environmental Health Risks and Safety Risks, dated April 21, 1997, federal agencies are encouraged to consider potential impacts of proposed actions on the safety or environmental health of children. Socioeconomic resources and EO 13045 are discussed below.

3.1.7.1. Population

The census population in 2010 and projected populations for 2012 and 2020 for the nine-county region are presented in Table 3-3 (USBC 2013a). The city of Cape Canaveral is the nearest community to CCAFS and KSC, has a population of roughly 9,912 (2010), and is located on the south side of Port Canaveral. Titusville with 43,761 (2010) residents and Merritt Island with 34,763 (2010) residents are located to the west of CCAFS and KSC. In addition, Palm Bay and the Melbourne area, which are communities to the south of CCAFS, have populations between 80,000 and 100,000 (USBC 2013a).

People belonging to the following population groups reside within this region: white, black or African American, American Indian, Alaska native, Asian, native Hawaiian and other Pacific Islander, some other race, two or more races, and Hispanic or Latino (of any race) (USBC 2013c).

Table 3-3 presents the total population in 2010 and the projected total populations for 2012 and 2020 for each of the counties in the nine-county region. Table 3-4 presents the minority population in 2010 and the projected minority population for 2020 for the respective counties.

Table 3-3. Population of the Nine-County Region

Geographic Area	Census Population 2010	Projected Population 2012	Projected Population 2020
Florida	18,801,310	19,317,568	21,528,304
County			
Brevard	543,376	547,307	563,317
Flagler	95,696	98,359	109,773
Indian River	138,028	140,567	151,199
Lake	297,052	303,186	329,015
Orange	1,145,956	1,202,234	1,456,375
Osceola	268,685	287,416	376,341
Polk	602,095	616,158	675,772
Seminole	422,718	430,838	464,908
Volusia	494,593	496,950	506,491
Nine-County Region	4,008,119	4,123,015	4,633,191

Source: Adapted from USBC 2013a, c

Note: Projected population values do not represent absolute limits to growth. For any county, the future population may be above or below the projected value.

Table 3-4. Minority Population of the Nine-County Region

Geographic Area	Minority Population 2010	Percent Minority 2010	Projected Minority Population 2012	Projected Percent Minority 2012	Projected Minority Population 2020	Projected Percent Minority 2020
Florida	4,692,148	25.0%	4,575,052	23.7%	5,098,629	23.7%
County						
Brevard	92,449	17.0%	90,401	16.5%	93,046	16.5%
Flagler	16,986	17.7%	20,485	20.8%	22,862	20.8%
Indian River	21,682	15.7%	19,898	14.2%	21,403	14.2%
Lake	53,428	18.0%	49,126	16.2%	53,311	16.2%
Orange	417,161	36.4%	424,732	35.3%	514,516	35.3%
Osceola	78,044	29.0%	72,216	25.1%	94,559	25.1%
Polk	149,241	24.8%	129,743	21.1%	142,296	21.1%
Seminole	92,054	21.8%	82,176	19.1%	88,674	19.1%
Volusia	86,337	17.5%	83,324	16.8%	84,924	16.8%
Nine-County Region	1,007,382	25.1%	972,101	23.6%	1,115,591	24.1%

Source: Adapted from USBC 2013a, c

Note: Projected population values do not represent absolute limits to growth. For any county, the future population may be above or below the projected value.

According to the Council on Environmental Quality (CEQ 1997), people whose incomes are less than the poverty threshold are defined as low-income. Data from Census 2010 (USBC 2013a) shows that 13.7 percent of the population living within the nine counties reported incomes below the poverty threshold; percentages lower than reported by Florida (14.7 percent) and the United States (14.3 percent).

3.1.7.2. Economy

An estimated 1,858,000 people were employed in the nine-county region in 2012 with an estimated unemployment rate of 8.8 percent (BEBR 2014).

The region's economic base is tourism and manufacturing, with tourism attracting more than 20 million visitors annually. Multiple theme parks, along with KSC, are among the most popular tourist attractions in the state. In 2010, 1.5 million out-of-state tourists visited the KSC Visitor Complex (NASA 2010c). In addition, the cruise and cargo industries at Port Canaveral contribute to the central Florida economy.

Industrial sectors in the region that provided significant employment in 2000 included: education, health and social services; arts, entertainment, recreation, accommodation and food services; retail trade; and professional, scientific, management, administrative, and waste management services (USBC 2000c).

The employment pool at CCAFS includes about 10,000 military and civilian personnel, all associated with the USAF (USAF 2013). Military personnel are attached to the 45th Space Wing at Patrick Air Force Base (PAFB), which is approximately 32 km (20 mi) south of CCAFS. A majority of the employed are contractor personnel from companies associated with missile testing and launch vehicle operations.

In FY 2012, of the $17.8 billion NASA budget, $1.3 billion in wages and purchases within the state of Florida were made by KSC and other NASA centers. For every dollar spent directly by NASA, about an additional dollar was added to the Florida economy, resulting in a total economic impact of $2.15 billion for the state. In addition to the jobs directly associated with KSC (2,100 government workers and 4,900 contractor employees) an additional 16,500 jobs are supported. While the overall NASA impact was significantly lower in FY 2012 from its FY 2009 peak, KSC remains the major economic driver in Brevard County (NASA 2012b). The gross state product of the overall economic activity of Florida for 2012 is estimated to be over $777 billion (BEA 2013).

3.1.7.3. Transportation Systems

The nine-county region is supported by a network of Federal, state and county roads; rail service; three major airports; and a sea port with cargo and cruise terminals (USAF 2002). CCAFS has a runway for government aircraft, delivery of launch vehicle components, and air freight associated with the operation of CCAFS launch complexes.

3.1.7.4. Public and Emergency Services

Emergency medical services for CCAFS and KSC personnel are provided at the Occupational Health Facility and Emergency Aid Clinic at KSC. These facilities are staffed by medical personnel specially trained in the treatment of hazards associated

with the facilities and operations at CCAFS and KSC. A Memorandum of Understanding for emergency treatment has been established with a network of hospitals in the region (NASA 2010).

Fire protection at KSC/CCAFS includes a comprehensive program of fire protection engineering, fire prevention, fire suppression and emergency response operations. Specialized equipment and training, suited to the potential fire and emergency hazards of operations, are provided. Three fire stations, one located in the Shuttle Landing Facility/Vehicle Assembly Building Area, one at Pads 39A and 39B, and the other located in the Industrial Area, provide effective coverage for all of KSC/CCAFS. Coordination support agreements between KSC/CCAFS and local municipalities provide for reciprocal support in the event of an emergency or disaster (NASA 2010).

Security forces maintain road access control gates and patrol the KSC/CCAFS perimeter boundary and have coordination agreements to support local municipalities in the event of an emergency or disaster. CCAFS and the Brevard County Office of Emergency Management have agreements for communications and early warning in the event of a launch accident (NASA 2010).

Range Safety at CCAFS monitors launch surveillance areas to ensure that risks to people, aircraft, and surface vessels are within acceptable limits. Control areas and airspace are closed to the public as required. The USAF is responsible for disseminating a “Notice to Aviators” through the Federal Aviation Administration (FAA); and air traffic in a FAA-designated area around the launch corridor is controlled. The USAF also ensures that a “Notice to Mariners” is disseminated within a predetermined impact debris corridor beginning 10 working days prior to a launch. The U.S. Coast Guard transmits marine radio broadcast warnings to inform vessels of the effective closure time for the sea impact debris corridor. Warning signs are posted in various Port Canaveral areas for vessels leaving port (USAF 2004). In addition, PAFB maintains an Internet website and toll-free telephone number with launch hazard area information for mariners and restricted airspace information for pilots.

CCAFS/KSC obtain their potable water from the city of Cocoa water system. The water distribution systems at CCAFS and KSC are sized to accommodate the short-term high-volume flows required for launches

3.1.7.5. Recreation

There is an abundance of public recreational opportunities in the Nine-County Region with beaches, waterways, lakes, open land, and parks. Within the confines of CCAFS, access to recreational areas and facilities is limited to CCAFS personnel.

3.1.7.6. Protection of Children from Environmental Health Risks and Safety Risks

The nearest location to the proposed launch areas containing a moderate concentration of children is the KSC Child Development Center located at least 9.6 km (6.0 miles) away. This is a childcare center with pre-school service available for children ages six weeks to five years old. There are no other schools, daycare facilities, playgrounds, or other places where children are concentrated within CCAFS/KSC.

3.1.8 Cultural and Historic Resources

Cultural resources include prehistoric and historic sites, archeological sites, structures/buildings, districts, historic landscapes, objects, artifacts, cemeteries, traditional cultural properties, sacred sites, monuments and memorials, or any other physical evidence of human activity considered important to a culture or community for scientific, traditional, religious, or any other reasons.

Eighty-eight archaeological sites have been identified on CCAFS and 24 have been determined eligible for listing in the National Register of Historic Places (NRHP) but have not currently been listed. There are numerous historic properties on CCAFS (over 100) including seven cemeteries/grave sites. In addition, there are six CCAFS contributing facilities listed as National Historic Landmarks (NHLs). Four are launch complexes and two are NASA property (LC-5/6 and part of LC-19) and, therefore, are not under the jurisdiction of CCAFS.

At CCAFS, a number of launch pads are listed on the NRHP and form a National Historic Landmark District. No NRHP-listed or eligible prehistoric or historic archaeological sites have been identified at either SLC-37 or SLC-41. However, the north and south area of SLC-41 is considered a “high” zone of archeological potential (Dankert 2014b).

In 1973, LC-39 became the first NASA site at KSC to be listed in the NRHP. The nomination highlighted the national significance of those principal facilities associated with the Apollo Manned Lunar Landing Program. LC-39, built between November 1962 and October 1968, was evaluated as significant in the areas of architecture, communications, engineering, industry, science, transportation, and space exploration (NASA 2010).

As of January 2014, a total of 103 historic properties have been identified within KSC, including 8 historic districts, 32 individually listed or eligible properties, and 69 resources that are contributing to a historic district, but not individually eligible (Dankert 2014b).

3.1.9 Hazardous Materials and Hazardous Wastes

3.1.9.1. Hazardous Materials Management

Numerous types of hazardous materials are used to support the missions and general maintenance operations at CCAFS and KSC. Management of hazardous materials, excluding hazardous fuels, is the responsibility of each individual or organization. Each organization has a supply organization and uses a “pharmacy” control approach to track hazardous materials and to minimize hazardous waste generation, thereby minimizing the use of hazardous materials. The PAFB supply system is the primary method of purchasing or obtaining hazardous materials. Resource Conservation and Recovery Act (RCRA) requirements are accomplished by the directives listed in the respective permits issued to KSC/CCAFS as per 45th SW Operation Plan (OPLAN) 32-3 and Kennedy NASA Procedural Requirement (KNPR 8500.1) (NASA 2010). Liquid propellants would be stored in tanks near the launch pad within appropriate cement containment basins and would be managed by a Launch Service Provider.

3.1.9.2. Hazardous Waste Management at CCAFS

Typical hazardous wastes at CCAFS include various solvents, paints and primers, sealants, photograph-developing solutions, adhesives, alcohol, oils, fuels, and various process chemicals (USAF 1998). Individual contractors and organizations maintain hazardous waste satellite accumulation points (SAPs) and 90-day hazardous waste accumulation areas. A maximum of 208 liters (55 gal) per waste stream of hazardous waste can be accumulated at a SAP. There is no limit to the volume of waste that can be stored at a 90-day accumulation area, but wastes must be taken to the permitted storage facility or disposed of offsite within 90 days. The permitted storage facility (RCRA Part B Permit, Number HO01-255040) is operated within Buildings 44200/44205. The facility is permitted to store hazardous wastes for up to 1 year under the current Florida Department of Environmental Protection (FDEP) permit and is operated by the launch base support contractor. However, the permit does not allow the waste storage site facility to store waste hydrazine, MMH, or nitrogen tetroxide (NTO) (NASA 2011). The 45th SW OPLAN 19-14, Petroleum Products and Hazardous Waste Management Plan, outlines specific measures for proper collection, and management and disposal of petroleum products/waste and hazardous/non-hazardous wastes. In the event of a spill, 45th SW OPLAN 10-2, Vol. 2, 45th SW Hazardous Material Response Plan provides for appropriate reporting and emergency response to mitigate environmental and human health impacts (USAF 2008).

3.1.9.3. Hazardous Waste Management at KSC

The main facility operating under the permitted KSC Transportation, Storage, and Disposal Facility (TSDF) is the Hazardous Waste Storage Facility (K7- 0164 and K7-0165) in the LC-39 area, which handles liquid and solid hazardous wastes. There are four cells at this facility each of which is designated and designed for the storage of specific hazardous wastes. Wastes permitted to be stored include the following: flammable, organic, toxic waste; caustic, toxic, reactive wastes; acidic waste; and solid hazardous and controlled wastes.

The quantity of hazardous and controlled waste generated at KSC depends on launch processing, construction and associated support activities. As part of KSC's waste management and pollution prevention programs, opportunities for waste prevention and reduction are continually assessed and implemented where cost-effective (NASA 2010).

3.1.9.4. Hazardous Waste Clean up

Solid Waste Management Unit (SWMU) 008

LC-39A has been designated as SWMU 008. RCRA Facility Investigation (RFI) activities were performed at LC-39A from early 1998 through mid-2000. In a portion of the site, groundwater impacts due to volatile organic compounds (VOCs) were observed and polycyclic aromatic hydrocarbons (PAHs), pentachlorophenol, and 2, 4, and 6-trichlorophenol were detected above maximum contaminant levels and groundwater cleanup target levels (GCTLs) have been established. Surface water inside and outside of the perimeter fence contained PAHs and metals above surface water cleanup target levels (SWCTLs); some pesticides were also detected outside the fence line. An interim

measure was conducted in 2000, which removed soils contaminated with polychlorinated biphenols (PCBs) and PAHs (KSC 2013).

Supplemental RFI activities were performed from mid-2000 through early 2003 to further evaluate the extent of contamination and potential ecological risks to the environment. As a result, groundwater at LC-39A will not be used as a future source of drinking water. Groundwater from the pad area discharges to surrounding surface waters, which are classified as OFW and, therefore, must not receive discharges of contaminants above background levels. A Corrective Measures Study (CMS) work plan has been developed to address groundwater contamination at LC-39A. Metals are present in the swale sediments and a CMS was recommended to evaluate means for controlling potential off-site migration of these contaminants. There are several contaminants in site soils that pose an unacceptable risk to future potential residents. Restrictions are in place for any site work to prevent soils from leaving the area from which they were excavated. An interim measure was completed in 2009 for trichloroethylene-contaminated soils in the area west of the LOx tank. This activity included excavation and disposal of 382 m^3 (500 cubic yards) of contaminated soil. A groundwater plume has been identified in the northwest portion of the pad and is under investigation (KSC 2013).

Sitewide soil and groundwater sampling at various intervals was conducted between December 2011 and October 2012 to determine current baseline conditions and further evaluate contamination resulting from former launch activities. The investigation confirmed the presence of VOCs in groundwater at concentrations greater than FDEP GCTLs. Soils were found to exceed the industrial soil cleanup target levels (SCTLs) for PAHs and PCBs. Additional soil areas have one or more chemicals of concern that exceed residential SCTLs. These contaminants include arsenic, barium, copper, nickel, thallium, PAHs, and PCBs (KSC 2013).

3.1.9.5. Pollution Prevention

CCAFS has a Pollution Prevention Program Guide (PPPG) and Pollution Prevention Management Action Plan. The PPPG establishes the overall strategy, delineates responsibilities, and specifies objectives for reducing pollution of the ground, air, surface water, and groundwater (USAF 1998).

KSC has established a Pollution Prevention Working Group to review all aspects of the KSC Pollution Prevention Program and to identify areas for additional pollution prevention activities. The team consists of KSC and contractor personnel. The NASA Acquisition Pollution Prevention Office assists KSC and other NASA centers in identifying, validating, and implementing less hazardous materials and processes (NASA 2011).

3.1.10 Health and Safety

The areas in and around CCAFS and KSC that could be affected by payload processing, transport, and launch are the subject of health and safety concerns. The objective of the Range Safety Program is to ensure that the general public, launch area personnel, foreign landmasses, and launch area resources are provided an acceptable

level of safety, and that all aspects of prelaunch and launch operations adhere to public laws. Range Safety organizations review, approve, monitor, and impose safety holds, when necessary, on all prelaunch and launch operations.

Hazardous materials, such as propellant, ordnance, chemicals, and booster/payload components, are transported in accordance with U.S. Department of Transportation regulations for interstate shipment of hazardous substances (Title 49 CFR 100-199). Hazardous materials, such as liquid rocket propellant, are transported in specially designed containers to reduce the potential risk of an unintentional release should an accident occur (USAF 1998).

3.1.10.1. Regional Safety

Prior to launch of a mission using MMRTGs or LWRHUs, a comprehensive set of plans would be developed by NASA to ensure that any launch accident could be met with a well-developed and tested response. NASA's plans would be developed in accordance with the National Response Framework (NRF) (DHS 2013) and the NRF Nuclear/Radiological Incident Annex (DHS 2008), combined with the efforts of the U.S. Department of Homeland Security (DHS), DHS's Federal Emergency Management Agency, DOE, the U.S. Department of Defense (DoD), the U.S. Department of State (DOS), the U.S. Environmental Protection Agency (EPA), the state of Florida, Brevard County, and local organizations. These organizations and other Federal agencies, as appropriate, could be involved in response to a radiological emergency. Future radiological contingency planning and implementation would be expected to be similar to the process used for the 2011 MSL mission launch (Scott 2012).

3.1.10.2. On-Station Safety

Launches are postponed if Range Safety models predict undue hazards for persons and property due to potential dispersion of hazardous materials or propagation of blast overpressure in the event of a launch vehicle flight termination. The 45th SW has prepared detailed procedures to be used to control toxic gas hazards. Atmospheric dispersion computer models are run to predict toxic hazard corridors (THCs) for both normal and aborted launches, as well as spills or releases of toxic materials from storage tanks, or during loading or unloading of tanks. Range Safety uses the THCs to reduce the risk of exposure of CCAFS and KSC personnel and the general public to toxic materials, including toxic gases.

For a NASA launch, the Launch Disaster Control Group is a joint NASA/USAF emergency response team formed prior to each launch and situated at a fallback location to coordinate emergency response (USAF1998).

The KSC Environmental Justice Plan (KSC 2010) was developed by the Environmental Office in 1997 and was updated in 2010. The purpose of the Environmental Justice Plan is to ensure KSC identifies and addresses activities which have disproportionately high adverse human health or environmental effects on minority or low-income populations in the surrounding Kennedy Space Center community and that the community participates in developing policies to prevent these effects.

KSC is committed to ensuring that the goals of Environmental Justice Strategy are met. Moreover, KSC will continue to communicate with and seek the input of local communities through public meetings, material distributions, information repositories, community events, open houses, press releases and public education campaigns. To ensure that members of the community are well informed of potential adverse environmental impacts from KSC activities, a mailing list with the names of local officials, community leaders, public interest groups, interested individuals, media, and community organizations was compiled. The mailing list is updated as changes are reported (NASA 2010).

3.1.11 Aesthetics

NASA considers the extent to which any lighting or other visual impacts associated with an action would create an annoyance among people in the vicinity or interfere with their normal activities. Visual and aesthetic resources refer to natural or developed landscapes that provide information for an individual to develop their perceptions of the area. Areas such as coastlines, national parks, and recreation or wilderness areas are usually considered to have high visual sensitivity. Heavily industrialized urban areas tend to be the areas of the lowest visual sensitivity. The existing conditions at KSC are characterized as having low visual sensitivity, because the site is currently an industrialized area that supports rocket launches. Notable visual structures include the lightning protection towers at LC-39B. Due to the flat topography and height of the lightning towers (approximately 161 m (528 ft)), the lightning protection towers can be seen several miles away. Existing light sources at KSC include nighttime security lighting at the launch complexes and buildings. NASA has guidelines to address the light impacts to wildlife species under the KSC Light Management Plan (NASA 2002, KSC 2013).

3.2 THE GLOBAL ENVIRONMENT

In accordance with Executive Order 12114, *Environmental Effects Abroad of Major Federal Actions*, this section provides a general overview of the global environment. Basic descriptions of the troposphere and stratosphere, global population distribution and density, distribution of land surface types, and a brief discussion of background radiation and the global atmospheric inventory of plutonium are included.

3.2.1 Troposphere

The troposphere is the atmospheric layer closest to the Earth's surface where all life exists and virtually all weather occurs. It extends from the Earth’s surface to a height of about 6 to 10 km (20,000 to 33,000 ft) (the lower boundary of the stratosphere). The atmosphere above 900 m (3,000 ft) includes the free troposphere ranging from 900 m (3,000 ft) to between 2 and 10 km (6,600 to 33,000 ft) in altitude and the stratosphere extending from 10 km (33,000 ft) to 50 km (164,000 ft). These boundaries should be taken as approximate annual mean values as the actual level of the boundary between the troposphere and stratosphere (tropopause) is variable on a seasonal and day-to-day basis (NASA 2011).

In general, the troposphere is well mixed and aerosols are removed in a short period of time (ranging from a few days to a few weeks) as a result of both the mixing within this layer and scavenging by precipitation. Removal of most emissions from rocket exhaust products from the troposphere occurs over a period of less than one week, thereby preventing a buildup of these products on a global level (USAF 1998).

The upper (free) troposphere is characterized by vigorous mixing driven by convective upwelling, horizontal and vertical winds, as well as transport and washout of gases that have been introduced into this region by industrial sources. This layer does not contain any uniquely important atmospheric constituents and it does not generally influence air quality in the lower troposphere (i.e., atmospheric boundary layer (ABL)). The air temperature of the ABL decreases with increasing altitude until it reaches the inversion layer where the temperature increases with increasing altitude. The ABL is considered the most important boundary layer with respect to the emission, transport, and dispersion of airborne pollutants. The part of the ABL between Earth's surface and the bottom of the inversion layer is known as the mixing layer. Almost all of the airborne pollutants emitted into the ambient atmosphere are transported and dispersed within the mixing layer. Some of the emissions penetrate the inversion layer and enter the free troposphere above the ABL.

Concentrations of gases and particles emitted into the free troposphere by transient sources, such as launch vehicles, are quickly diluted to very low levels before they can be deposited onto or transported near the ground by precipitation or strong down-welling events (NASA 2011).

3.2.2 Stratosphere

The stratosphere extends from the tropopause up to an altitude of approximately 50 km (31 mi or 164,000 ft). In general, vertical mixing is limited within the stratosphere, providing little transport between the layers above (mesosphere) and below (troposphere). The lack of vertical mixing and exchange between these layers provides for extremely long residence times, on the order of months, causing the stratosphere to act as a reservoir for certain types of atmospheric pollution (USAF 1998).

The stratospheric ozone absorbs most of the most harmful ultraviolet (UV-B) radiation from the sun. Depletion of ozone following the introduction of man-made materials can result in an increase in solar UV on the ground, which can pose a serious ecological and health hazard. The importance and global nature of the ozone layer requires a careful consideration of all sources of disturbance (NASA 2011).

Solid and liquid rocket propulsion systems emit a variety of gases and particles directly into the stratosphere (WMO 1991). A large fraction of these emissions, carbon dioxide (CO_2) for example, is chemically inert and does not affect ozone levels directly. Other emissions, such as hydrogen chloride (HCl) and water, are not highly reactive, but have an impact on ozone since these gases participate in chemical reactions that help determine the concentrations of the ozone-destroying radical gases. A small fraction of rocket engine emissions are highly reactive radicals. Particulate emissions, such as aluminum oxide powder and carbon (soot), may mimic or enhance the role of natural stratospheric particles by enabling or enhancing ozone-related chemical reactions.

Greenhouse gases absorb the radiant energy from the Sun and Earth. Some of the greenhouse gases (e.g., CO_2, chlorofluorocarbons (CFCs), and water) are emitted during the processes of preparing for and launching spacecraft. Other gases (e.g., NOx and VOCs) emitted from these processes contribute indirectly by forming ozone and other reactive species that photochemically react with greenhouse gases and control the radiation's penetration to the troposphere. Greenhouse gases are thought to potentially have a negative effect on the ozone protective layer of the atmosphere. Research on greenhouse gas production (and possible effects of certain related pollutants, such as pollutants contributing to global warming) is ongoing by the EPA and some states.

The Montreal Protocol is designed to protect the stratospheric ozone layer by phasing out production and consumption of substances that deplete the ozone layer. Measurements have shown that atmospheric concentrations of ozone-depleting substances are decreasing, indicating that emissions have been greatly reduced (EPA 2003).

3.2.3 Orbital Re-entry Debris

Space debris can be classified as either natural or man-made objects. The measured amount of man-made debris equals or exceeds that of natural meteoroids at most low-Earth orbit altitudes (i.e., below 2,000 km (1,200 mi)). Man-made debris consists of material left in Earth orbit from the launch, deployment, deactivation, and fragmentation of spacecraft and launch vehicle components. It exists at all inclinations and has the greatest density at Low Earth Orbit altitudes of approximately 800 to 1,000 km (500 to 625 mi) (UN 1999). Orbital debris moves in many different orbits and directions, at velocities ranging from 3 to over 8 km/s (1.9 to over 5 mi/s) relative to Earth (NASA-HDBK 8719.14).

Reentry debris would include non-recoverable items from launch activities such as jettisoned vehicle stages, as well as recoverable items like solid rocket boosters and manned spacecraft. Impacts from recoverable and non-recoverable components from launch activities are typically planned to occur in broad ocean areas cleared of shipping or air traffic. Reentry is controlled by Range Safety and efforts would be coordinated to reduce the risk to shipping lanes and ensure vessel activity would be outside the launch and reentry zone (NASA 2013a).

There are two issues of note in evaluating orbital and reentry debris. The first is the physical reentry of foreign objects and the resulting noise, contact force, and settling of the debris. The second is the potential for hazardous materials that may be contained in or on the debris.

There are four statutes relating to marine debris: 1) the Marine Plastic Pollution Research and Control Act; 2) the Marine Debris Research, Prevention, and Reduction Act (MDRPRA); 3) the Shore Protection Act; and 4) the Marine Protection, Research, and Sanctuaries Act which regulates the ocean disposal of hazardous waste. The most applicable law governing reentry boosters is the MDRPRA. This Act tasks NOAA and the U.S. Coast Guard to assess, reduce, and prevent marine debris and its adverse impacts on the marine environment and navigation safety (NASA 2013a).

Space programs managed by U.S. Government organizations are directed to follow the U.S. Government Orbital Debris Mitigation Standard Practices. Commercial operations are addressed in regulations by the Department of Transportation, the Department of Commerce, and the Federal Communications Commission.

3.2.4 Global Population Distribution

The distribution of the Earth's population is an important characteristic in considering the potential consequences of accident scenarios. For this purpose, global population statistics and other information are distributed among equal-sized areas (cells) of the Earth's surface. The cells are derived by first dividing the Earth from pole to pole into 20 latitude bands of equal area. Each latitude band is then segmented into 36 equal-sized cells, for a total of 720 cells. Each cell covers an area of 708,438 square kilometers (273,529 square miles) (HNUS 1992).

The total population of the Earth in 2020 is projected to be approximately 7.7 billion people (Lipinski 2014a). Table 3-5 lists the estimated global distribution of the projected population in 2020 across each of the 20 equal-area latitude bands. The greatest population densities occur in a relatively narrow grouping of the five northern bands between latitudes 44° north and 11° north (bands 4 through 8). Florida lies within latitude band 6. Due to launch azimuth angle constraints, launches from CCAFS/KSC to other solar system objects (e.g., planets such as Mars) would partially circle the Earth between 28° north and 28° south latitudes (bands 6 through 15) before departing for interplanetary space.

Table 3-5. Global Population and Surface Characteristics by Latitude Band

Latitude Band	Latitude Range, degrees	Band Population Estimate for 2020, millions	Band Surface Fractions			
			Water	Land	Land Rock Fraction	Land Soil Fraction
1	90N – 64N	5.5	0.7332	0.2668	1.0[a]	0.0[a]
2	64N – 53N	201	0.4085	0.5915	1.0[a]	0.0[a]
3	53N – 44N	597	0.4456	0.5544	0.251[a]	0.749[a]
4	44N – 36N	1020	0.5522	0.4478	0.251	0.749
5	36N – 30N	1250	0.5718	0.4282	0.153	0.847
6	30N – 23N	1490	0.6064	0.3936	0.088	0.912
7	23N – 17N	764	0.6710	0.3290	0.076	0.924
8	17N – 11N	618	0.7514	0.2486	0.058	0.924
9	11N – 5N	562	0.7592	0.2408	0.077	0.923
10	5N – 0	188	0.7854	0.2146	0.084	0.916
11	0 – 5S	217	0.7630	0.2370	0.044	0.956
12	5S – 11S	303	0.7815	0.2185	0.055	0.945
13	11S – 17S	113	0.7799	0.2201	0.085	0.915
14	17S – 23S	118	0.7574	0.2426	0.089	0.911
15	23S – 30S	136	0.7796	0.2204	0.092	0.980
16	30S – 36S	78	0.8646	0.1354	0.112	0.888
17	36S – 44S	20	0.9538	0.0462	0.296	0.704
18	44S – 53S	1.0	0.9784	0.0216	0.296[a]	0.704[a]
19	53S – 64S	0.3	0.9930	0.0070	1.0[a]	0.0[a]
20	64S – 90S	--	0.3863	0.6137	1.0[a]	0.0a

Sources: Population estimates from Lipinski 2014a; Surface characteristics adapted from HNUS 1992

(a) Assumed values
Note: N = North Latitude, S = South Latitude

3.2.5 Earth Surface Characteristics

The worldwide distribution of surface types is also an important characteristic in considering the potential consequences of accident scenarios. Table 3-5 also provides a breakdown of the total land fraction for each of the 20 latitude bands (HNUS 1992). The total land fraction was further subdivided by the fraction consisting of soil or rock cover. For the most densely populated bands (bands 4 through 8), the land fraction varies from about 25 percent in band 8 to about 45 percent in band 4, and is predominately soil (from about 75 percent in band 4 to about 92 percent in bands 7 and 8).

3.2.6 Background Radiation

3.2.6.1. Natural and Manmade Sources

The general population is exposed to various sources of natural and human-made radiation. These sources are divided into six broad categories: (1) cosmic radiation (from space), (2) external terrestrial radiation or groundshine (from naturally occurring radiation in rocks and soil), (3) internal radiation (from inhalation or ingestion), (4) consumer products (from smoke detectors, airport x-ray machines, televisions), (5) medical diagnosis and therapy (e.g., diagnostic x-rays, nuclear medical procedures), and (6) other sources (e.g., nuclear power plants, transportation).

Dose is the amount of ionizing radiation energy deposited in body tissues via various exposure pathways and is expressed in units of measurement called rem, (Roentgen equivalent in man). An average person in the United States receives a total dose of about 0.31 rem per year from all natural sources (see Table 3-6).

The average dose from man-made sources is also about 0.31rem. Exposure to radon, the largest component of natural background radiation, accounts for about 74 percent or 0.23 rem of the yearly total natural dose received. Exposure to cosmic and terrestrial radiation collectively is about 16 percent of the yearly total natural dose. The dominant contributor to the man-made dose is from medical uses, nuclear medicine, and medical procedures. The dose from these two sources has increased dramatically in recent years with the increase in the use of technologies such as computed tomography (commonly referred to as CT scans). A single CT scan can result in a dose of anywhere between 0.1 and 2 rem. For perspective, a simple chest x-ray results in a dose of about 0.002 rem, and about 0.065 rem is received from a diagnostic pelvic and hip x-ray. Not everyone is subject to exposure and subsequent dose from the medical sources; the dominant contributor to man-made background doses. There is a wide disparity in the background dose to people who receive medical doses and those that don’t.

Table 3-6. Average Annual Effective Dose Equivalent of Ionizing Radiation to a Member of the U.S. Population

Source	Effective Dose Equivalent[a]	
	rem per year	percent of total
Natural		
Radon[b]	0.229	37
Cosmic	0.032	5
Terrestrial	0.019	5
Internal	0.031	5
Subtotal — Natural	0.310	50
Manmade		
Medical procedures	0.223	36
Nuclear medicine	0.074	12
Consumer products	0.012	2
Industrial	<0.6	0.1
Subtotal — Manmade	0.310	50
Total Natural and Manmade	**0.620**	**100**

Source: NRC 2011

(a) Effective dose equivalent is proportional to incremental risk in cancer.

(b) Dose equivalent to bronchi from radon decay products. The assumed weighting factor for the effective dose equivalent relative to whole-body exposure is 0.08.

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Due to its low elevation, Florida receives less exposure to cosmic radiation than most parts of the country (HPS 2014). Assessments performed by the U.S. Geological Survey and the U.S. Environmental Protection Agency indicate that KSC, CCAFS, and adjacent communities have a low potential for geologic radon (USGS 1995). In other categories of background radiation exposure, Florida is consistent with the national average.

3.2.6.2. Worldwide Plutonium Levels

Plutonium-238 (Pu-238) exists in the environment as a result of atmospheric testing of nuclear weapons and a 1964 launch accident. The following information provides a perspective against which to compare the scope of postulated incremental releases of plutonium from potential mission accidents.

Between 1945 and 1974, aboveground nuclear weapons tests released about 440,000 curies (Ci) of plutonium to the environment (AEC 1974). About 97 percent (approximately 430,000 Ci) of this plutonium was Pu-239 and Pu-240, essentially identical isotopes with respect to chemical behavior and radiological emission energies. The remainder consists primarily of Pu-238 (approximately 9,000 Ci), along with much smaller amounts of Pu-241 and Pu-242. (Some of the Pu-238 and Pu-241 have decayed since the time of release.) About 9,000 Ci of Pu-238 was released to the atmosphere from weapons tests.

The 1964 reentry and burn-up of a Systems for Nuclear Auxiliary Power (SNAP)-9A radioisotope thermoelectric generator (RTG) released 17,000 Ci of Pu-238 into the atmosphere. This release occurred because the RTG design philosophy of the time was to not contain the plutonium. Since 1964, essentially all of the Pu-238 released from SNAP-9A has been deposited on the Earth's surface (AEC 1974). About 25 percent (approximately 4,000 Ci) of that 1964 release was deposited in the northern hemisphere, with the remaining 75 percent settling in the southern hemisphere. In April 1986, approximately 369,000,000 Ci of various radioisotopes were released to the environment from the Chernobyl nuclear power station accident (IAEA 2005a). Approximately 400 Ci of the total Chernobyl release was Pu-238.

The total plutonium released to the ocean environment by overseas nuclear reprocessing plants between 1952 and 1992 was more than 100,000 Ci (Gray et al. 1995), of which approximately 3,400 Ci was Pu-238 (Gray et al. 1995; IAEA 2005b; OSPAR 2005), bringing the total amount of Pu-238 dispersed into the environment to about 38,800 Ci.

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4. ENVIRONMENTAL CONSEQUENCES

This chapter of the Mars 2020 mission Draft Environmental Impact Statement (DEIS) presents information on the potential environmental impacts of launching the proposed mission. The evaluations presented in this DEIS; based on representative configurations of Atlas V, Delta IV, and Falcon Heavy launch vehicles; were completed prior to NASA's selection of the launch vehicle for the Mars 2020 mission. NASA considers these evaluations to adequately bound the potential environmental consequences of the alternatives described in this DEIS. If new and or significant information becomes available, NASA would evaluate the need for additional environmental analysis and documentation.

The potential environmental impacts of launching the proposed Mars 2020 mission are expected to be similar in nature to those evaluated in the *Mars Science Laboratory Mission Final Environmental Impact Statement* (MSL FEIS) (NASA 2006). The proposed Mars 2020 mission would be launched on a similar medium to large expendable launch vehicle, resulting in similar normal launch and launch accident non-radiological impacts. The Mars 2020 spacecraft for the proposed action would be essentially identical to the MSL spacecraft and have a similar Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) as a power source. Therefore, it is expected that the radiological impacts of accidents would also be similar to those evaluated in the MSL EIS. Mars 2020 mission-specific nuclear risk analyses have been performed by the Department of Energy (DOE) for both the MMRTG-powered alternative and the solar power augmented with Light-Weight Radioisotope Heater Unit (LWRHU) alternative. These analyses evaluated the impacts of launch accidents using representative configurations of the Atlas V and Delta IV launch vehicles proposed for the Mars 2020 mission and the results are reported in the *Nuclear Risk Assessment for the Mars 2020 Mission Environmental Impact Statement* (SNL 2014).

The MMRTG hardware has already been manufactured and assembled by industry under contract to DOE; those flight units are in bonded storage at the contractor facility. Testing and fueling of the MMRTGs would be done by DOE at existing facilities. The plutonium dioxide would be formed into pellets suitable for use in an MMRTG or LWRHU at DOE's Los Alamos National Laboratory (LANL) in New Mexico. The pellets would be encapsulated in an iridium cladding at LANL. The encapsulated pellets would then be shipped to Idaho National Laboratory (INL) in Idaho for final MMRTG assembly and testing. The LWRHUs have already been manufactured; final assembly of the LWRHUs occurred at LANL. DOE would then transport the MMRTG or LWRHUs to the appropriate launch site. The impacts of these activities have been addressed in existing DOE environmental documentation (DOE 1993, 2000, 2002b, 2008, 2013).

DOE's process for preparing an MMRTG for the proposed Mars 2020 mission would be very similar to the process they used in preparing nearly identical MMRTGs for the MSL and Pluto New Horizons missions. The environmental impacts of preparing an MMRTG by the DOE for the Mars 2020 mission have already been evaluated in existing DOE NEPA documents. The plutonium that would be used for an MMRTG for the Mars 2020 mission was previously purchased from Russia and is in secure storage vaults at DOE facilities. As stated y the terms of the purchase agreement with Russia, plutonium can

only be used for peaceful space exploration missions. The stockpiled plutonium would be fabricated into fueled clads at the Los Alamos National Laboratory (LANL). (The potential impacts of that process are described in the LANL Site-Wide EIS (DOE 2008).) The fuel clads would then be securely shipped to the Idaho National Laboratory (INL) for integration into MMRTG assemblies. The potential impacts of that process have been described in the LANL Site-Wide EIS and other specific DOE NEPA documents addressing portions of the MRTG fabrication process (DOE 2002b, 2008). The DOE found that the principal environmental impacts — shipping the plutonium in various forms, fabricating the plutonium into fueled clads, then fabricating the clads into an MMRTG, and shipping to CCAFS—are the generation of solid radioactive wastes and potential external radiation exposure to DOE facility radiation workers. Radioactive wastes would be generated at LANL and INL. Most of the radioactive wastes would be in the form of plutonium-contaminated solid wastes called transuranic (TRU) wastes. Production of an MMRTG for a potential Mars 2020 mission would temporarily increase radioactive wastes generated annually by LANL and INL and routinely shipped for ultimate deep geologic disposal at the DOE Waste Isolation Pilot Plant facility in New Mexico. The generation, handling, transportation, and disposal of these wastes have been described and impacts evaluated in multiple DOE NEPA documents (DOE 1993, 2000, 2002b, 2008, 2013). Since the production of an MMRTG for the proposed Mars 2020 mission would use similar steps, processes, and facilities as that followed for recent space missions, no new environmental impacts would be expected.

The discussion of the environmental impacts associated with Alternatives 1, 2, and 3 are separated into four categories of impacts:

- Environmental impacts associated with preparation for launch,
- Environmental impacts associated with a normal (successful) launch,
- Non-radiological impacts associated with launch accidents, and
- Radiological impacts associated with launch accidents.

The impacts associated with the first two categories would occur with every launch. The impacts from the second two would be seen only if there were to be a failure of the launch vehicle that results in an accident either with or without the release of radioactive material. For the three alternatives, the environmental impacts associated with preparation for a launch, a normal launch, and the non-radiological impacts of a launch accident would be the same for that launch system with or without radiological materials on a rover. These impacts are discussed in Section 4.1 for the Proposed Action, Alternative 1, Section 4.2, Environmental Impacts of Alternative 2, and Section 4.3, Environmental Impacts of Alternative 3.

4.1 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION (ALTERNATIVE 1)

Under Alternative 1, NASA proposes to continue preparations for and to implement the Mars 2020 mission. The proposed Mars 2020 mission would include an autonomous rover that would perform science operations on the surface of Mars. One MMRTG would provide the necessary electric power to operate the Mars 2020 rover and its science instruments. The Mars 2020 spacecraft would be launched on an Atlas V, a

Delta IV Heavy, or a Falcon Heavy launch vehicle (see Section 2.1.5) from SLC-41, SLC-37, or LC-39A, respectively, at CCAFS/KSC.

Sections 4.1.1 and 4.1.2 present the environmental impacts of preparing for launch and the environmental impacts resulting from a normal launch event, respectively. These impacts were addressed in the MSL EIS (NASA 2006), the *Final Environmental Assessment for Launch of NASA Routine Payloads on Expendable Launch Vehicles* (Routine Payload EA) (NASA 2011), the PEIS MEP (NASA 2005a), *Environmental Assessment for Falcon 9 and Falcon 9 Heavy Launch Vehicle Programs from Space Launch Complex 4 East Vandenberg Air Force Base California (*USAF 2011), and the *Final Supplemental Environmental Assessment to the November 2007 Environmental Assessment for the Operation and Launch of the Falcon 1 and Falcon 9 Space Vehicles At Cape Canaveral Air Force Station Florida (SpaceX 2013b)*. The USAF has assessed environmental impacts of Atlas V and Delta IV launches through 2020 based upon an annual average launch rate of 10 launches and 11 launches, respectively, from CCAFS (USAF 2000). Launch of the Mars 2020 mission would be included in and not increase this previously approved launch rate. Launch of a Falcon Heavy was addressed in the Routine Payload EA (NASA 2011) and the environmental impacts are expected to be similar to that of an Atlas V or Delta IV launch vehicle.

The potential non-radiological environmental impacts of a launch accident are discussed in Section 4.1.3. Section 4.1.4 addresses radiological impacts, which may result from a launch accident.

4.1.1 Environmental Consequences of Preparing for Launch

Launch processing activities for the Mars 2020 mission would be subject to Federal, state, and local environmental laws and regulations; and USAF and NASA regulations and requirements (see Section 4.9). All CCAFS/KSC launch sites have established plans to implement these regulations, including hazardous materials management plans and hazardous waste disposal plans. Responsibilities and procedures for management of hazardous materials and hazardous wastes (HM/HW) are clearly defined in those operating plans. Processing facilities must prepare and retain a written contingency plan and emergency procedures for responding to emergencies involving hazardous materials. In addition, all proposed processing facilities and launch sites have active pollution prevention programs to reduce the use of hazardous materials and generation of hazardous waste.

Spacecraft and launch vehicle processing at CCAFS or KSC would involve a number of industrial activities that include the use of hazardous materials, and would generate hazardous wastes, other solid and liquid wastes, and air emissions. Such hazardous materials would include but not be limited to acetone, chromate conversions coating, denatured alcohol, epoxy, flux, inks, lacquer, paints, propellants, oils, solvents, primers, sealants, and other process chemicals.

NASA or its contractors would acquire the required hazardous materials for the Mars 2020 mission use and would properly dispose of any generated hazardous wastes. If the Mars 2020 spacecraft uses an MSL heritage cooling system, it would contain about 5 liters (1.3 gallons) of trichlorofluoromethane (also known as Freon-11), a Class I ODS,

as the coolant circulated in stainless steel tubing for spacecraft thermal control. Freon-11 would be loaded into the spacecraft via a closely monitored, closed-loop system that would minimize the possibility of a significant portion of the substance escaping to open atmosphere.

CCAFS, KSC, NASA, and NASA Launch Service (NLS) contractors must adhere to established programs for pollution and spill prevention. Airborne emissions from liquid propellant loading and off-loading of spacecraft and launch vehicles are closely monitored using vapor detectors. Systems for loading hypergolic fuels (fuels which ignite spontaneously when mixed with an oxidizer) also use air emission controls (USAF 1998). Liquid hypergolic fuels make up the largest proportion of hazardous materials used in processing spacecraft and these propellants are extremely hazardous and toxic. However, they are transported and controlled by the facility propellant contractor and are not stored at the processing facilities. Each facility that is permitted to process hypergolic propellant transfers is configured to manage hypergolic propellants and waste products in accordance with Federal, state, and local regulations (NASA 2011).

Some spacecraft and launch vehicle integration personnel would be exposed to very low doses of radiation (substantially below regulatory limits) during pre-launch testing and integration of the MMRTG to the Mars 2020 spacecraft. Integration and launch processing activities involving ionizing and non-ionizing radiation at KSC and CCAFS are subject to extensive review and authorization of all activities by the local radiation protection authority prior to initiation of any operation. Such operations are actively monitored by launch site radiation safety personnel to ensure adherence to approved operating and emergency procedures and to maintain operational personnel exposures at levels that are as low as reasonably achievable (USAF 1999, NASA 2001).

The hazardous materials used to process spacecraft and launch vehicles could potentially generate hazardous waste. Liquid and solid waste would be generated almost exclusively from fuel and oxidizer transfer operations. Processing of launch vehicles would increase hazardous waste production at CCAFS/KSC launch sites by very small percentages. The spacecraft and launch vehicle contractors would be responsible for identifying, containing, labeling, and accumulating the hazardous wastes in accordance with all applicable Federal, state, and local regulations. All hazardous wastes generated from spacecraft and launch vehicle processing would be transported, treated, stored, and disposed of by the responsible base contractor (NASA 2011).

Due to extensive HM/HW management programs and established safety programs, processing the spacecraft and the launch vehicle for the Mars 2020 mission is not expected to cause adverse environmental impacts.

DOE’s preparation of an MMRTG for the proposed Mars 2020 mission would be very similar to their process in preparing the nearly identical MMRTG for the MSL mission. The environmental impacts of preparing an MMRTG by the DOE for the Mars 2020 mission have already been evaluated in existing DOE NEPA documents (DOE 1993, 2000, 2002, 2002b, 2008, 2013).

4.1.2 Environmental Impacts of a Normal Launch

Environmental impacts of a normal launch of the Mars 2020 mission on an expendable launch vehicle would be associated with airborne exhaust emissions from propellant combustion, hazardous materials usage, hazardous waste generation, and wastewater generation.

4.1.2.1. Land Use

The proposed processing and launch of spacecraft would not include any new construction or modification of facilities or roadways that would potentially impact land resources. Processing activities would take place within closed structures, and precautions would be taken to prevent spills and control hazardous materials in accordance with facility operating plans. Spills of liquid propellants would be controlled through catchment systems and holding tanks in the processing facilities and would not impact surrounding soils or land use resources (NASA 2011).

Processing and launch of the Mars 2020 mission on either an Atlas V, Delta IV, or Falcon Heavy would be consistent with the designated land uses of CCAFS and KSC; and no impacts to land use resources are anticipated (USAF 2001, NASA 2002b, NASA 2005a, NASA 2006, NASA 2011).

4.1.2.2. Air Quality

Inadvertent releases of toxic air contaminants are possible as a result of improper handling of hazardous materials during payload processing, transportation, and launch. During payload processing and transportation, the largest releases would result from the spillage of the entire quantity of liquid propellants. CCAFS and KSC have safety procedures in place to ensure that these events are unlikely to occur and all spills must be managed in accordance with existing Spill Prevention, Control, and Countermeasures (SPCC) plans. Liquid propellants would be stored in tanks near the launch pad and within cement containment basins designed to retain 110 percent of the storage tank volume. Propellant spills from the launch vehicle would be channeled into sealed concrete catchment basins and disposed of according to appropriate Federal and state regulations. Propellant loading operations would be postponed if Range Safety models predict that a potential propellant spill would result in a toxic hazard to the public or unprotected personnel (NASA 2011).

ODSs may be used in fully self-contained spacecraft cooling systems. Any ODS use would be accomplished in accordance with Federal, state, and local laws regulating ODS use, reuse, storage, and disposal. Release of materials other than propulsion system exhaust would be limited to inert gases. Preparation of rocket vehicles would not result in a release of ODSs into the atmosphere (NASA 2011).

Rocket launches can cause short-term impacts on local air quality from routine launch vehicle exhaust emissions. After ignition of the first stage and the first few seconds of liftoff through launch vehicle ascent, the exhaust emissions would form a buoyant cloud at the launch pad. This high-temperature cloud would rise quickly and stabilize at an altitude of several hundred meters near the launch area. The cloud would then dissipate through mixing with the atmosphere. The exhaust products would be distributed along

the launch vehicle's trajectory as the vehicle moves through the atmosphere. Airborne emissions from a normal launch of the Mars 2020 mission at CCAFS/KSC would not be expected to result in adverse impacts to the public (USAF 1998, USAF 2000, NASA 2005a, NASA 2006, NASA 2011). The nearest residential areas to SLC-37, LC-39A, or SLC-41 are about 10 to 20 kilometers (km) (6 to 12 miles) in the cities of Merritt Island to the southwest, Cape Canaveral and Cocoa Beach to the south, and Titusville to the west.

First-stage liquid propellant engines that use rocket propellant-1 (RP-1) and liquid oxygen (LOx), such as the Atlas V and Falcon Heavy, would primarily produce carbon monoxide (CO), carbon dioxide (CO_2), and water vapor as combustion products. First-stage liquid propellant engines that use liquid hydrogen (LH_2) and LOx, such as the Delta IV, would produce water vapor. Solid propellant, consisting of ammonium perchlorate, aluminum powder, and hydroxyl-terminated polybutadiene (HTPB) binder in the solid rocket boosters (SRBs) of the Atlas V, would primarily produce aluminum oxide (Al_2O_3) particulates, CO, hydrogen chloride (HCl), and nitrogen (N_2). Under the high temperatures of the SRB's exhaust, the CO would be quickly oxidized to CO_2, and the N_2 may react with ambient oxygen to form nitrogen oxides (NO_X). Most of these emissions would be removed from the atmosphere over a period of less than one week, yielding no long-term accumulation of these products (USAF 1998).

No short- or long-term air quality impacts are expected as a result of the handling and usage of liquid propellants and ODSs during a normal launch. Previous analyses have shown that emissions from a normal launch of an Atlas V with SRBs would not create short- or long-term adverse impacts to air quality in the region (USAF 2000, NASA 2005a, NASA 2011). The same result would be expected from the launch of a Delta IV Heavy or Falcon Heavy rocket. Section 4.1.2.14 discusses local as well as global ozone impacts.

4.1.2.3. Noise

Noise impacts may be considered substantial if (1) the proposed action substantially increases the ambient noise level for adjoining areas, and (2) the increased ambient noise affects the use of the adjoining areas. NASA, the FAA, and USAF carefully consider the potential impacts from noise, (including sonic boom) on workers and the public as well as environmental resources including endangered species, marine mammals, historic structures, or any other protected property (NASA 2011).

The processing of the proposed spacecraft would not produce any substantial amount of noise outside of the processing facilities. The facilities employed for spacecraft processing, however, may generate moderate amounts of industrial noise due to operating machinery, generators, public address systems, and similar typical industrial systems. All such systems are subject to occupational safety and health regulations, and hearing protection would be utilized if and when required. The standard for noise, such as from generators, is based on the Noise Control Act of 1972 (P.L. 92-574), as amended. State and local standards serve as a guide if these are at least as stringent as Federal standards (NASA 2011).

Noise impacts associated with launches occur due to sound from the launch pad from ignition through lift-off. Increased noise levels would occur for only a short period (typically less than two minutes) during the vehicle's early ascent, and diminish rapidly as the vehicle gains altitude and moves downrange offshore (USAF 1998).

Non-essential workers would not be present in the launch area during the Mars 2020 liftoff, and those essential workers remaining in the area would be exposed to noise levels anticipated to be below Occupational Safety and Health Administration (OSHA) regulations for unprotected workers (140 A-weighted decibels (dBA) maximum and 115 dBA over a 15-minute average). While some area residents may be momentarily annoyed by noise during the Mars 2020 launch, such noise would be transient and would not be expected to exceed the EPA maximum 24-hour average exposure level of 70 dBA[12] for the general public and would therefore present no health hazard (NASA 2005a).

Sonic booms would be generated by the normal launch of the Mars 2020 mission, but would occur offshore over the Atlantic Ocean and no adverse impact to human populations would be expected. Ships and other vessels in the area would be warned in advance of the launch event and would not be adversely affected (USAF 1998).

Florida scrub jays and southeastern beach mice occur in the vicinity of launch facilities at CCAFS and KSC. A small potential exists that individuals of these species would be directly impacted by noise from launch operations. Previous environmental analyses concluded that impacts on these species are expected to be minimal. The behavior of scrub jays observed after Delta, Atlas, and Titan launches has been normal, indicating no noise-related effects (Schmalzer 1998, NASA 2011).

Sonic booms created by launches from CCAFS/KSC would occur over the open Atlantic Ocean. Typically, marine species in the ocean's surface waters are present in low densities (although spring and fall migration will see periodic groups of migrating whales that follow the coastline), and the sonic boom footprint lies over 48 km (30 mi) from CCAFS/KSC. Therefore, sonic booms from launches are not expected to adversely affect the survival of any marine species (USAF 1998, NASA 2011).

4.1.2.4. Geology and Soils

For the Atlas V with SRBs, the Mars 2020 launch would result in deposition of solid rocket exhaust products, consisting primarily of Al_2O_3 particulates and HCl, onto soils.

During a Delta II launch on November 4, 1995, pH in the surrounding air was monitored to detect any changes caused by HCl vapors or deposition. Test strips were placed at the perimeter of the launch pad and launch conditions were calm, which would yield maximum HCl deposition. No pH changes were observed on any test strips, and there was no evidence of acid deposition. The lack of pH changes associated with the small

[12] For comparison, a typical household vacuum cleaner generates about 70 dBA at a distance of 3 m (10 ft); the sound level in a quiet bedroom at night is about 30 dBA (USAF 1998).

ground cloud indicates that even with exposure to the concentrated cloud, acid deposition would be minimal (USAF 1996b, NASA 2011).

Soils typically contain a substantial amount of organic matter, which results in a natural buffering capacity that would potentially counteract the effects of any HCl they receive. The soils of the barrier islands in this region are alkaline with high buffering capacity (Schmalzer 1998). For example, despite additions of substantial amounts of acidic deposition from 43 launches over a 10-year period, the affected soils at CCAFS showed no decrease in buffering capacity. The HCl content of the exhaust plume from SRBs would not be expected to adversely affect soils around launch sites at any of the proposed launch sites. In addition, aluminum oxide would not affect the soils because it would be deposited as a stable compound. Therefore, no measurable direct or indirect, short- or long-term effects on soil chemistry would be expected as a result of launch activities (USAF 1998, NASA 2011).

4.1.2.5. Water Quality

Impacts on water resources may be considered significant if processing or launch activities interfere with surface water drainage, exceed the capacity of regional water supply systems, or result in degradation of surface water or groundwater quality such that existing water uses would be impaired.

Processing activities would take place within existing structures and precautions would be taken to prevent and control spills of hazardous materials. Large spills of spacecraft liquid propellant would be controlled through catchment systems in the processing facilities. All chemicals used for processing would be managed to prevent contamination of surface waters and groundwater.

Large quantities of water are used during launch of an Atlas V, a Delta IV, or a Falcon Heavy for cooling, acoustic damping, post-launch wash-down, fire suppression, and potable uses. The city of Cocoa, which pumps water from the Floridan aquifer, is contracted to supply water to CCAFS and KSC, and has sufficient capacity to supply sources to meet usage demands for launch of the Mars 2020 mission. Water used at the launch complex during launch would be collected and treated, if necessary, prior to being released to the CCAFS/KSC industrial wastewater treatment plant. At KSC, well water is also used for some industrial purposes, including service to the LOx storage tanks at LC-39A (KSC 2013).No short- or long-term environmental impacts from contaminated wastewater are expected as a result of normal launch operations.

Short-term acidification of surface water could result from contact with the launch exhaust cloud and through HCl fallout from the exhaust cloud. Wet deposition of HCl may also occur during simultaneous rainfall. Impacts on surface waters would be restricted to the area immediately adjacent to the launch pad. No substantial impacts on surface waters of nearby oceans, lagoons, or large inland water bodies should occur due to their buffering capacity. A short-term decrease in pH could occur in small streams and canals near the launch pad. Since there would only be a temporary decrease in pH, aluminum oxide deposition should not contribute to increased aluminum solubility in area surface waters (Schmalzer 1998, NASA 2011). A normal launch would have no substantial long-term impacts on the local water quality.

Under normal flight conditions, vehicle stages that do not reach orbit have trajectories that result in ocean impact. Stages that reach initial orbit would eventually reenter the atmosphere as a result of orbital decay. Corrosion of stage hardware would contribute various metal ions to the water column. Due to the slow rate of corrosion in the deep-ocean environment and the large quantity of water available for dilution, toxic concentrations of metals are not likely to occur.

The relatively small amounts of propellant left in the vehicle stages that impact the ocean could release solid and liquid propellants into the water column; however this release would be slow, with potentially toxic concentrations occurring only in the immediate vicinity of the propellant. Insoluble fractions of RP-1 propellant would float to the surface and spread rapidly to form a localized surface film that would evaporate. Hydrazine fuels are soluble and would also disperse rapidly. Because of the small amount of residual propellants present, and the large volume of water available for dilution, no long-term adverse impacts to hydrology or surface water quality would be expected from a normal launch of the Mars 2020 mission (USAF 1998, NASA 2005a, NASA 2011).

4.1.2.6. Offshore Environment

Offshore environments at CCAFS/KSC would receive jettisoned launch vehicle sections in pre-approved drop zones (see Section 4.1.2.11). Small amounts of residual propellants associated with these launch vehicle sections would be released to the surrounding water. Metal parts would eventually corrode, but toxic concentrations of the metals would be unlikely because of the slow rate of the corrosion process and the large volume of ocean water available for dilution (USAF 1998, NASA 2005a). In this regard, there would be no short- or long-term effects of jettisoned launch vehicle sections on offshore environments.

4.1.2.7. Biological Resources

Impacts to biological resources may be considered significant if processing and launch activities could materially impact a threatened or endangered species or critical habitat, substantially diminish habitat for a plant or animal species, substantially diminish a regionally or locally important plant or animal species, interfere substantially with wildlife movement or reproductive behavior, and/or result in a substantial infusion of exotic plant or animal species.

Launch vehicle processing would occur in existing facilities and payloads would be transported on existing roadways. Adjacent habitats would not be disturbed. Exterior lighting at all facilities used for spacecraft processing at CCAFS/KSC would comply with established lighting policy for minimizing disorienting effects on sea turtle hatchlings.

Biological resources may be impacted due to launch activities in terms of the following categories: (1) exhaust emissions directly at the launch pad that remain and are deposited in the area, (2) near-field impacts from the exhaust cloud (generally within 500 m (1,640 ft)) but sometimes up to 1 km (0.62 mi) from the pad, and (3) impacts from far-field deposition of the buoyant portion of the launch cloud (more than a few km from the launch pad).

The near-field impacts from an exhaust cloud depend primarily on the amount of sound-suppression water (its evaporation lowers the temperature and the altitude of the exhaust cloud) and on the time the launch vehicle remains near the launch pad during ascent. The observations of near-field impacts from previous launches have been well documented based on years of launching the space shuttle and expendable launch vehicles. For launch of the space shuttle, observations have included destruction of sensitive plant species followed by re-growth during the same growing season and 2 to 3 days drop in pH (a measure of acidity/alkalinity) in nearby waters (down to 1 m (3.3 ft) which have resulted in fish kills in nearby shallow surface waters. This was followed by a return to normal pH levels. There was also a possibility of death of fauna, including burrowing animals, in the path of the exhaust cloud. These near-field impacts from exhaust clouds were observed at distances up to a few hundred meters from the launch pad, well within launch site boundaries, and did not reach human populations offsite (NASA 2007, NASA 2011).

Minor brush fires are infrequent byproducts of launches and are usually contained and limited to vegetation within the launch complexes. HCl deposition could be created by rain falling through the SRB exhaust cloud. Wet deposition of HCl on leaves has been observed to persist on leaf surfaces for considerable periods; no mortality of these plants and no changes in plant community composition or structure have been observed in the far field related to launch effects (NASA 2007).

The U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) have previously reviewed NEPA documentation for the Atlas and Delta launch vehicles at CCAFS/KSC and have specified required launch restrictions and other impact mitigation measures. Any additional permits, permit modifications, and/or mitigation measures based on selection of the Falcon Heavy rocket will be obtained/addressed by CCAFS/KSC prior to implementation of the proposed action.

Unlike the experience with space shuttle launches, exhaust plumes from solid and liquid propellants produced by expendable launch vehicles such as the Delta and Atlas launch vehicles have not produced substantial acidification and have not resulted in recorded fish kills to date. Without substantial acidification of surface waters, any aluminum oxide deposited in surface waters would remain insoluble and nontoxic to the biota. No animal mortality has been observed at CCAFS/KSC that could be attributed to Delta and Atlas launches (Schmalzer 1998, NASA 2011)

In summary, biological resources are not expected to be adversely affected by the Mars 2020 launch except for short-term effects on fauna and flora in the immediate vicinity of the launch complex. Impacts to vegetation from other launch vehicles have been observed up to about 800 meters (2,625 feet) from the launch pads. Acidic deposition from solid propellant exhaust products and high temperatures from the exhaust cloud could damage or kill biota within the immediate vicinity of the launch pad; however, long-term population effects on terrestrial biota would not be expected. Jettisoned launch vehicle sections that land in the ocean would be subject to corrosion and release of residual propellant. However, it is unlikely that these vehicle sections would have an adverse impact on marine species (USAF 1996a, NASA 2005a, NASA 2006, NASA 2011).

During the launch, wildlife in the vicinity of the launch site would be temporarily disturbed due to noise, generally amounting to a startle effect. Because launches are infrequent events, no long-term impacts would be anticipated on wildlife and marine species from noise from the Mars 2020 launch (NASA 2005a).

No adverse impacts on threatened or endangered species would be expected from a normal launch. Observations of conditions at launch facilities provided evidence that the extent of impacts from similar launches have been minimal to threatened/endangered species located near the launch complex (USAF 2000). Launch of the Mars 2020 mission would not interfere with CCAFS/KSC management of Florida scrub jay habitat. CCAFS/KSC have a light management plan that addresses mitigation of impacts to nesting sea turtles during nighttime launches and the plan would be implemented should the Mars 2020 launch occur at night (USAF 2001).

4.1.2.8. Socioeconomics and Children's Environmental Health and Safety

Launch of the proposed Mars 2020 mission from CCAFS/KSC would be part of the normal complement of launches. Thus, a single launch would result in negligible impacts to socioeconomic factors such as demography, employment, transportation, and public or emergency services.

The only location where children are concentrated in the vicinity of the proposed launch areas is at the KSC Child Development Center, which is more than 9.6 km (6.0 mi) from any of the launch sites. Children at the Center may be exposed to increased noise levels during launches. However, noise levels are expected to be greatly diminished at that distance from the launch pad. Estimates of sound levels that the KSC Child Development Center would experience during a launch event with either of the potential Mars 2020 launch vehicles would be comparable to that previously evaluated for an Ares 1 or Ares V launch, which were estimated to result in the rise of daycare center exterior sound levels to 80 or 90 dBA. The interior sound levels at this time may differ from 10 to 15 dBA less than the exterior. The duration of these increased sound levels, both interior and exterior, would be less than 30 seconds (NASA 2007c). These sound levels would be shorter in duration and lower in frequency than experienced during the use of gas-powered mowers maintaining the grounds at the KSC Child Development Center. Therefore, the proposed action would not pose disproportionately high or adverse short- or long-term impacts to children's environmental health or safety (NASA 2013a).

4.1.2.9. Cultural/Historic/Archaeological Resources

Impacts on cultural resources could be considered substantial if the proposed action results in disturbance or loss of values or data that qualify a site for listing in the National Register of Historic Places (NRHP); substantial disturbance or loss of data from newly discovered properties or features prior to their recordation, evaluation and possible treatment; or substantial changes to the natural environment or access to it such that the practice of traditional culture or religious activities would be lost.

The proposed action would use existing facilities for payload processing, existing roadways for payload transportation, and existing launch facilities. No new facilities are

proposed and no new construction or modifications to existing facilities would be required for the proposed action. There would be no effect on buildings, structures, objects, districts, or sites such as LC-39A that are listed or eligible for listing in the NRHP. New facilities or modifications to existing facilities required to support near-term Falcon Heavy operations at KSC/CCAFS are expected to be in place with multiple Falcon Heavy launches occurring prior to the proposed Mars 2020 mission. In addition, there is a programmatic agreement between KSC, the Advisory Council on Historic Places and the Florida State Historic Preservation Officer regarding management of historic properties at KSC (NASA 2005a, 2010, 2011). No short- or long-term impacts would occur to cultural, historic, or archeological resources as a result of a normal launch.

4.1.2.10. Hazardous Materials and Hazardous Waste

Hazardous materials and solid wastes are controlled in accordance with federal and state regulations. CCAFS and KSC have established procedures to implement these regulations. All hazardous material releases must be reported to the Florida Department of Environmental Protection (FDEP). All hazardous waste must be properly containerized, stored, labeled, manifested, shipped, and disposed of in full regulatory compliance. Any hazardous materials remaining after completion of processing would be properly stored for future use or disposal in accordance with applicable regulations.

The processing of a launch vehicle at a launch site requires the use of hazardous materials and results in the production of hazardous wastes. Impacts due to use of large quantities of hazardous materials and creation of large quantities of hazardous waste could be significant; however, through the use of established hazardous material management and pollution prevention procedures the amounts would be minimized to the greatest extent possible. Hazardous materials and hazardous waste impacts from launch and launch vehicle processing are therefore considered minimal (KSC 2013).

With the proper procedures and safeguards in place, it is not expected that soil, water or groundwater impacts would be caused by operations associated with handling hazardous materials or the production and handling of hazardous waste during a normal launch phase. In this regard, no short- or long-term impacts are expected.

4.1.2.11. Health and Safety

At CCAFS/KSC, procedures would be in place for the Mars 2020 mission launch operations, and would include considerations for a normal launch, launch-related accidents, fire protection, alarm, fire suppression, flight termination, and explosive safety (USAF 1998, USAF 2000). Using procedures established for existing launch systems, risks to installation personnel and the general public would be minimized to acceptable levels during both a normal and aborted launch in accordance with the most current USAF's *Range Safety User Requirements Manual* (USAF 2004).

Regardless of the launch vehicle selected, Range Safety at CCAFS/KSC would use models to predict launch hazards to the public and to launch site personnel prior to the launch. The most substantial potential health hazard during a normal Mars 2020 launch would be exposure to HCl emitted from the Atlas V SRBs if the Atlas V is selected as

the launch vehicle. These models calculate the risk of injury resulting from toxic exhaust gases from normal launches and from potentially toxic concentrations due to a failed launch. The launch would be postponed if the predicted collective public risk of injury from exposure to toxic exhaust gases exceeds acceptable limits (USAF 2004). This approach takes into account the exhaust plume's concentration, direction, and dwell time; and emergency preparedness procedures (USAF 2000).

CCAFS/KSC Range Safety would monitor launch surveillance areas to ensure that risks to people, aircraft, and surface vessels are within acceptable limits. For the Mars 2020 mission, a launch trajectory would be created and modified to ensure safety on the ground and at sea, and control areas and airspace would be closed to the public as required. The underlying areas at risk from falling debris or jettisoned stages would be cleared until all launch operations are completed. The SRB casings of the Atlas V would land closest to shore, in pre-approved drop zones centered at distances of approximately 230 km (143 mi) from shore. The strap-on common booster cores (CBCs) of the Delta IV and the boosters of the Falcon Heavy would land in pre-approved drop zones farther from shore. Finally, the payload fairing sections and the first stage would land much farther from shore, also in pre-approved drop zones (USAF 2000). These distances would be highly dependent on the specific Mars 2020 launch vehicle, its launch trajectory characteristics, and other factors such as wind effects.

The USAF would disseminate a Notice to Aviators through the Federal Aviation Administration (FAA); and air traffic in a FAA-designated area around the launch corridor would be controlled. Radar surveillance for intruding aircraft within a 50 nautical mile (93 km, 58 miles) radius of the launch site would be conducted beginning 30 minutes prior to the scheduled launch and continue until the launch is complete. The USAF also would ensure that a Notice to Mariners within a predetermined impact debris corridor is disseminated 10 working days prior to launch. The U.S. Coast Guard would transmit marine radio broadcast warnings to inform vessels of the effective closure time of the sea impact debris corridor. Warning signs would be posted in various Port Canaveral areas for vessels leaving port (USAF 1998). In addition, Patrick Air Force Base would maintain a website and toll-free telephone number with launch hazard area information for mariners and restricted airspace information for pilots.

4.1.2.12. Environmental Justice

Launch of the proposed Mars 2020 mission would not be anticipated to result in disproportionately high and adverse impacts to low income or minority populations. Further details are presented in Appendix C.

4.1.2.13. Aesthetics

Because the launch sites at CCAFS/KSC considered for the proposed action are existing sites and are located in industrialized areas, the visual sensitivity is low. Therefore, the proposed action is not expected to have short- or long-term impacts related to aesthetics.

4.1.2.14. Global Environment

While not regulated, rocket engine combustion is known to produce gases and particles that reduce stratospheric ozone concentrations locally and globally (WMO 2006, NASA 2011). A large fraction of these emissions, CO_2 for example, are chemically inert and do not affect ozone levels directly. Other emissions, such as HCl and H_2O, are not highly reactive, but have an impact on ozone globally since they participate in chemical reactions that help determine the concentrations of ozone-destroying gases known as radicals.

Table 4-1 presents the emissions from propulsion systems of the type utilized by launch vehicles that could most affect stratospheric ozone, grouped according to oxidizer and fuel combination: solid propellant using ammonium perchlorate and aluminum, LOx and liquid hydrogen, and LOx and kerosene. Table 4-1 does not account for all emissions, only those most relevant to ozone chemistry. For example, all of the systems emit CO_2, but CO_2 does not play a direct role in ozone chemistry in the stratosphere.

Table 4-1. Launch Vehicle Emissions

Propellant	Launch Vehicles	Emissions
LOx/H_2	Delta IV	H_2O (NO_x, HO_x)
LOx/RP-1 (kerosene)	Atlas series, Falcon series	H_2O (NO_x, HO_x), soot (carbon), H_2SO_4
Solid	Atlas series with SRBs	H_2O, HCl, Cl_x, NO_x, (HO_x), Al_2O_3

Note: Al_2O_3, soot, and sulfate particles less than 5 microns. Parenthesis denotes compounds that have not yet been measured but are expected to be present.
Key: Al_2O_3=Alumina; Clx=Chlorine, includes: Cl, Cl_2, and ClO; H_2=Hydrogen; H_2O=Water; HCl=Hydrogen Chloride; HOx=Hydrogen Oxides, includes: OH=hydroxide ion, H_2O; H_2SO_4=Hydrogen Sulfate; LOx=Liquid oxygen; NOx=Nitrogen Oxides, includes: NO, NO_2, NO_3; RP-1=Rocket Propellant.

The relative emission rate (mass of emitted compound per mass of propellant consumed) has not been accurately determined for all of the compounds listed in Table 4-1. Rocket engine combustion computer models have been used to estimate the emission rates for some compounds (NASA 2011).

Direct measurements using high-altitude aircraft have validated the model predictions in some cases (Ross 2000, Ch. Voigt et.al. 2013). The combustion models have not yet been used to estimate the rates for some important compounds, although theoretical considerations suggest they should be present in the exhaust in small quantities.

The impact of rocket emissions is separated into an immediate local response following each launch and a long-term global response that reflects the steady, cumulative influence of all launches. Fast chemical reactions between reactive plume gases, particles, and the surrounding air cause the local response. This can result in 100 percent ozone loss within the plume (Ross 2000, Murray, et.al. 2013). This phase can last for several days until the reactive exhaust gases have been largely deactivated, and the plume has substantially dispersed. The ozone loss in this phase, while dramatic, does not likely contribute significantly to the global impact (Danilin 2001), at least for SRB emissions and additional data collected by NASA indicate local ozone levels

tended to recover to ambient levels after a number of hours (NASA 2011, Murray et al. 2013).

The global response is driven by the accumulation of all gas and particulate emissions over a long period of time after the exhaust has been mixed throughout the stratosphere. An approximate steady state is achieved as exhaust from newer launches replaces the exhaust from older launches, which is removed from the stratosphere by the global atmospheric circulation, a process that takes about 3 years. The emitted compounds add to the natural reservoirs of reactive gases and particle populations that control ozone amounts (NASA 2011).

Of the three propellant combinations that would be utilized by the proposed launch vehicles and listed in Table 4-1, only SRB emissions have been studied in depth. The local and global impact of chlorine emitted by SRBs has been extensively measured and modeled and is relatively well understood (i.e., WMO 1991, 2006). SRBs release reactive chlorine gases directly in the stratosphere and in this case, the quantities are small in comparison with other tropospheric sources. Stratospheric accumulation of chlorine and alumina exhaust from current launch activities leads to small (less than 0.1 percent) global column ozone decreases and data support this conclusion (WMO 2006, NASA 2011).

The global atmospheric models that have been successfully applied to SRB emissions have not been applied to liquid emissions. The few findings that have been published highlight the reactive gas and soot emissions of kerosene-fueled engines and associated potential for ozone impacts (Newman 2001; Ross 2000). Because of the scant data and lack of modeling tools, it is not possible to estimate the impact of liquid propellant systems with the same degree of confidence as has been done for solid propellant systems. Further research is required before the stratospheric impacts of LOx/LH_2 and LOx/RP-1 (kerosene) combustion emissions can be quantified (NASA 2011).

Among the proposed launch vehicles, the Atlas V 551 emits the greatest amount of SRB exhaust into the stratosphere. It has been estimated that the ozone loss per Atlas V 551 launch is 0.077 percent (USAF 2000). The present state of the stratosphere is characterized by global ozone loss of about 4 percent, caused by past use of chlorofluorocarbons (CFCs) and other controlled materials (NASA 2011). The launch of any of the proposed launch vehicles is not expected to significantly increase ozone loss.

As a result of launch of the Delta or Falcon rockets, black carbon "soot" would be emitted directly in the stratosphere above 20 km (12 mi). These black carbon or soot particles can have a greater impact on climate change than rocket emissions of CO_2. Black carbon is known to be the second most important compound driving climate change. In modeling studies, utilizing the Whole Atmosphere Community Climate Model, researchers have shown these soot particles may accumulate into a thin cloud at an altitude of about 40 km (25 mi), which remains relatively localized in latitude and altitude (Ross, et al. 2010). The model suggests that if this layer reached high enough concentrations, the Earth’s surface and atmospheric temperatures could be altered. The globally integrated effect of these changes is, as for carbon dioxide, to increase the

amount of solar energy absorbed by the Earth's atmosphere. Research on the potential climate change impacts of black carbon from rockets is in a very early stage and projections of impacts are being refined (NASA 2013a).

Mitigation and/or minimization of this potential impact are being addressed in the aerospace industry by advancing propulsion system designs and innovative fuel mixtures that burn cleaner and reduce soot formation (NASA 2013a). At present, impacts from black carbon "soot" emitted as a result of the launch of one Atlas or Falcon series vehicle are considered minor

Concerning long-term effects, launch of the proposed Mars 2020 mission on the Atlas V, Delta IV, or Falcon Heavy would not be expected to make substantial contributions to the amounts of ozone-depleting chemicals or greenhouse gases in the atmosphere. Some short-term ozone depletion affects would occur within the exhaust plume of the launch vehicle, but the depletion trail would be largely temporary and dissipate within a few hours of the vehicle's passage. Greenhouse gases, principally CO_2 (from the Atlas V and Falcon Heavy), would be emitted during launch, but the amount would be negligible. The Falcon Heavy is estimated to produce up to 976,000 kg (2,151,000 lb) of CO_2 per launch (USAF2011). This is on the order of one hundred-thousandths (10^{-5}) of a percent compared to the net greenhouse gases emitted by the United States in 2011 of approximately 5.8×10^{12} kg (1.3×10^{13} lb) measured as carbon dioxide equivalent (EPA 2013).

In conclusion, the amount of greenhouse gases emitted by the launch vehicle for the Mars 2020 mission would therefore be anticipated to negligibly contribute to ozone depletion and global climate change (NASA 2005a).

4.1.2.15. Orbital and Reentry Debris

During the launch sequence of either the Atlas V, the Delta IV, or the Falcon Heavy for the Mars 2020 mission (see Figures 2-12, 2-14, and 2-16 respectively), the SRB casings of the Atlas V, the strap-on CBCs of the Delta IV, or the boosters of the Falcon Heavy; the first stage, and the PLF would be jettisoned and fall into the Atlantic Ocean in predetermined drop zones (see Section 4.1.2.11) well before reaching Earth's orbit. Shortly after separating from the first stage, the second stage engine would be ignited, accelerating the second stage and the attached spacecraft to low Earth orbit. After a brief coast period, the second stage engine would be reignited, accelerating to Earth escape velocity. After propellant depletion, the second stage would be separated from the Mars 2020 spacecraft, and the second stage would continue separately into interplanetary space. Therefore, a normal launch of the Mars 2020 mission would not contribute to orbital or reentry debris.

4.1.3 Non-radiological Environmental Impacts of Potential Accidents

The potential non-radiological environmental impacts associated with expendable vehicle launch accidents have been discussed in previous USAF environmental documentation (USAF 1998, USAF 2000), and are summarized here and augmented with new information where applicable. A variety of accidents could occur during preparations for launch and during launch. Only two types of non-radiological accidents

would have potential environmental consequences: a liquid propellant spill occurring after the start of propellant loading operations and a launch accident. A launch accident that leads to loss of the Mars 2020 mission is estimated to occur with a probability of about 25 times out of 1,000 (SNL 2014). All launch accidents would have non-radiological impacts.

The potential consequences of these accidents are presented below.

4.1.3.1. Liquid Propellant Spills

A typical Atlas V uses about 284,089 kg (626,309 lb) of RP-1 and LOx for the first stage, and about 20,830 kg (45,922 lb) of LH_2 and LOx, with less than 91 kg (201 lb) of hydrazine for the Centaur second stage (USAF 2000, ILS 2001). A typical Delta IV Heavy uses about 606,300 kg (1,336,663 lb) of LH_2 and LOx for the first stage, about 27,200 kg (60,000 lb) of LH_2 and LOx for the second stage, with about 154 kg (340 lb) of hydrazine for the second stage (ULA 2013, Freeman 2006). The proposed Falcon Heavy would be expected to use about 784,000 kg (1,730,000 lb) of RP-1 and LOx for the first stage, and about 49,000 kg (108,000 lb) of LH_2 and LOx for the second stage (NASA 2011).

The Mars 2020 spacecraft would use about 460 kg (1014 lb) of hydrazine. The first stage and second stage fueling operations for both vehicles are performed in accordance with CCAFS/KSC propellant loading protocols. Standard procedures such as use of closed loop systems are practiced, which would minimize worker exposure and the potential for fuel releases.

Accidental leaks or spills of RP-1, LOx, LH_2, and hydrazine could occur during propellant loading and unloading activities. Range safety requirements specify that plans and procedures be in place to protect the workforce and the public during fueling operations (USAF 2004). Spill containment would be in place prior to any propellant transfer to capture any potential release. Hydrazine transfer would involve a relatively small amount of liquid through a relatively small transfer system, so any leakage would be held to an absolute minimum. It is expected that, because of the limited quantities involved, there would be no impact to the public.

Spill kits located in the work area would be used if a release were detected during RP-1 loading. Personnel would be present in the immediate area to handle any release. Workers would be required to wear personal protective equipment while loading RP-1 and hydrazine, and all unprotected workers would be removed from the area prior to loading. The operator would remotely close applicable valves to minimize any release and safe the system.

If a spill or release is detected during LOx and LH_2 loading at the launch pad, the operator would remotely close the applicable valves to minimize the amount of liquid released, and safe the system. Water deluge would be used if heat were detected in the area of concern. Deluge water would be collected and treated, if necessary, prior to being released to the CCAFS/KSC wastewater treatment plant.

4.1.3.2. Launch Failures and Suborbital, Orbital and Reentry Debris

Air Quality

The USAF has modeled postulated accidents at CCAFS involving combustion of typical launch vehicle propellants (USAF 2000). Representative meteorological conditions were used in the analyses to model movement of the exhaust cloud. Release and combustion of both liquid and solid propellants were assumed to be involved. For the modeled accidents, the principal constituents resulting from burning propellant were CO, Al_2O_3 particulates, and HCl; but also included H_2, H_2O, and CO_2. Although Al_2O_3 particulates would be deposited from the explosion cloud as it was carried downwind, little wet deposition of HCl would be expected unless rain falls through the cloud of combustion products. The estimated concentrations of combustion products resulting from these postulated accidents were found to be well within applicable Federal, state, and USAF standards. Based on these analyses, emissions resulting from an accident during the Mars 2020 mission launch would not be expected to exceed any of the applicable environmental standards, and would not adversely create short- or long-term impacts on air quality in the region.

Geology and Soils

Launch accidents could result in impacts on near-field soils due to contamination from rocket propellant. In the unlikely occurrence of a launch accident, any spilled propellant would be collected and disposed of by a certified disposal/remediation contractor in accordance with the facility Spill Prevention, Control, and Countermeasures (SPCC) plan. Contaminated soils would be removed and treated as hazardous waste in accordance with Federal, state, and local regulations. Short-term impacts to soils may result but would be minimal due to soil buffering capacities. No long-term adverse impacts to geology or soils at CCAFS/KSC would be expected from the Mars 2020 launch (USAF 1998, NASA 2005a, NASA 2006, NASA 2011)

Water Quality

Unburned pieces of solid propellant with high concentration of ammonium perchlorate could fall on land or into nearby bodies of water. Trace amounts of solid propellant could disassociate into ammonium ion and perchlorate ion. At low to moderate concentrations, the ammonium ion is a plant nutrient and could stimulate plant growth for short periods of time. At higher concentrations, the ammonium ion is toxic to aquatic life and could cause short-term mortalities of aquatic animals within the immediate vicinity of the launch vehicle impact.

Perchlorate could leach into surrounding water, but it would take about one-half year for 90 percent of the perchlorate to leach out in fresh water and about one year for 90 percent to leach out in salt water. At these rates, the perchlorate would be diluted as it mixes with the surrounding water. Therefore, no substantial impacts to water quality and biota in those areas would be expected as the solid propellant dissolves slowly. Pieces of unburned solid propellant falling on land would be collected and disposed of as hazardous waste. Similarly, large pieces falling in fresh water areas would be collected

and properly disposed of, minimizing the potential for perchlorate contamination (DOD 2003).

Launch vehicle debris from a liquid propellant fueled rocket is considered a negligible hazard because virtually all hazardous materials are consumed in the destruct action or dispersed in the air, and only structural debris could potentially fall into the water. As with solid propellant, liquid propellant fuel also introduces ammonium perchlorate oxidizer into the water by leaching over a period of time. Studies have shown that the rate of perchlorate extraction is a function of water temperature and salinity, with the highest rates observed at the highest temperature and lowest salinity (USAF 2005).

The low toxicity of this compound together with the slow release into the water does not present a known substantial health hazard to marine life (TRW 2002).

Biological Resources

Birds, reptiles, and small mammals would be most at risk from impacts due to a launch accident. Potential fires could result in temporary loss of habitat and mortality for species that do not leave the area. An accident on the launch pad would frighten nearby sensitive animal species that use the Indian and Banana Rivers (such as birds in rookeries and neo-tropical birds). Threatened and endangered species, such as manatees, sea turtles, and other aquatic species, would not be expected to be adversely affected by a launch accident. Launch pad accidents resulting in full stack intact impact could result in impacts on local water bodies due to contamination from rocket propellant. In the unlikely occurrence of a launch accident, spilled propellant could enter water bodies close to the launch pad and could cause contamination primarily from hydrazine, monomethyl hydrazine (MMH), nitrogen tetroxide (NTO), and SRB propellant. Powdered aluminum from the SRB propellant would rapidly oxidize to aluminum oxide, which is non-toxic at the pH that prevails in surface waters surrounding all proposed launch sites (NASA 2011).

In the event of a launch accident, hydrazine fuel tanks may impact water. Hydrazine fuels are soluble and would disperse rapidly. Because of the small amount of hydrazine present (even in the event of a full spacecraft fuel tank impacting water), short-term impacts on the near-shore environments may result, but long-term impacts would not be significant due to the buffering capacity of large water bodies (NASA 2008). Debris from launch failures has the potential to adversely affect managed fish species and their habitats in the vicinity of the launch site. Ammonium perchlorate in solid propellant contains chemicals that, in high concentrations, have the potential to result in adverse impacts to the marine environment. As noted above, however, perchlorate would leach out slowly and be diluted to low concentrations in the surrounding water, posing little impact to the marine environment (DOD 2003). The USAF has consulted with the National Marine Fisheries Service on essential fish habitat regarding launches from CCAFS (USAF 2000) of vehicles using SRBs. Launch of the Mars 2020 mission from CCAFS would be covered under this consultation.

Residual RP-1 fuel is weakly soluble, would spread over the surface of the water, and should evaporate within a few hours, resulting in only a short-term impact to aquatic biota.

The environmental impact of objects falling into the ocean would depend on the physical properties of the materials (e.g., size, composition, quantity, and solubility) and the marine environment of the impact region. Based on past analyses of other space components, it is expected that the environmental impact of reentering orbital debris would be negligible (NASA 2005b; USAF 1998). There is a remote possibility that surviving pieces of debris could impact marine life or vessels on or near the ocean surface. Once the pieces travel a few feet below the ocean surface, their velocity would be slowed to the point that the potential for direct impact on sea life would be low (NASA 2008, NASA 2011).

Health and Safety

A launch vehicle accident either on or near the launch pad within a few seconds of lift-off presents the greatest potential for impact to human health, principally to workers. For the proposed Mars 2020 mission, the primary potential health hazard during a launch accident would be from the HCl emitted from burning solid propellant from the SRBs. Range Safety at CCAFS/KSC uses models to predict launch hazards to the public and to personnel prior to every launch. These models calculate the risk of injury resulting from toxic gases, debris, and blast overpressure from potential launch failures. Launches are postponed if the predicted collective public risk of injury exceeds acceptable limits, which are applied separately for the risk of injury from exposure to toxic gases, debris, and blast overpressure (USAF 2004). This approach takes into account the probability of a catastrophic failure, the resultant plume's toxic concentration, direction, and dwell time, and emergency preparedness procedures (USAF 2000).

Range Safety requirements mandate destruct systems on liquid propellant tanks and SRBs (see Section 2.1.6.4). In the event of destruct system activation, the propellant tanks and SRB casings would be ruptured and the entire launch vehicle would be destroyed. A catastrophic launch failure would involve burning solid propellant and the ignition of liquid propellant. The potential short-term effects of an accident would include a localized fireball, falling debris from explosion of the vehicle, release of unburned propellants and propellant combustion products, on-pad or very low altitude explosions, death or damage to nearby biota, and brush fires near the launch pad.

Beginning two hours before launch, a Brevard County Emergency Management Center representative would be present at a CCAFS launch console with direct audio and video communications links to the Center. The USAF also has a direct emergency phone line to the Florida State Emergency Response Center.

For suborbital, orbital. and reentry debris, standard safety review processes require that NASA missions comply with the re-entry requirements of the NASA Standard 8719.14, Process for Limiting Orbital Debris. This NASA Standard (i.e., Requirement 4.7.1) limits the risk of human casualty from re-entry debris to 1 in 10,000 and requires that missions be designed to assure that, in both controlled and uncontrolled entries, domestic and foreign landmasses are avoided.

NASA studied the potential risks associated with reentry and Earth impact of spacecraft propellant tanks, specifically in regard to a late launch failure to insert a spacecraft into

a typical parking orbit for later deep space trajectory injection. The study relied primarily on existing data and analyses supplemented by a detailed assessment of the potential impacts of a suborbital accident from the Eastern Range (CCAFS) involving approximately 400 kg (882 lb) of hydrazine reaching land. This case was determined to represent a wide range of potential accidents involving hydrazine propellants (NASA 2011).

The study of a postulated release of approximately 400 kg of residual hydrazine as a result of a suborbital accident for a launch from the Eastern Range indicates there is less than 1 chance in 10,000 (including the probability of the launch accident and ground impact) of harming any individual based on the 1-hour interim Acute Exposure Guideline Level-2 (AEGL-2) value of 13 ppm (17 mg/m3) established by the EPA for hydrazine [http://www.epa.gov/oppt/aegl/index.htm]. In fact, a larger release of hydrazine (i.e., a factor of 2 to 3 higher) or approximately 1,200 kg under the same circumstances would still pose less than 1 chance in 10,000 of harming any individual, including the probability of the launch accident and ground impact (NASA 2011). Specifically, for the MSL spacecraft, an analysis showed that under certain launch accident conditions, there was a small probability the spacecraft with a full propellant load (475 kg) could reenter prior to achieving orbit and impact land in southern Africa or Madagascar. The probability of such an accident occurring and leading to a land impact was determined to be on the order of 1 in 20,000. The overall risk of an individual injury resulting from the land impact of a spacecraft and exposure to hydrazine was determined to be less than 1 in 100,000 (NASA 2010b).

In accident scenarios occurring after achievement of the parking orbit, analysis for the MSL spacecraft determined it could reenter from orbit and potentially impact land anywhere between 36° north and south of the equator. Under these conditions, only a small portion (i.e., less than about 5%) of the full propellant load could reach the ground if the tanks did not burst due to reentry heating effects and release their contents into the atmosphere. The overall probability of this type of accident occurring was determined to be less than 1 in 200. In this type of accident, it is extremely unlikely that there would be any residual hydrazine remaining inside the propellant tanks at the point of ground impact (NASA 2010b).

Because of the increasing number of objects in space and their potential for reentry, NASA adopted guidelines and assessment procedures to reduce the number of non-operational spacecraft and spent rocket upper stages orbiting the Earth. NASA's launch Project Managers must employ design and operation practices that limit the generation of orbital debris, consistent with mission requirements and cost effectiveness.

NPR 8715.6A, *NASA Procedural Requirements for Limiting Orbital Debris*, requires that each program or project conduct a formal assessment for the potential to generate orbital debris and to analyze the impacts of space structure reentry. NASA also has a technical standard (NASA-STD 8719.14) and corresponding handbook (NASA-NHBK 8719.14) to provide specific guidelines and methods to limit orbital debris generation.

To mitigate potential safety and environmental impacts from orbital debris generation and space structure reentry, all NASA orbital missions originating from the proposed launch facilities would comply with the processes outlined in NPR8715.6A and NASA-

STD 8719.14, both of which establish requirements for (1) limiting the generation of orbital debris, (2) assessing the risk of collision with existing space debris, (3) assessing the potential of space structures to impact the surface of the Earth, and (4) assessing and limiting the risk associated with the end of mission of a space object. These requirements apply to both full spacecraft and jettisoned components, including launch vehicle orbital stages.

For accidents involving suborbital debris, parts of the exploded vehicle would fall back to Earth. Except for on-pad or near-pad accidents, most of the fragments would fall into the Atlantic Ocean, where the metal parts would eventually corrode. Toxic concentrations of metals would be unlikely because of slow corrosion rates and the large volume of ocean water available for dilution (USAF 1996, NASA 2011).

4.1.4 Environmental Impacts of Potential Accidents Involving Radioactive Material

NASA and the U.S. Department of Energy (DOE) have assessed the potential environmental impacts of launch accidents involving release of plutonium dioxide (PuO_2). The analysis results indicate that the most likely outcome of implementing the proposed Mars 2020 mission is a successful launch of the spacecraft toward Mars. If, however, a launch accident were to occur, the most probable outcome is an accident without a release of the PuO_2. Specifically:

- There is a 97.5% chance of a successful launch.
- There is a 2.5% chance of a launch accident.
- There is a 1 in 2,600 chance of a launch accident that would release plutonium dioxide.
  - There is a 1 in 11,000 chance of a launch accident that would result in a release of plutonium dioxide in the launch area.
  - There is a 1 in 3,500 chance of a launch accident that would result in a release of plutonium dioxide outside the launch area.
- No radiological fatalities would be expected to occur as a result of any accident.
- The average maximum dose to any member of the public from an accident with a release would be equal to about 3 months of exposure to natural background radiation for a person living in the United States.

The launch success probability is estimated for a composite launch vehicle to successfully complete all pre-launch operations, first stage flight, second stage flight, and conclude with successful insertion of the spacecraft into the proper Earth escape trajectory toward Mars. The composite launch vehicle accident probabilities were derived by combining the estimated accident probabilities for the Atlas V and Delta IV launch vehicles from the Mars 2020 Representative Databook (NASA 2013). As such, these estimated probabilities do not reflect the reliability of any single launch vehicle.

The consequences and their probabilities are based upon these launch vehicle accident probabilities and estimated release probabilities in DOE's *Nuclear Risk Assessment for the Mars 2020 Mission Environmental Impact Statement* (SNL 2014).

This section summarizes the results from the DOE's nuclear risk assessment (SNL 2014).

NASA, DOE, and its contractors have conducted several safety assessments of launching and operating spacecraft using RTGs (e.g., the Galileo mission in 1989, the Ulysses mission in 1990, the Cassini mission in 1997, the New Horizons mission in 2005, and the Mars Science Laboratory mission in 2011). In developing the nuclear risk assessment for this DEIS, NASA and DOE have drawn from an extensive experience base that involves:

- testing and analysis of the General Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG) and its components *(*e.g., fueled iridium clads and GPHS modules) (see Section 2.1.3) under simulated launch accident environments;
- evaluating the probability of launch-related accidents based on evaluations of system designs and launch histories, including extensive studies of the January 1997 Delta II accident at CCAFS, and of launch vehicle designs; and
- estimating the outcomes of the response of an RTG and its components to the launch accident environments.

The information and results presented in the DOE risk assessment and summarized in this DEIS are the result of the evolution of the risk assessments performed for previous missions which included nuclear materials (e.g., Cassini, the Mars Exploration Rovers (MERs), New Horizons, and Mars Science Laboratory).

4.1.4.1. Risk Assessment Methodology

The nuclear risk assessment for the Mars 2020 mission considers (1) potential accidents associated with the launch and their probabilities and resulting environments; (2) the response of the MMRTG to such accident environments in terms of varying amounts of radioactive material that are released and become airborne (source terms) and the release probabilities; and (3) the radiological consequences and risks associated with such a release. The risk assessment was based on an MMRTG typical radioactive material inventory of approximately 60,000 curies (Ci) of plutonium (Pu) 238 (an alpha-emitter with a 87.7 year half-life) in the form of plutonium dioxide. The activity includes minor contributions from other related plutonium and actinide radionuclides (see Table 2-3).

As discussed in Chapter 2, previous missions (MER and MSL, for example) have carried instruments that included up to two curies of radioactive source material. While the Science Definition Team for the Mars 2020 Mission identified the types of instruments that would be needed to meet the goals of the mission (Mars 2020 SDT 2013), it did not specify the instrumentation that would be included on the rover. NASA is currently in the process of selecting the instrumentation package for the Mars 2020 mission. The selection criteria do not preclude instrumentation with small quantity radioactive sources. Therefore, in addition to the plutonium in the MMRTG, the Mars 2020 rover could carry small quantities of radioactive sources. DOE's risk analysis does address small quantity source terms. Previous analyses have shown that of the radioisotopes that might be used on the science instruments for the Mars 2020 mission, the most risk significant isotope would be curium-244 (Cm-244). This isotope has

previously been used on the MERs as well as on the MSL Curiosity rover. Since the selection of science instruments, and any associated radioisotopes, is pending and is independent of the power source for the rover (MMRTG, solar, or solar and LWRHUs) the results of the small source term risk analysis are presented separately from those for the MMRTG. These results should provide some perspective on the relative risks associated with the MMRTG and any small quantity radioactive sources that could be used in the Mars 2020 mission.

A composite approach has been taken in reporting the results in the DOE risk assessment for this DEIS for accident probabilities, potential releases of PuO_2 in case of an accident (with that portion of the release becoming airborne called source terms), radiological consequences, and mission risks. In the composite approach, the results for the representative Atlas V 551 and Delta IV Heavy launch vehicles were combined in a probability-weighted manner. DOE's risk assessment was developed during the time when the candidate launch vehicles being considered by NASA for the Mars 2020 mission were the Atlas V 541 and 551, the Delta IV Heavy, and the Falcon Heavy. Data for the Atlas V 551 was used to represent both Atlas V launch vehicles; Delta IV Heavy data was used to represent both the Delta IV Heavy and the Falcon Heavy. The primary difference between the Atlas V 551 and the Atlas V 541 is one additional solid rocket booster on the Atlas V 551. Therefore, the consequences associated with launch accidents for the Atlas V 541 would be enveloped by those for the Atlas V 551 launch accidents. While many details regarding the Falcon Heavy design are not presently available, both the Delta IV Heavy and Falcon Heavy are large boost capacity liquid fueled launch vehicles. Both consist of a liquid propellant fueled first stage core with two nearly identical boosters and a second stage powered by a single liquid fueled engine. Differences in the launch vehicles in terms of design, accident probabilities, and accident environments have been taken into account in developing composite results.

The basic steps in the risk assessment methodology are presented in Figure 4-1. The nuclear risk assessment for the Mars 2020 mission DEIS began with the identification of initial launch vehicle system failures and the subsequent chain of accident events that could ultimately lead to accident environments that could threaten the MMRTG. These launch vehicle system failures were based on Atlas V 551 and Delta IV Heavy system reliabilities and estimated failure probabilities developed by NASA (NASA 2012, 2013).

Some intermediate accident events (such as fragments from a propellant tank explosion) and final accident configurations (such as the MMRTG impacting the ground near burning solid propellant) have the potential to create accident environments that could damage the MMRTG and result in the release of PuO_2. Based on analyses performed for earlier missions that carried radioisotope devices[13], DOE identified the specific accident events that could potentially threaten the MMRTG. Eight accident events were identified for consideration for the Mars 2020 mission DEIS:

[13] RTGs and radioisotope heater units (which contain about 2.7 grams (0.1 ounce) of PuO_2, and generate 1 watt of heat for passive thermal control). Radioisotope heater units are not planned for the Proposed Action (Alternative 1).

(1) Liquid propellant explosions;

(2) Solid propellant explosions;

(3) Liquid propellant fires;

(4) Solid propellant fires;

(5) Fragments;

(6) Ground impacts;

(7) Debris impact; and

(8) Reentry conditions (i.e., aerodynamic loads and aerodynamic heating).

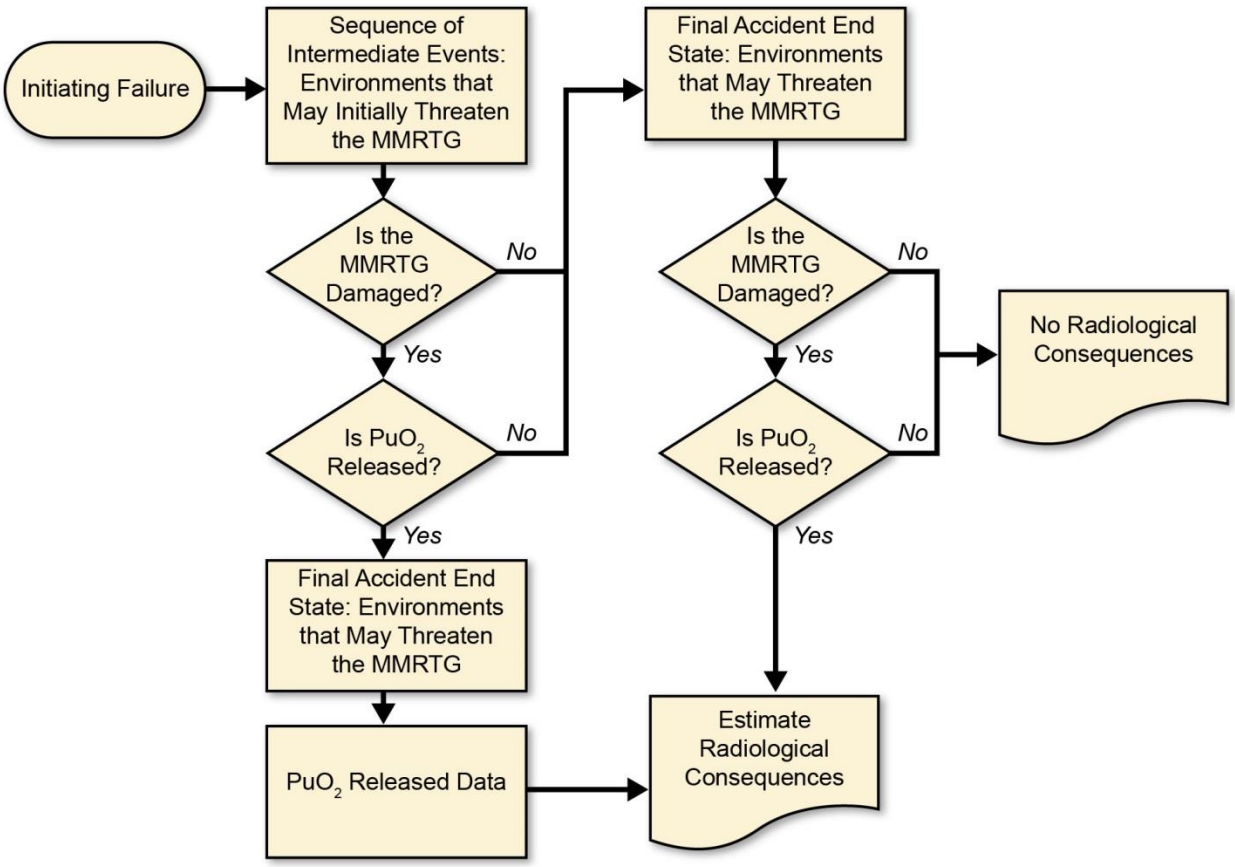

Figure 4-1. The Radiological Risk Assessment Methodology

A given accident could involve one or more of these environment characteristics. The severity of the environments would vary from accident to accident. NASA has conducted a number of experiments to improve understanding of accident environments. The ongoing Solid Propellant Fire Tests and the Star 37 Motor Drop Tests are two most recent experiments for this purpose.

DOE determined the response of the MMRTG and GPHS modules to these accident environments and estimated the amount of radioactive material that could potentially be released. Results of DOE's testing and analyses program for previous configurations of RTGs were used to determine if a release of radioactive material from the MMRTG could potentially occur. The release fractions (the fraction of the PuO_2 that would be released to the environment) were determined by considering five accident environments: explosive overpressure, fragment impact, mechanical impact, thermal environments (liquid propellant fires and explosions and solid propellant fires), and reentry conditions. The source term (that portion of PuO_2 released from the MMRTG that becomes airborne and can be transported downwind) for the MMRTG are based on the results of DOE safety testing and computer modeling.

DOE's testing program examined the response of the MMRTG and GPHS modules to accident environments. The testing program has improved DOE's understanding of the response of the MMRTG and GPHS modules to reentry, impact, and solid propellant fire conditions. DOE incorporated design modifications to address issues identified in testing or changes in mission architecture. In particular, the GPHS modules have been updated over time with design improvements for increased reentry survivability, impact, and fire protection since its original design for the GPHS-RTG.

A better understanding of the response of the MMRTG to accident environments has also allowed DOE to reduce conservatisms in the computer models used to simulate their response to accident environments. Combined with improving computing capabilities (both in machine capability and computer model refinements that result in higher fidelity models), the computer models are better and more precisely able to predict the response of the MMRTG to accident environments.

The consequences of postulated releases were estimated by determining the consequences associated with each of the two surrogate launch vehicles (the Atlas V 551 and the Delta IV Heavy) as they would be used for the Mars 2020 mission. Parameters considered in the consequence analysis include: 2020 population estimates, plume configuration, launch complex location, historical meteorology during the July to September launch period, particle size distributions derived from the response of the MMRTG to accident environments, and key environmental factors such as solid propellant amount and geometry. Consequence values for population dose, maximum exposed individual dose, population health effects[14], and land contamination were estimated at both mean and 99th percentile values.

4.1.4.2. Launch Accidents and Accident Probabilities

For the purpose of this risk assessment, the Mar 2020 mission was divided into six mission phases on the basis of mission elapsed time, the time in seconds relative to launch, reflecting principal launch events. The key events in defining the mission

[14] Additional latent cancer fatalities due to a radioactive release (i.e., the number of cancer fatalities resulting from this release that are in addition to those cancer fatalities which the general population would normally experience from other causes).

phases are: the start of the first stage main engines which occurs shortly before liftoff, liftoff[15], the time at which the there is no longer a possibility that debris from an accident would impact in the vicinity of the launch area, the time at which any debris from an accident would be subject to suborbital reentry heating, and the time orbit is achieved. These events occur at different mission elapsed times for the Atlas V and Delta IV vehicles.

- Phase 0—Pre-Launch: from the installation of the MMRTG to just prior to the start of the first stage main engine
- Phase 1—Early Launch: from the start of the first stage main engines to just prior to the time after which there would be no potential for debris or an intact vehicle configuration to impact land in the launch area, and water impact would occur
- Phase 2—Late Launch: from the end of Phase 1 to when the launch vehicle reaches an altitude of about 30 km (100,000 ft), an altitude above which reentry heating could occur
- Phase 3—Suborbital Reentry: from an altitude of about 30 km (100,000 ft) to the first engine cutoff of the second stage and the Command Destruct System (CDS) is disabled
- Phase 4—Orbit Reentry: from the first engine cutoff of the second stage to separation of the spacecraft from the second stage
- Phase 5—Long-term Reentry: from spacecraft separation to no chance of spacecraft reentry.

The methodology used to calculate the Atlas V and Delta IV probabilities utilized flight histories of comparable United States and Russian launch vehicles flown since 1988. This flight history consists of earlier versions of Atlas and Titan launch vehicles manufactured by the Lockheed Martin Corporation, Delta launch vehicles manufactured by The Boeing Company, and other launch vehicles. This is done to provide some assurance to the estimate that all past applicable and partially applicable flight failure experiences are considered in the reliability estimate of the launch vehicle for the Mars 2020 mission. The analytical approach for the overall mission launch reliability is considered by NASA to be generally representative of the available launch vehicles for this mission, including the Falcon Heavy, and is based upon the most recent best available information at the time of the analysis. NASA continues to evaluate the reliability of the candidate launch vehicles (NASA 2013).

Accidents and their associated probabilities were developed in terms of initiating failures, defined as the first system-level indication of an anomaly that could lead to a launch abort (i.e., safe hold or termination of the launch countdown), catastrophic accident, or mission failure. An example of an initiating failure would be a trajectory control malfunction resulting in the launch vehicle deviating from its planned trajectory. An initiating failure is the beginning of a sequence of intermediate events that lead to a

[15] The main engine undergoes an automatic health check beginning at first-stage main engine start. Should a malfunction be detected before liftoff, the engine would be shut down and the launch would be aborted.

range of possible end states, including accident configurations involving the MMRTG and various launch vehicle stages[16] and the Mars 2020 spacecraft. For example, activation of the Flight Termination System (FTS) following a trajectory control malfunction could lead to the MMRTG impacting the ground. Associated with the accident configuration end states are the environments that could damage the MMRTG and result in the release of PuO_2.

Pre-Launch (T < 0 seconds) initiating failures include tank failures, MMRTG cooling system failures, and inadvertent FTS activation. Pre-Launch initiating failures generally involve conditions that can be mitigated by existing systems or procedures, leading to mission abort rather than accidents that threaten the MMRTG.

The Launch and Post Launch (T ≥ 0seconds) initiating failures include:

- Ground Support Equipment failure during liftoff
- Trajectory and attitude control malfunctions
- Propellant tank failures
- Catastrophic main engine failures affecting either the Stage 1 or Stage 2 engines
- SRB case failure (in the Atlas V 551)
- Structural failure
- Inadvertent FTS activation or payload fairing (PLF) separation
- Staging failure.

The post launch (Phase 1 and 2) accident end states that can result from the initiating failures are determined to a large degree by the FTS actions (see Section 2.1.6.4) that occur or do not occur during the accident progression following the initiating failure. Important FTS considerations affecting the end states are:

- Automatic Destruct System (ADS). The ADS destroys the Stages 1 and 2 liquid propellant tanks and the SRBs (on the Atlas V 551). The ADS is safed (automatically deactivated) prior to Stage 1 / 2 separation.
- Command Destruct System (CDS): The CDS is activated by the Mission Flight Control Officer (MFCO) and destroys the launch vehicle in the same manner as the ADS. The MFCO would likely issue a CDS in case of a trajectory or attitude control malfunction, where the launch vehicle deviation from the planned trajectory violates specific range safety criteria for continuation of a safe launch. Should the MFCO response time needed for a CDS be insufficient, ground impact of the entire vehicle (termed full-stack intact impact, or FSII) could result. The CDS is safed at the end of the first Stage 2 burn.

The initiating failures therefore lead to one or more of the following accident end states, denoting conditions of first threat to the MMRTG:

[16] For brevity in the following discussion, the first and second stages of the Mars 2020 launch vehicle and the Mars 2020 spacecraft, are sometimes referred to as Stages 1 and 2, and SV respectively.

- On-Pad Explosion, occurring as a result of accidents occurring during Pre-Launch or very near the pad just prior to actual liftoff and after completion of the Stage 1 engine health check
- Low and High Altitude FTS. “Low Altitude” denotes conditions where impacts are likely to occur on land, while “High Altitude” denotes conditions leading to impact on the Atlantic Ocean. The response of the spacecraft (SC) to an FTS would depend on the launch vehicle and the accident environment conditions
- Full Stack Intact Impact (FSII), in which the entire launch vehicle stack impacts the ground
- Stage 2/ Space Vehicle (SV) Impact, in which Stage 2/SV impacts the ground
- SV Intact Impact (SVII), in which the intact SV impacts the ground
- Sub-orbital reentry
- Orbital reentry, referring to reentry after decay from orbit. Other types of reentry are possible (e.g., prompt), but at a much lower probability.
- Long-term reentry, referring to Earth reentry of the spacecraft after a spacecraft maneuver failure enroute to Mars. These type accidents may not occur for tens to hundreds of years after launch.

The composite accident end state probabilities for the composite launch vehicle are presented in Table 4-2.

For this DEIS, the initiating probabilities and total probabilities of an accident with a release of PuO2 are grouped into categories that allow for a descriptive characterization of the likelihood of each accident. The categories and their associated probability ranges are:

- unlikely: 10-2 to 10-4 (1 in 100 to 1 in 10 thousand)
- very unlikely: 10-4 to 10-6 (1 in 10 thousand to 1 in 1 million)
- extremely unlikely: less than 10-6 (less than 1 in 1 million).

Some of these types of launch accidents occurred during the early development of launch vehicles in the United States; subsequently, changes were made to both vehicle design practices and range safety systems to prevent future occurrences. These accidents, in general, require multiple failures of both launch vehicle and range safety systems. Probability differences of a factor of a few percent would not represent statistically significant differences and are well within uncertainty bounds. The discussion of the probabilities by broad frequency categories is more appropriate.

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Table 4-2. Alternative 1 Accident End State Probabilities

Ground Impact Configuration[(a)]	Phase 0	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Total Probability
On-Pad Explosion	$3.0x10^{-5}$	$9.8x10^{-5}$	-	-	-	-	$1.3x10^{-4}$
FSII	-	$2.2x10^{-5}$	-	-	-	-	$2.2x10^{-5}$
Stage 2/SV	-	$4.8x10^{-5}$	-	-	-	-	$4.8x10^{-5}$
SVII	$2.8x10^{-6}$	$6.3x10^{-7}$	-	-	-	-	$3.4x10^{-6}$
Low Altitude FTS	-	$2.9x10^{-3}$	-	-	-	-	$2.9x10^{-3}$
High Altitude FTS	-	-	$3.6x10^{-3}$	-	-	-	$3.6x10^{-3}$
Sub-Orbital Reentry	-	-	-	$1.3x10^{-2}$	-	-	$1.3x10^{-2}$
Orbital Reentry	-	-	-	-	$4.7x10^{-3}$	-	$4.7x10^{-3}$
Long-term Reentry	-	-	-	-	-	$1.0x10^{-6}$	$1.0x10^{-6}$
Total	**$3.3\ x10^{-5}$**	**$3.1x10^{-3}$**	**$3.6x10^{-3}$**	**$1.3x10^{-2}$**	**$4.7x10^{-3}$**	**$1.0x10^{-6}$**	**$2.5x10^{-2}$**

Source: SNL 2014

(a) The table presents a composite of the accident end state probabilities for the Atlas V 551and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.

Some of these types of launch accidents occurred during the early development of launch vehicles in the United States; subsequently, changes were made to both vehicle design practices and range safety systems to prevent future occurrences. These accidents, in general, require multiple failures of both launch vehicle and range safety systems. Probability differences of a factor of a few percent would not represent statistically significant differences and are well within uncertainty bounds. The discussion of the probabilities by broad frequency categories is more appropriate.

The potential accident environments include blast (explosion overpressure), fragments, thermal energy (burning liquid propellant and/or solid propellant), reentry conditions (aerodynamic loads and heating), and surface impact. A given accident could involve one or more sequential and/or simultaneously occurring accident environments. The nature and severity of such environments would be a function of the type of accident and its timing (relative to launch). There are two representative launch vehicles for the Nuclear Risk Assessment that bound the set of LV that could be selected for the proposed Mars 2020 mission: the Atlas V 551 and the Delta IV Heavy. DOE's nuclear risk assessment for this DEIS uses a composite average of the two sets of accident probabilities in performing the nuclear risk assessment for the Mars 2020 mission, as presented in Table 4-2. This approach reflects the state of knowledge at this early stage in the mission with respect to the launch vehicle to be used on the Mars 2020 mission. Preliminary analyses indicate that the differences between the two representative launch vehicles are not expected to be significant, given the uncertainties in estimates made as part of the overall nuclear risk assessment. At the same time, differences in accident environments for the two representative launch vehicles are taken into account in developing composite source terms for use in the analysis.

4.1.4.3. MMRTG Response to Accident Environments

The nature and severity of the accident environments and the design features of the MMRTG and its components determine the response of the MMRTG and its components to the accident environments. These responses are then characterized in terms of the probability of release and the source terms.

The response of the MMRTG to accident environments is based on consideration of

- prior safety testing of the GPHS-RTG and its components (including the GPHS module),
- modeling of the response of the MMRTG and its components (including the GPHS module) to accident environments, and
- the types of launch vehicle accidents and their environments.

This information allows estimates to be made of the probability of release of PuO_2 and the amount of the release for the range of accident scenarios and environments that could potentially occur during the mission. The protection provided by the GPHS module, its graphite components, and the iridium clad encapsulating the PuO_2 reduces the potential for release in accident environments. Potential responses of the MMRTG and its components in accident environments are summarized below (SNL 2014).

- **Explosion Overpressure and Fragments:** Liquid propellant explosions and resulting fragments are expected to damage the MMRTG, but not result in any release of plutonium dioxide.

- **Impact:** The GPHS module and its graphitic components are expected to fracture under mechanical impact conditions. This provides some energy absorbing protection to the fueled clad. Under most accident conditions this results in little or no release of plutonium dioxide from the GPHS modules.

    - Most impacts of an intact MMRTG or GPHS modules on steel or concrete near the launch pad could result in little or no release of PuO_2, depending on the impact velocity.
    - Suborbital or Orbital Reentry accidents lead to GPHS modules impacting rock following reentry; a small release could occur.
    - The SV is expected to stay intact until impact due to the protection of the SV back shell and heat shield in any ground impact. The combined effect of the SV hitting the ground and the MMRTG subsequently being hit by the SV components above it, occasionally results in a fuel release; depending on the impact velocity and orientation.
    - Larger intact configurations, such as FSII and Stage 2/SV intact impact could result in higher releases for certain orientations in which launch vehicle and/or SV components impact directly onto the MMRTG.

- **Thermal:** The response of the PuO_2 to the thermal environment is highly dependent upon the intensity of that environment. Exposure to liquid propellant and solid propellant fires results in very different source terms.

  - Exposure of released PuO_2 to a liquid propellant fireball environment would be of short duration (nominally 20 s or less). Very minor vaporization of exposed PuO_2 particles would occur depending on the timing of the ground impact release and the fireball development. Vaporization of PuO_2 is negligible below about 2,177°C (3,951°F) and the fireball temperature would decrease below this temperature in less than 1 second, and continue dropping as the fireball expands.
  - For the Atlas V 551, exposure of released PuO_2 fuel to the higher-temperature (up to 2,827°C (5,121°F)), longer burning (up to 250 seconds) solid-propellant from SRB fragments could lead to more substantial vaporization of exposed PuO_2. In addition, exposure of a bare (or breached) iridium clad could result in clad degradation either through chemical interactions or melting, resulting in more exposed PuO_2 and additional partial vaporization. The GPHS aeroshell graphitic components could be damaged in accident environments, which would allow such an exposure of the iridium clads. In addition, very minor PuO_2 vapor releases from intact aeroshell modules are possible in certain exposure conditions (e.g., underneath large pieces of burning solid propellant). Under such conditions, temperatures inside the module could be high enough to degrade the iridium clads and vaporize some PuO_2, which, in turn, could permeate through the somewhat porous graphitic materials.

- **Reentry:** Impacts resulting from reentry of the MMRTG are dependent upon when and from where reentry occurs.
  - Most suborbital reentries are predicted to result in intact impact of the SV due to the presence of the SV aeroshell for Mars entry. Releases in these cases are similar in nature to those from SV impact near the launch pad.
  - Reentry from circular orbital decay or long-term reentry is predicted to cause breakup of the SV and the MMRTG with subsequent release of the GPHS modules. (This breakup of the MMRTG and release of the GPHS modules is intentional and designed to limit the release of PuO_2 in this type of accident.) This will result in some heating and ablation of the surface of the GPHS modules, but no containment failure or release in the air. When these separated components impact land, there is a potential for release from the GPHS module if the impact is on rock or a similar hard surface. No release is expected from a water impact or soil impact.

Most launch accidents in Phases 0 and 1 would lead to one of several types of ground impact configurations (e.g., FSII, Stage 2/SV, SV, SV/MMRTG, MMRTG, or free GPHS modules). Ground impacts of the SV on steel or concrete can occasionally lead to a release. For larger impacting configurations, such as an FSII or Stage 2/SV intact impact, larger fuel releases are expected. Exposure to the liquid propellant fireball could lead to some vaporization of released PuO_2 depending on the relative timing of the impact release and the fireball development. Subsequent exposure of MMRTG components and PuO_2 to burning solid propellant could result in increased releases through partial vaporization of the PuO_2.

Nearly all Phase 2 accidents lead to impact of debris in the Atlantic Ocean with no releases. However, there are some very small releases in air from blast-generated debris.

Phase 3 accidents could lead to sub-orbital reentry heating and ground impact of the intact SV and MMRTG. The GPHS modules are designed to survive reentry, however, any subsequent ground impact of the MMRTG on hard surfaces (e.g., rock) could result in small releases of PuO_2. Additionally, there is a possibility that the Mars 2020 entry vehicle aeroshell might provide some reentry protection such that the SV or portions of it, including the rover/MMRTG or the MMRTG, could survive reentry and result in SV components impacting the MMRTG. This could also occasionally result in small releases of PuO_2.

Phase 4 and 5 accidents lead to orbital, and long-term reentry heating and ground impact environments. The GPHS modules are designed to survive reentry; however, any ground impact on rock could result in small releases of PuO_2.

4.1.4.4. Accident Probabilities and Source Terms

In the nuclear risk assessment, DOE evaluated each of the identified end states and estimated the accident environments to which the MMRTG would likely be exposed. From that information, conditional probabilities that a release would occur and estimated source terms were developed based on the known response of GPHS modules to various accident environments.

The probability of a launch accident involving any release of PuO_2 is very small, approximately 1 in 2,600. The most severe accident environments would occur during launch area accidents that might expose the MMRTG to mechanical impacts, explosion overpressures and fragments, and fire environments from burning liquid and solid propellants.

A summary of the accident and source term probabilities by mission phase, along with mean and 99th percentile source terms, is presented in Table 4-3. For the purpose of this DEIS, "source term" is defined as the quantity of radioisotope that is released from the fueled clads in the GPHS modules and becomes airborne. Consequences associated with the material released in an accident are driven by the portion of the release that can become airborne and be transported away from the impact site. Not all of the material released from the fueled clads is expected to become airborne; the amount that does is dependent upon the accident conditions. Several factors contribute to a reduction in the released material to the source term. Some of the release could become trapped in debris or slag at the MMRTG impact site. Plutonium dioxide could be retained inside the graphite components of the GPHS module, and some could be shielded from any fire environments by the graphite components and other debris, including sand. In addition, the size of the plutonium dioxide particles affects the likelihood of the plutonium dioxide becoming airborne, the larger the particles the less likely they are to become airborne.

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Table 4-3. Summary of Accident Probabilities and MMRTG Source Terms

Mission Phase [(a)]	Accident Probability	Source Term, Ci (given an accident)		Conditional Probability of Release [(b)]	Total Probability of a Release	Source Term [(c)], Ci (given a release)	
		Mean	99th Percentile			Mean	99th Percentile
0: Pre-Launch	Very Unlikely ($3.3x10^{-5}$)	0.092	0.048	0.33	Very Unlikely ($1.1x10^{-5}$)	0.28	6.7
1: Early Launch							
On-Pad Explosion	Very Unlikely ($9.8x10^{-5}$)	2.0	0.035	0.085	Very Unlikely ($8.3x10^{-6}$)	23	40
FSII	Very Unlikely ($2.2x10^{-5}$)	15	340	0.14	Very Unlikely ($3.2x10^{-6}$)	110	1,800
Stage 2/SV	Very Unlikely ($4.8x10^{-5}$)	2.8	55	0.036	Very Unlikely ($1.8x10^{-6}$)	77	910
SVII	Extremely Unlikely ($6.3x10^{-7}$)	2.7	40	0.054	Extremely Unlikely ($3.4x10^{-8}$)	50	580
Low Altitude FTS	Unlikely ($2.9x10^{-3}$)	1.5	16	0.025	Very Unlikely ($7.5x10^{-5}$)	61	620
Overall Phase 1	Unlikely ($3.1x10^{-3}$)	1.7	16	0.028	Very Unlikely ($8.8x10^{-5}$)	59	630
2: Late Launch	Unlikely ($3.6x10^{-3}$)	$3.4x10^{-5}$	-	0.0021	Very Unlikely ($7.7x10^{-6}$)	0.016	0.23
3: Suborbital	$1.3x10^{-2}$	0.047	-	0.0013	Very Unlikely ($1.5x10^{-5}$)	42	930
4: Orbital	Unlikely ($4.7x10^{-3}$)	0.030	0.65	0.056	Unlikely ($2.6X10^{-4}$)	0.53	6.2
5: Long-term Reentry	Very Unlikely ($1.0x10^{-6}$)	0.073	1.5	0.094	Extremely Unlikely ($9.4x10^{-8}$)	0.77	7.8
Overall Mission [(d)]	**$2.5x10^{-2}$**	**0.24**	**0.0095**	**0.016**	**Unlikely ($3.8x10^{-4}$)**	**16**	**340**

Source: SNL 2014

(a) The table presents a composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.
(b) The conditional probability of a release of PuO_2 given that an accident has occurred.
(c) Total source terms given. The source term is that portion of the release which becomes airborne would represent the amounts of PuO_2 released that are no more than 100 microns (100 micrometers) in diameter. Particles larger than this do not generally become airborne and would remain in the vicinity of the accident.
(d) Overall mission values are weighted by the total probability of release for each mission phase.
Notes: Differences in multiplications and summations are due to rounding of results as reported in SNL 2014. Probability categories, i.e., unlikely, very unlikely, defined by NASA.

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As noted in Table 4-3, particles larger than 100 micrometers (µm) are expected to remain in the vicinity of the MMRTG impact site. The 99th percentile source term is the value predicted to be exceeded with a probability of 0.01 (1 in 100), given a release in an accident. (This percentile is derived from a statistical analysis to model the progression of the accident. In this analysis, DOE has used a computer code that performs multiple trials, typically 150,000, in which the probabilities of the parameters that affect the size of the source term are varied according to their probability distributions. The 99th percentile is therefore the value exceeded in 1 percent of these trials.) In this context, the 99th percentile value reflects the potential for higher radionuclide releases at lower probabilities. The 99th percentile releases are one to approximately 24 times the mean estimates reported in this DEIS, but at probabilities of a factor of 100 times lower than the mean probabilities.

- **Phase 0 (Pre-Launch):** During the pre-launch period, and prior to ignition of the Stage 1 liquid rocket engine, most initiating failures result in a mission abort. Those failures that result in on-pad accidents and a release have a total probability of 1.1×10^{-5} (1 in 93,000). The mean source term, given that an accident with a release has occurred, is estimated to be 0.28 Ci.
- **Phase 1 (Early Launch):** During Phase 1, during which land impacts, including near the launch complex, are possible, the accidents resulting in a release have a total probability estimated to be 8.8×10^{-5} (or 1 in 11,000). The mean source term, given that an accident with a release has occurred, is estimated to be 59 Ci.

  Most initiating failures occurring in Phase 1 would lead to activation of the FTS. The elements of the FTS are highly redundant and reliable. As a result, the expected outcome of a Phase 1 accident is ground impact of the spacecraft or portions thereof, including possibly the rover with attached MMRTG, the MMRTG alone, or free GPHS modules. In this case, mechanical damage and, for an Atlas V 551 accident, potential exposure to burning solid propellant could occur. The probability for this impact configuration with a release is estimated to be 7.5×10^{-5} (or 1 in 13,000), with an estimated mean source term, given an accident with a release has occurred, is estimated to be 61 Ci).

  A much less likely outcome of a Phase 1 accident involves failure of some or all of the FTS elements to perform properly. This could lead to ground impact of the spacecraft (with the MMRTG inside) still attached to other launch vehicle stages (Stages 1 and 2, or Stage 2). Since this would require multiple failures of safety systems, such ground impact configurations leading to a release are very unlikely, estimated probability of 5.0×10^{-6} (1 in 200,000). However, because the MMRTG could impact the ground within the spacecraft at higher velocities and with additional mass above the spacecraft due to the attached Stage(s), the potential for more severe mechanical damage is higher than with the expected accident conditions associated with normal activation of the FTS. For impact configurations leading to the largest estimated releases, such as the Intact Stage 2/SV and the FSII, slightly larger estimated mean source terms given an accident with a release, of 77 Ci and 110 Ci, respectively could occur.

- **Phase 2 (Late Launch):** All accidents that could occur in Phase 2 would lead to impact of debris in the Atlantic Ocean. Most such accidents result in no release of PuO_2. However, in some cases, small quantities of PuO_2 can be released. It is possible that blast and fragment impacts could result in some at altitude releases. The total probability of a release is very unlikely — 7.7×10^{-6} (one in 130,000). The estimated mean source term, given an accident with a release would be 0.016 Ci.
- **Phase 3 (Suborbital):** Accidents during Phase 3 include sub-orbital reentries. Prior to the attainment of Earth parking orbit, these conditions could lead to prompt sub-orbital reentry within minutes. Following spacecraft breakup during reentry, this could result in impacts of individual GPHS modules along the vehicle flight path over the Atlantic Ocean and southern Africa. Additional sub-orbital land impacts are possible after crossing over Africa, depending on the launch vehicle and its mission timeline. Should the GPHS modules impact hard surfaces (e.g., rock), small releases are possible at ground level. There is a possibility that the SV or portions thereof, including the rover/MMRTG or the MMRTG would survive sub-orbital reentry. The total probability of release in Phase 3 is estimated to be 1.5×10^{-5} (or 1 in 67,000). The mean source term given that a release has occurred is estimated to be 42 Ci.
- **Phase 4 (Orbital):** Accidents which occur after attaining parking orbit could result in orbital decay reentries from minutes to years after the accident, affecting Earth surfaces between approximately 29° north latitude and 29 south latitude. Post-reentry impact releases would be similar to those in Phase 3. The total probability of a release is estimated to be 2.6×10^{-4} (or 1 in 3,800). The mean source term given that a release has occurred is estimated to be 0.53 Ci.
- **Phase 5 (Long-Term Reentry):** The potential exists for an inadvertent long-term (hundreds to thousands of years) reentry should the SC be left in an Earth crossing orbit. Based on considerations of long-term inadvertent reentry for other missions, the probability of such an occurrence is estimated to be less than 1×10^{-6}. Post-reentry impact releases would be similar to those in Phase 3. The total probability of a release is estimated to be 9.4×10^{-8} (or 1 in 11,000,000). The mean source term given that a release has occurred is estimated to be 0.77 Ci.

4.1.4.5. Radiological Consequences

The radiological consequences (assuming no post-accident mitigation) of a given accident that results in a radiological release have been calculated in terms of maximum individual dose, collective dose, health effects, and land area contaminated at or above specified levels. The radiological consequences have been determined from atmospheric transport and dispersion simulations incorporating both launch-site specific and worldwide meteorological and population data. Biological effects models, based on methods prescribed by the Interagency Steering Committee on Radiation Standards (ISCORS), were applied to predict the number of health effects following a launch accident that results in a release of PuO_2. The analysis assumes that no mitigation measures (e.g., sheltering, evacuation, and decontamination) are taken to reduce the health impacts. Additional information on the behavior of plutonium in the environment (environmental transport and health impact mechanisms) can be found in Appendix B.

The maximum individual dose is the mean maximum dose delivered to a single individual for a given accident. Collective dose is the sum of the radiation dose received by all individuals exposed to radiation from a given release in units of “person-rem.” Internal doses are determined using particle-size dependent dose conversion factors based on ICRP-60 (ICRP 1979) and ICRP-66/67 (ICRP 1993, ICRP 1994). The exposure pathways considered include direct inhalation, inhalation of re-suspended material, ingestion (e.g., vegetables, fruit, and seafood), and external exposure. Due to the insoluble nature of PuO_2, other secondary exposure pathways (e.g., meat and milk) would be far less important, and their contributions to dose would be negligible. The collective dose is used to estimate the health effects impacts of launch accidents.

The health effects represent incremental cancer fatalities induced by releases, determined using the ISCORS estimates of $6x10^{-4}$ fatalities per person-rem for the general population (DOE 2002). The health effects estimators are based on a linear, non-threshold model relating health effects and effective dose. This means that health effects decrease as the dose decreases down to zero, rather than assuming a threshold dose below which there would be no health effects. The probability of incurring a health effect is estimated for each individual in the exposed population and then the probabilities summed over the population; an estimate of the total health effects in the population results.

Table 4-4 presents a summary of DOE’s risk assessment of radiological consequences given an accident with a release for each of the mission phases. The radiological consequences were estimated by mission phase in terms of both the mean and 99th percentile values. The 99th percentile radiological consequence is the value predicted to be exceeded 1 percent of the time for an accident with a release.

The radiological consequences summarized in Table 4-4 are proportional to the source terms listed in Table 4-3. Key results for the mean estimates are summarized below; the corresponding 99th percentile estimates can be found in Table 4-4.

Should the mission be delayed, the proposed Mars 2020 mission would be launched during the next available launch opportunity in August through September 2022. Since this launch period is in a similar season as the 2020 launch period, the projected radiological impacts associated with releases from the MMRTG (Alternative 1) would be similar to those associated with the 2020 launch, with only a small increase in population impacts due to population growth. Thus, within the overall uncertainties, the radiological impacts associated with a 2022 launch would be the same as those for the proposed 2020 launch. This similarity in impacts for a 2020 and a 2022 mission launch applies to the impacts associated with releases from LWRHUs (Alternative 3) and science instrument sources (Alternative 1, 2, and 3).

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Table 4-4. Summary of Estimated MMRTG Accident Radiological Consequences

Mission Phase [(a)]	Total Probability of Release	Maximum Individual Dose, rem		Health Effects [(b)]		Land Contamination [(c)] km^2	
		Mean	99th Percentile	Mean	99th Percentile	Mean	99th Percentile
0: Pre-Launch	Very Unlikely ($1.1x10^{-5}$)	0.00029	0.0068	0.0014	0.033	0.035	0.83
Early Launch							
On-Pad Explosion	Very Unlikely ($8.3x10^{-6}$)	0.024	0.040	0.11	0.19	2.9	4.9
FSII	Very Unlikely ($3.2x10^{-6}$)	0.11	1.9	0.52	8.9	13	230
Stage2/SV	Very Unlikely ($1.8x10^{-6}$)	0.079	0.93	0.38	4.5	9.7	110
SVII	Extremely Unlikely ($3.4x10^{-8}$)	0.051	0.59	0.25	2.9	6.3	73
Low Altitude FTS	Very Unlikely ($7.5x10^{-5}$)	0.062	0.63	0.30	3.0	7.6	77
1: Overall Phase 1	Very Unlikely ($8.8x10^{-5}$)	0.060	0.65	0.29	3.1	7.4	79
2: Late Launch	Very Unlikely ($7.7x10^{-6}$)	$1.6x10^{-5}$	0.0002	$7.8x10^{-5}$	0.0011	0.0020	0.029
3: Suborbital	Very Unlikely ($1.5x10^{-5}$)	0.043	0.95	0.20	4.6	5.2	120
4: Orbital	Unlikely ($2.6X10^{-4}$)	0.0005	0.0063	0.0026	0.030	0.066	0.77
5: Long-term Reentry	Extremely Unlikely ($9.4x10^{-8}$)	0.0008	0.0080	0.0038	0.038	0.097	0.98
Overall Mission [(d)]	**Unlikely ($3.8x10^{-4}$)**	**0.016**	**0.35**	**0.076**	**1.7**	**1.9**	**43**

Source: SNL 2014

(a) The table presents a composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.
(b) Based on ISCOR health effects recommendation of $6x10^{-4}$ health effects per person-rem for the general population.
(c) Land area contaminated above 0.2 $\mu Ci/m^2$; 1 km^2 = 0.386 mi^2.
(d) Overall mission values weighted by total probability of release for each mission phase.
Notes: Differences in multiplications and summations are due to rounding of results as reported in SNL 2014. Probability categories, *i.e.*, unlikely, very unlikely, defined by NASA.

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- **Phase 0 (Pre-Launch):** The initiating failures that result in Phase 0 accident configurations are very unlikely, having very low probabilities of occurrence. Most problems that arise during Phase 0 can be successfully mitigated by safety systems and procedures leading to safe hold or termination of the launch countdown.

  In the very unlikely possibility (probability of 1.1×10^{-5} or a 1 in 91,000 chance) that an accident were to occur during Phase 0, however, there is a potential for measurable releases and contamination. The probability of the MMRTG being close to large pieces of burning solid propellant would be higher in Phase 0 accidents than in other phases. For this very unlikely accident with a release, the mean maximum dose to an individual is estimated to be approximately 0.00029 rem (0.29 millirem), less than 0.1 percent of the dose an individual might receive annually from natural background radiation[17].

  Assuming no mitigation actions, such as sheltering and exclusion of people from contaminated land areas, the radiation doses to the potentially exposed population are predicted to result in 0.0014 mean health effects among the potentially exposed population.

  For Phase 0 accidents with a release, the mean area contaminated above 0.2 microcuries per square meter ($\mu Ci/m^2$) (see Section 4.1.4.7) is estimated to be about 0.035 square kilometers (km^2) (about 0.014 square miles (mi^2)). Detectable levels below 0.2 $\mu Ci/m^2$ would be expected over a larger area.

- **Phase 1 (Early Launch):** Phase 1 consequences consist of contributions from two types of accident scenarios. Most initiating failures occurring in Phase 1 would lead to activation of the FTS. The elements of the FTS are highly redundant and very reliable. As a result, the expected outcome of a Phase 1 accident is that the SV and MMRTG or its components could fall free to the ground and would be subject to mechanical damage and potential exposure to burning solid propellant resulting in a release of material. For this very unlikely impact configuration, with a probability estimated to be 7.5×10^{-5} (or 1 in 13,000), the mean maximum individual dose is estimated to be 0.062 rem (62 millirem), equivalent to about 20 percent of the dose an individual might receive annually from natural background radiation.

  Assuming no mitigation action, such as sheltering, the radiation dose to the potentially exposed population is predicted to result in 0.30 mean health effects among the potentially exposed population over the long term.

  The risk assessment indicates that about 7.6 km^2 (about 2.9 mi^2) could be contaminated above 0.2 $\mu Ci/m^2$.

[17] An average of about 0.31 rem per year for an individual in the United States from natural sources. Man-made sources add an additional 0.060 to 0.31 rem. The dominant man-made contribution is from medical radiological diagnosis and therapy. See Section 3.2.6 for further information.

A less likely outcome of a Phase 1 accident involves failure of some or all of the FTS elements to perform properly. This could lead to ground impact of the spacecraft (with the MMRTG inside) still attached to other launch vehicle stages (Stages 1 and 2, or Stage 2). Since this would require multiple failures of safety systems, such ground impact configurations leading to a release are very unlikely, estimated probability of 5.0 $x10^{-6}$ (1 in 200,000). However, because the MMRTG could impact the ground within the spacecraft at high speed, the potential for more severe mechanical damage and exposure to burning liquid and, possibly, solid propellant, could result in higher source terms.

In the more severe impact configurations leading to the largest estimated releases, such as the FSII, mean exposures as high as about 0.11 rem (110 millirem) to the maximum exposed individual might occur. This dose is about a third of the dose an individual might receive annually from natural background radiation. Assuming no mitigation action, such as sheltering, radiation doses to the potentially exposed population are predicted to result in an estimated 0.52 mean health effects. An estimated area of nearly 13 km^2 (about 5.0 mi^2) might be contaminated above 0.2 $\mu Ci/m^2$. Detectable levels below 0.2 $\mu Ci/m^2$ would be expected over a larger area.

- **Phase 2 (Late Launch):** The total probability of a release in Phase 2, categorized as very unlikely, is estimated to be $7.7x10^{-6}$ (or 1 in 130,000). Accidents in this phase result in smaller releases and impacts than in any other phase. The mean maximum individual dose is estimated to be $1.6x10^{-5}$ rem (0.016 millirem), a very small fraction of the dose an individual might receive annually from natural background radiation.

  Assuming no mitigation action, such as sheltering, the radiation dose to the potentially exposed population is predicted to result in $7.8x10^{-5}$ mean health effects among the potentially exposed population over the long term.

  The risk assessment indicates that about 0.002 km^2 (about 0.0008 mi^2) could be contaminated above 0.2 $\mu Ci/m^2$.

- **Phases 3 (Suborbital):** The total probability of a release in Phase 3, categorized as very unlikely, is estimated to be $1.5x10^{-5}$ (or 1 in 68,000). Mean consequences are estimated to be 0.043 rem (43 millirem) for maximum individual dose,0.20 health effects among the potentially exposed population , and 5.2 km^2 (about 2.0 mi^2) could be contaminated above 0.2 $\mu Ci/m^2$.

- **Phase 4 (Orbital):** The total probability of a release in Phase 4, categorized as very unlikely, is estimated to be $2.6x10^{-4}$ (or 1 in 3,800). Mean consequences are estimated to be 0.0005 rem (0.5 millirem) for the maximum individual dose, 0.0026 health effects among the potentially exposed population, and 0.066 km^2 (about 0.025 mi^2) could be contaminated above 0.2 $\mu Ci/m^2$.

- **Phase 5 (Long-term Reentry):** The total probability of a release in Phase 5, categorized as extremely unlikely, is estimated to be $9.4x10^{-8}$ (or 1 in 11,000,000). Mean consequences are estimated to be 0.0008 rem (0.8 millirem)

for the maximum individual dose, 0.0038 health effects among the potentially exposed population, and 0.097 km^2 (about 0.037 mi^2) could be contaminated above 0.2 $\mu Ci/m^2$.

4.1.4.6. Discussion of the Results

Maximum Individual Doses

The maximum individual dose is the maximum dose delivered to a single individual for each accident. During Phase 1, the predicted mean radiation dose to the maximally exposed individual ranges from about 0.024 rem (24 millirem) for the on-pad explosion launch area accident up to about 0.11 rem (110 millirem) for a very unlikely FSII in combination with burning solid propellant. No near-term radiological effects would be expected from any of these exposures. The dose to the maximally exposed individual for the FSII is the largest single maximally exposed individual dose for any phase. Each exposure would increase the statistical likelihood of a health effect. It should be noted that the prediction of doses to the maximally exposed individual is subject to large variations and uncertainties in the locations of individuals, meteorological conditions, periods of exposure, and dispersion modeling.

Population Exposures

Impacts to downwind populations that might be exposed to releases following an accident are estimated by first calculating the collective dose to that population. This is simply the sum of the radiation dose received by all individuals exposed to radiation from a given release. These collective doses are assumed to result in the potential for health effects among the potentially exposed population following an accident. The health effects induced by releases are calculated using the methods described above in Section 4.1.4.5. The consequences discussed below have been estimated considering impacts to both the local population and the global population. Because of a variety of factors, principally involving meteorological conditions at the time of launch and the amount and particle size distribution of any PuO_2 released, not all persons in the affected regions would be exposed to a release.

Prior to launch, most problems that could potentially lead to an accident would be mitigated by safety systems and procedures that would lead to safe hold or termination of the launch countdown. After launch, most significant problems would lead to activation of the FTS, which would result in the destruction of all of the vehicle stages. This would lead to the spacecraft or portions thereof, including possibly the rover with attached MMRTG, the MMRTG alone, or free GPHS modules, falling to the ground, where it could be subject to ground impact mechanical damage and potential exposure to burning solid propellant. The probability for this scenario with a release is 7.5×10^{-5} (or 1 in 13,000). Assuming no mitigation actions, such as sheltering and exclusion of people from contaminated land areas, the radiation dose to the potentially exposed population is predicted to result in less than one additional health effect over the long term. The mean estimate for this release scenario is 0.30 health effects.

Even for the very and extremely unlikely launch area accidents, mean releases are not significantly higher than for the most probable accident and release. Assuming no

mitigation actions (e.g., sheltering), estimated mean health effects range from a low of less than 0.11 to a high of 0.52. As with the maximum individual dose the largest population dose is associated with a phase 1 release. In the event of a launch area accident, it is unlikely that any given racial, ethnic, or socioeconomic group of the population would bear a disproportionate share of the consequences.

Impacts of Radiological Releases on the Environment

The environmental impacts of the postulated accidents include the potential for PuO_2 to be released to the environment, resulting in land and surface water contamination. The health and environmental impacts associated with plutonium-238 in the environment were addressed extensively in the EISs for previous NASA missions that used RTGs, including the Galileo, Ulysses, Cassini, New Horizons and Mars Science Laboratory missions (NASA 1989, NASA 1990, NASA 1995, NASA 1997, NASA 2005, NASA 2006). Each of these documents identified the potential for launch area accidents contaminating land areas. These EISs referenced evaluations of the potential impacts of PuO_2 releases on natural vegetation, wetlands, agricultural land, urban areas, inland water, the ocean, and other global areas. Based on these previous analyses, the potential impacts of plutonium releases from the launch area accidents on the environment are discussed in Appendix B.

The affected environment, described in Section 3 of this DEIS, includes the regional area near CCAFS and the global area. Launch area accidents (Phases 0 and 1) would initially release material into the regional area, defined in this DEIS to be within 100 km (62 mi) of the launch pad. Since some of the accidents result in the release of very fine particles (less than a micron in diameter), a portion of such releases could be transported beyond 100 km (62 mi) and become well mixed in the troposphere, and thus affecting the global environment. Releases during Phase 3 could involve reentering GPHS modules that could impact the ground in southern Africa. Releases during Phase 4 could affect the environment anywhere between 29° north and 29° south latitude. Releases during phase 5 could nominally affect the environment anywhere on Earth, but only when the spacecraft impacts land.

Potential environmental contamination was evaluated in terms of areas exceeding various screening levels (0.1 and 0.2 $\mu Ci/m^2$), and dose-rate related criteria (15, 25, and 100 millirem per year) considered by the U.S. Environmental Protection Agency (EPA), the Nuclear Regulatory Commission, and DOE in evaluating the need for land cleanup following radioactive contamination.

The risk assessment for this DEIS uses the 0.2 $\mu Ci/m^2$ screening level (a screening level used in prior NASA environmental documentation (e.g., NASA 1989, NASA 1997, NASA 2002b, NASA 2005) as an indicator of the extent of land area contaminated due to a release of PuO_2 from a potential launch accident. The results are summarized in Table 4-4. The area of land contaminated above the EPA lifetime-risk criterion, associated with an average annual dose rate criterion of 15 mrem/yr, could be higher or lower than the land area contaminated above the 0.2 $\mu Ci/m^2$ level in the first year following the release, depending on the particle size distribution of the release and the potential for resuspension. The resuspension contribution to dose assumes that no mitigation measures are taken.

DOE's risk assessment indicates that for the most likely type of launch area accidents with a release, (that is the intentional destruction of all the vehicle stages) would result in about 7.6 km^2 (about 2.9 mi^2) being contaminated above 0.2 $\mu Ci/m^2$. The risk assessment also indicates that in at least one very unlikely ground impact configuration, FSII with a total estimated probability of 3.2 $x10^{-6}$ (one in 310,000), a mean area of 13 km^2 (about 5.0 mi^2) could be contaminated above 0.2 $\mu Ci/m^2$. Detectable levels below 0.2 $\mu Ci/m^2$ would be expected over an even larger area.

Land areas contaminated at levels above 0.2 $\mu Ci/m^2$ would potentially need further action, such as monitoring or cleanup. Costs associated with cleanup efforts, as well as continued monitoring activities, could vary widely depending upon the characteristics of the contaminated area. These costs do not include costs of government oversight, management or administration nor litigation costs. Indirect costs could double the cost per unit area. Potential cost estimating factors for decontamination (cleanup) of various land types are summarized in Table 4-5. These cost factors address a wide variety of possible actions, including land acquisition, waste disposal, site restoration, and final surveys of remediated sites.

Table 4-5. Potential Land Decontamination Cost Factors

Land Type	Cost Factor in 2013 Dollars	
	Cost per km^2	Cost per mi^2
Farmlands	$110 million	$285 million
Rangeland	$108 million	$280 million
Forests	$196 million	$507 million
Mixed-Use Urban Areas[a]	$600 million	$1.6 billion

a. Mixed use urban area applicable to a U.S. city of approximately 100,000 population. Costs are not applicable to downtown business districts, heavy industrial areas, or high-rise apartment buildings.

Source: Adapted from Chanin et al. 1996

In addition to the potential direct costs of radiological surveys, monitoring, and potential cleanup following an accident, there are potential secondary societal costs associated with the decontamination and mitigation activities with the very unlikely, potentially higher consequence launch area accidents. Those costs could include, but may not be limited to:

- temporary or longer term relocation of residents;
- temporary or longer term loss of employment;
- destruction or quarantine of agricultural products, including citrus crops;
- land use restrictions (which could affect real estate values, tourism and recreational activities);
- restriction or bans on commercial fishing; and
- public health effects and medical care.

As indicated in Table 4-5, costs for farmland decontamination have been identified. In addition to the costs of decontamination, there is the potential that the contamination of crops would require additional mitigation measures. These actions could be required to

prevent contaminated foodstuffs from being consumed by the public. In the case of plutonium dioxide contamination, the preventive measures could include the collection and disposal of contaminated crops. The Food and Drug Administration has established Derived Intervention Levels (DILs) (FDA 1998) designed to limit the dose to an individual from consuming contaminated foodstuff. These DILs identify recommended levels of contamination above which individuals consuming the contaminated foodstuff would receive an unacceptable dose. The DIL varies depending upon the receptor (the individual consuming the foodstuff) primarily based upon the age of the individual. In the case of plutonium-238, the limiting DIL (that is, the lowest allowable concentration) of 2.5 Bq/kg [18] (FDA 1998) is the DIL for infants.

As a part of the Nuclear Risk Assessment, DOE performed an analysis to determine the extent of cropland that could be contaminated to levels in excess of this DIL. The analysis used the same accident and meteorological data used in the NRA to address the release and dispersal of plutonium dioxide in the event of an accident, i.e., the same accident conditions, release quantities, and weather data. In addition, the analysis considered the following items:

- The acreage of land used as farmland (and the fraction of land used for each crop type (leafy vegetables, fruit, pasture, etc.),
- The types of crops grown in Florida and in the KSC area,
- The quantities of each crop type grown, and
- The fraction of plutonium dioxide deposited on cropland that would be deposited on or absorbed by each crop type.

The results of this analysis indicated that for all phases and for all accidents, the area contaminated above the DIL is consistently more than 50 times lower than (less than 2 percent) the area contaminated at or above the 0.2 µCi/m^2 level that are shown in Table 4-4. For example, in assessing the Phase 1 accident with Low Altitude FTS, DOE calculated that the DIL value of 2.5 Bq/kg would be exceeded in an area of 0.13 km^2 (0.05 mi^2 or about 32 acres). This is the mean value for the cropland area where some mitigation measures could be required to limit the public health impact from the consumption of food contaminated by a release from this accident. The 99th percentile area would be 1.35 km^2 (0.52 mi^2 or 330 acres). These values are less than 2% of the calculated land contamination area using the 0.2 µCi/m^2 criteria (See Table 4-4) (SNL 2014).

The Price-Anderson Act of 1957, as amended (42 U.S.C. 2210), governs liability and compensation in the event of a nuclear incident arising out of the activities of the DOE. The Price-Anderson Act is incorporated into the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.). A "nuclear incident" is defined under the Atomic Energy Act as “any occurrence, including an extraordinary nuclear occurrence, within the United States causing, within or outside the United States, bodily injury, sickness,

[18] A Becquerel (Bq) is one disintegration per second. One curie is equal to 37,000 million Bq. The land contamination criteria of 0.2 microcuries/m^2 is equivalent to 7.4 Bq/m^2.

disease, or death, or loss of or damage to property, or loss of use of property, arising out of or resulting from the radioactive, toxic, explosive, other hazardous properties of source, special nuclear or byproduct material…" (42 U.S.C. 2014 (q)). In the case of the Mars 2020 mission, DOE retains title to the MMRTG. The MMRTG would, therefore, be subject to Price-Anderson Act provisions. In the unlikely event that an accident were to occur resulting in release of PuO_2, affected property owners would be eligible for reimbursement for loss of property due to contamination.

4.1.4.7. Mission Risks

A summary of the mission risks is presented in Table 4-6. For the purpose of this DEIS, risk is defined as the expectation of health effects in a statistical sense (i.e., the product of total probability times the mean health effects resulting from a release, and then summed over all conditions leading to a release). The risk of health effects in the potentially exposed populations is determined for each mission phase and the overall mission. Since the health effects resulting from a release equals the sum of the probability of a health effect for each individual in the exposed population, risk can also be interpreted as the total probability of one health effect given the mission. The overall radiological risk for the Mars 2020 mission is estimated to be 2.6×10^{-5}. Thus, the total probability of one health effect for the Proposed Action (Alternative 1) is about 1 in 39,000.

Table 4-6. Summary of MMRTG Health Effect Mission Risks

Mission Phase [(a)]	Accident Probability	Conditional Probability of a Release	Total Probability of a Release	Mean Health Effects (given a release)	Mission Risks
0: Pre-Launch	3.3×10^{-5}	0.33	Very Unlikely (1.1×10^{-5})	0.0014	1.5×10^{-8}
1: Early Launch	3.1×10^{-3}	0.028	Very Unlikely (8.8×10^{-5})	0.29	2.5×10^{-5}
2: Late Launch	3.6×10^{-3}	0.0021	Very Unlikely (7.7×10^{-6})	7.8×10^{-5}	6.0×10^{-10}
3: Suborbital	1.3×10^{-2}	0.0013	Very Unlikely (1.5×10^{-5})	0.20	3.0×10^{-6}
4: Orbital	4.7×10^{-3}	0.056	Unlikely (2.6×10^{-4})	0.0026	6.8×10^{-7}
5: Long-term Reentry	1.0×10^{-6}	0.094	Extremely Unlikely (9.4×10^{-8})	0.0038	3.6×10^{-10}
Overall Mission	**2.5×10^{-2}**	**0.016**	**Unlikely (3.8×10^{-4})**	**0.076**	**2.9×10^{-5}**

Source: SNL 2014

(a) The table presents a composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5. Accident probabilities are the average of individual values for the two vehicles. Based on the current state of knowledge, the specific accident probabilities for the accident conditions for each vehicle are expected to be similar.

Differences in multiplications and summations are due to rounding of results as reported in SNL 2014.

Probability categories (i.e., unlikely, very unlikely) as defined by NASA.

The risk contribution from Phase 1 accidents, 2.5×10^{-5} (or a probability of about 1 in 40,000 that a health effect will occur), represents 87 percent of the radiological risk for

the Mars 2020 mission. The primary contributors to the Phase 1 risk in order of significance are (1) Low Altitude FTS, (2) FSII, and (3) On-Pad Explosion. Phase 3 contributes 10 percent of the overall mission risk, due primarily to releases from GPHS modules impacting hard surfaces (e.g., rock) following suborbital reentry and possibly other impact configurations up to and including the spacecraft.

The contributions to risk within 100 km (62 mi) of the launch site and in the global area are summarized in Table 4-7. The launch area risk is about 57 percent of the overall mission risk, while the risk to global areas is 43 percent. The launch area risks are due entirely from accidents during Phases 0 and 1, with Phase 1 being the primary contributor. The global risks are due to accidents in all mission phases, with Phase 1 being the primary contributor due to the atmospheric transport of small particles beyond 100 km from the launch site.

Table 4-7. MMRTG Health Effect Mission Risk Contributions by Affected Region

Mission Phase [(a)]	Mission Risks		
	Launch Area [(b)]	Global [(c)]	Total
0: Pre-Launch	8.9×10^{-9}	5.9×10^{-9}	1.5×10^{-8}
1: Early Launch	1.7×10^{-5}	8.9×10^{-6}	2.5×10^{-5}
2: Late Launch	—	6.0×10^{-10}	6.0×10^{-10}
3: Suborbital	—	3.0×10^{-6}	3.0×10^{-6}
4: Orbital	—	6.8×10^{-7}	6.8×10^{-7}
5: Long-term Reentry	—	3.6×10^{-10}	3.6×10^{-10}
Overall Mission	**1.7×10^{-5}**	**1.3×10^{-5}**	2.9×10^{-5}

Source: SNL 2014

(a) The table presents a composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.
(b) Phases 0 and 1: within 100 km (62 mi) of the launch site.
(c) Phase 3: southern Africa; Phase 4: land impacts between 29° north and 29° south latitude.
Note: Differences in summations may be due to rounding

Individual Risks (Maximum Exposed Individual)

Individual risk can be interpreted as the probability of a particular individual in the exposed population incurring a fatal cancer. For an accident near the launch site, not everyone within the regional area would be expected to receive a dose as a result of the accident. Due to meteorological conditions prevailing at the time of launch, only a portion of the total regional population is estimated to receive some measurable radiological exposure should an accident occur.

Even those individuals within the exposed population, such as those very close to the launch area that might receive the highest exposures, would face very small risks. The risk to the maximally exposed individual within the launch-area and global populations (Table 4-8) is estimated to be less than 1 in 300 million for the Mars 2020 mission. Most people in the potentially exposed population would have much lower risks.

Table 4-8. MMRTG Maximum Individual Risk

Mission Phase [(a)]	Release Probability	Maximum Individual Dose, (rem)	Maximum Individual Risk [(b), (c)]
0: Pre-Launch	Very Unlikely ($1.1x10^{-5}$)	0.00029	$1.9x10^{-12}$
1: Early Launch	Very Unlikely ($8.8x10^{-5}$)	0.060	$3.2x10^{-9}$
2: Late Launch	Very Unlikely ($7.7x10^{-6}$)	$1.6x10^{-5}$	$7.6x10^{-14}$
3: Suborbital	Very Unlikely ($1.5x10^{-5}$)	0.043	$3.8\ x10^{-10}$
4: Orbital	Unlikely ($2.6X10^{-4}$)	0.0005	$8.5\ x10^{-11}$
5: Long-term Reentry	Extremely Unlikely ($9.4x10^{-8}$)	0.0008	$4.5\ x10^{-14}$

Source: SNL 2014

(a) A composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.
(b) Determined as the product of total probability of release, maximum individual dose (mean value) and a health effects estimator of $6x10^{-4}$ latent cancer fatalities per rem.
(c) The individuals associated with the maximum individual risk in Phase 0 and 1 are assumed to be the same individual, so the two risks are additive. The individuals associated with the maximum individual risk in Phases 3, 4, and 5 would not be the same individual due to different global regions potentially affected.
Probability categories (i.e., unlikely, very unlikely) as defined by NASA.

The individual risk estimates are small compared to other risks. For example, Table 4-9 presents information on annual individual fatality risks to residents of the United States due to various types of hazards. This data indicates that in 2010 the average individual risk of accidental death in the United States was about 1 in 2,600 per year, while the average individual risk of death due to any disease, including cancer, was about 1 in 140.

4.1.4.8. Uncertainty

An uncertainty analysis to estimate uncertainties in probabilities, source terms, radiological consequences, and mission risks has not been performed as part of this report. Based on experience with uncertainty analyses in the risk assessment of previous missions (e.g., for the Cassini, Mars Exploration Rover, New Horizons, and Mars Science Laboratory missions), the uncertainty in the estimated mission risk for the Mars 2020 mission can be approximated. The FSAR analysis for those missions indicate that the uncertainty is dominated by the uncertainty associated with the launch vehicle accident probabilities. The 5th and 95th percentile accident probabilities are about a factor of 25 lower and higher, respectively, than the accident median probabilities. The Mars 2020 mission risk estimate of $2.9x10^{-5}$ (or a probability of about 1 in 34,000 that a health effect would occur) can be treated as the median of the uncertainty probability distribution (i.e., it is equally probable that the mission risk could be higher or lower than this value). The mission risks at the 5th and 95th percent confidence levels are then estimated to be $1.2x10^{-6}$ (or a probability of about 1 in 860,000 that a health effect will occur) and $7.3x10^{-4}$ (or a probability of about 1 in 1,400 that a health effect will occur), respectively.

Table 4-9. Calculated Individual Risk and Probability of Fatality by Various Causes in the United States in 2010

Accident Type	Number of Fatalities	Approximate Individual Risk Per Year	Probability
Extremely Unlikely			
Lightning	29	9.39×10^{-8}	1 in 11 million
Tornadoes	45	1.46×10^{-7}	1 in 6.9 million
Flood	103	3.33×10^{-7}	1 in 3 million
Extreme Heat or Cold	172	5.57×10^{-7}	1 in 1.8 million
Very Unlikely			
Legal Intervention	412	1.33×10^{-6}	1 in 750,000
All Weather	490	1.59×10^{-6}	1 in 630,000
Accidental Discharge of Firearms	606	1.96×10^{-6}	1 in 510,000
Water, Air and Space Transport Accidents (includes unspecified transport accidents)	1,600	5.18×10^{-6}	1 in 190,000
Accidental Exposure to Smoke, Fires and Flames	2,782	9.01×10^{-6}	1 in 110,000
Accidental Drowning and Submersion	3,782	1.22×10^{-5}	1 in 82,000
All Fatal Injuries at Work	4,690	1.52×10^{-5}	1 in 66,000
Assault (Homicide)	16,259	5.27×10^{-5}	1 in 19,000
Alcohol-induced deaths	25,692	8.32×10^{-5}	1 in 12,000
Falls	26,009	8.42×10^{-5}	1 in 12,000
Accidental Poisoning and Exposure to Noxious Substances	33,041	1.07×10^{-4}	1 in 9,300
Motor Vehicle	35,332	1.14×10^{-4}	1 in 8,700
Suicide	38,364	1.24×10^{-4}	1 in 8,000
Drug-induced deaths	40,393	1.31×10^{-4}	1 in 7,600
All Accidents	120,859	3.91×10^{-4}	1 in 2,600
Unlikely			
All Diseases	2,254,585	7.30×10^{-3}	1 in 140
All Causes	**2,468,435**	**7.99×10^{-3}**	**1 in 125**

Sources: USBC 2013b, BLS 2013, NOAA 2013, HHS 2013.

Note: The census population of the United States for the year 2010 was 308,745,538.

4.1.5 Radiological Impacts Due to Accidents Releasing Science Instrumentation Source Terms

The Mars 2020 mission may include instrumentation that requires the use of small quantities of radioactive material. While the specific suite of instrumentation has not

been identified, instruments incorporating small sources have been used in past missions. The DOE performed a risk assessment using a representative instrument and source term, and information in previous risk assessments that addressed these types of sources. Since the instrument package for the Mars 2020 mission should be independent of the power source—MMRTG, solar, or solar augmented with LWRHUs—this analysis is applicable to all alternatives being considered.

4.1.5.1. Response to Accident Environments and Accident Probabilities and Source Terms

Unlike the MMRTG and the LWRHUs, the radioisotope sources in the science instruments are not designed to be contained in a launch accident. For example, the Cm-244 in an Alpha-Particle X-Ray Backscatter Spectrometer (APXS) is mounted close to a 3-micron-thick foil so that its alpha particles can probe the rocks on Mars. The MER EIS (NASA 2002b) presents estimated probabilities of release in an accident. These numbers are reproduced for the APXS Cm-244 and only the phase roll-ups are given. The mean release, given a release, is also obtained from the MER EIS (NASA 2002b). However, a launch accident is not always severe enough to cause a release. This results in a conditional probability of release less than one. Detailed analyses to obtain the 99th percentiles were not conducted.

The risks from other source terms from instruments considered for analysis in the DOE NRA (the Co-57 in the Mossbauer spectrometer and the tritium in the Dynamic Albedo of Neutrons (DAN) instrument), are orders of magnitude lower than for the Cm-244 because of the much lower energy of the emitted gamma rays or beta particles and the lower quality factor of the radiation. The risks associated with these possible source terms were not analyzed. Thus, the reported source terms, consequences, and risks are for the Cm-244 in the APXS, and these are expected to approximate the source terms and consequences for all the science instruments.

The probability of a launch accident involving any release of radioactive material from the science instruments is approximately 1 in 87. Because the science instrument radioisotope must be relatively unprotected to perform its function, both the probability of release and the quantity of material released is only slightly affected by the accident environments. The source term values in all phases vary by at most a factor of about 6.

A summary of the accident and source term probabilities by mission phase, along with mean source terms, are presented in Table 4-10.

- **Phase 0 (Pre-Launch):** During the Pre-launch period prior to ignition of the Stage 1 liquid rocket engine, on-pad accidents could result in a release at a total probability of 1.8×10^{-6} (one in 550,000). The mean source term given an accident is estimated to be 0.018 Ci, and the mean source term given a release is estimated to be 0.033 Ci.

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Table 4-10. Summary of Science Instrumentation Radioisotope Accident Probabilities and Source Terms

Mission Phase [(a)]	*Accident Probability*	Conditional Probability of Release [(b)]	Total Probability of a Release	Mean Source Term Given an Accident	Mean Source Term Given a Release
0: Pre-Launch	Very Unlikely ($3.3x10^{-6}$)	0.56	Very Unlikely ($1.8x10^{-6}$)	0.018	0.033
1: Early Launch	Unlikely $3.1x10^{-3}$	0.19	Unlikely ($6.0x10^{-4}$)	0.0021	0.011
2: Late Launch	Unlikely $3.6x10^{-3}$	0.032	Unlikely ($1.2x10^{-4}$)	0.00097	0.030
3: Suborbital	$1.3x10^{-2}$	0.50	Unlikely ($6.6x10^{-3}$)	0.015	0.030
4: Orbital	Unlikely ($4.7x10^{-3}$)	0.90	Unlikely ($4.2X10^{-3}$)	0.027	0.030
5: Long-term Reentry	Very Unlikely ($1.0x10^{-6}$)	1.00	Very Unlikely ($1.0x10^{-6}$)	0.060	0.060
Overall Mission [(c)]	**$2.5x10^{-2}$**	**0.47**	**$1.2x10^{-2}$**	**0.013**	**0.028**

Source: SNL 2014

(a) The table presents a composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.
(b) The conditional probability of a release of Cm-244 given that an accident has occurred.
(c) Overall mission values weighted by total probability of release for each mission phase.
Notes: Differences in multiplications and summations are due to rounding of results as reported in SNL 2014.
Probability categories (i.e., unlikely, very unlikely) as defined by NASA.

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- **Phase 1 (Early Launch):** During Phase 1, during which there is the potential for land impacts in the launch area, the total probability of release is 6.0×10^{-4} (one in 1,700). The mean source term given an accident with a release is estimated to be 0.011 Ci.
- **Phase 2 (Late Launch):** In Phase 2, all accidents lead to impact of debris in the Atlantic Ocean. However, there are some releases into the air from blast-generated debris. The total probability of release is 1.2×10^{-4} (one in 8,300). The mean source term given an accident with a release is estimated to be 0.030 Ci.
- **Phase 3 (Suborbital):** Accidents during Phase 3 include suborbital reentries. Prior to the attainment of Earth park orbit, these conditions could lead to prompt suborbital reentry within minutes. This could result in impacts of the intact SV entry vehicle along the vehicle flight path over the Atlantic Ocean and Africa. Additional suborbital land impacts are possible after crossing over Africa, depending on the launch vehicle selected and its nominal mission timeline. Should the SV impact land, releases are possible. The total probability of release in Phase 3 is estimated to be 6.6×10^{-3} (or 1 in 150). The mean source term given an accident with a release is estimated to be 0.030 Ci.
- **Phase 4 (Orbital):** Accidents that may occur after attaining park orbit could result in orbital decay reentries from minutes to years after the accident, affecting Earth surfaces between approximately 29° north latitude and 29° south latitude. The SV would break apart during reentry, releasing the LWRHUs before impact. The total probability of release is estimated to be 4.2×10^{-3} (or 1 in 240). The mean source term given an accident with a release is estimated to be 0.030 Ci.
- **Phase 5 (Long-term Reentry):** The potential exists for an inadvertent long-term (hundreds to thousands of years) reentry should the SC be left in an Earth crossing orbit. Based on considerations of long-term inadvertent reentry for other missions, the probability of such an occurrence is estimated to be less than 1×10^{-6}, 1 in 1,000,000. The mean source term given an accident with a release is estimated to be 0.060 Ci.

The specific probability values presented in this DEIS are estimates and will likely differ from those that might ultimately be developed in the more detailed FSAR that would be prepared by DOE if the Proposed Action (Alternative 1) is selected. Some probabilities would likely increase while others may decrease. However, NASA expects the overall probability of an accidental release of radioactive material would not vary substantially from the values presented in this DEIS.

4.1.5.2. Radiological Consequences

The radiological consequences of a given accident that results in a radiological release have been calculated in terms of maximum individual dose, collective dose, health effects, and land area contaminated at or above specified levels. The analysis of the radiological consequences associated with the science instrument small source term CM-244, was performed using the same techniques as previously described for the analysis of the consequences associated with the release of plutonium dioxide. Key results for the mean estimates are summarized below and in Table 4-11.

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Table 4-11. Summary of Science Instrumentation Radioisotope Estimated Radiological Consequences

Mission Phase [(a)]	Total Probability of Release	Mean Maximum Individual Dose, rem	Mean Health Effects [(b)]	Mean Land Contamination [(c)] km^2
0: Pre-Launch	Very Unlikely ($1.8x10^{-6}$)	$3.4x10^{-5}$	0.00016	0.0041
1: Early Launch	Unlikely ($6.0x10^{-4}$)	$1.1x10^{-5}$	$5.3x10^{-5}$	0.0014
2: Late Launch	Unlikely ($1.2x10^{-4}$)	$3.1x10^{-5}$	0.00015	0.0038
3: Suborbital	Unlikely ($6.6x10^{-3}$)	$3.1x10^{-5}$	0.00015	0.0038
4: Orbital	Unlikely ($4.2X10^{-3}$)	$3.1x10^{-5}$	0.00015	0.0038
5: Long-Term Reentry	Very Unlikely ($1.0x10^{-6}$)	$6.1x10^{-5}$	0.00029	0.0075
Overall Mission [(d)]	**$1.2x10^{-2}$**	**$3.0x10^{-5}$**	**0.00014**	**$3.6x10^{-3}$**

Source: SNL 2014

(a) The table presents a composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results and treating the conditional probability of having a given launch vehicle as 0.5. All values are for an accident with a release.

(b) Based on ISCORS health effects recommendation of $6x10^{-4}$ health effects per person-rem for the general population.

(c) Land area contaminated above 0.2 $\mu Ci/m^2$; 1 km^2 = 0.386 mi^2.

(d) Overall mission values weighted by total probability of release for each mission phase.

Notes: Differences in multiplications and summations are due to rounding of results as reported in SNL 2014.
Probability categories (i.e., unlikely, very unlikely) as defined by NASA.

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The consequences associated with the instrumentation source term are very similar for all launch phases. In general, the range of consequences varies by less than an order of magnitude (less than a factor of 10). The largest impacts are associated with Phase 5, the long-term reentry phase. For this phase, the maximum individual dose is 6.1×10^{-5} rem, the collective population dose results in 0.00029 health effects; land contamination above the 0.2 μCi/m^2 level would be 0.0075 km^2 (2.9×10^{-3} mi^2, 1.9 acres).

4.1.5.3. Discussion of the Results

Maximum Individual Doses

The maximum individual dose is the maximum dose delivered to a single individual for each accident. During all phases, the predicted mean radiation dose to the maximally exposed individual ranges from about 1.1×10^{-5} rem (0.011 millirem) up to about 6.1×10^{-5} rem (0.061 millirem). The largest maximum individual dose is about two percent of the dose from natural background radiation. No short-term radiological effects would be expected from any of these exposures.

Population Exposures

The population exposure is the dose delivered to all affected individuals for each accident. During all phases, the predicted mean population dose are sufficiently small that no short-term radiological effects (the largest estimate of the number of latent cancer fatalities is 0.00029) would be expected from any of these exposures.

In the event of a launch area accident, it is unlikely that any given racial, ethnic, or socioeconomic group of the population would bear a disproportionate share of the consequences.

Impacts of Radiological Releases on the Environment

The affected environment, described in Section 3 of this DEIS, includes the regional area near CCAFS and the global area. Launch area accidents (Phases 0 and 1) would initially release material into the regional area, defined in this DEIS to be within 100 km (62 mi) of the launch pad. Since some of the accidents result in the release of very fine particles (less than a micron in diameter), a portion of such releases could be transported beyond 100 km (62 mi) and become well mixed in the troposphere, and thus affecting the global environment. Releases during Phase 3 could involve reentering material that could impact the ground in southern Africa. Releases during Phase 4 could affect the environment anywhere between 29° north latitude and 29° south latitude.

DOE's risk assessment indicates that, for all phases, an area of between 1.4×10^{-3} km^2 (5.4×10^{-4} mi^2, 0.35 acres) to 0.0075 km^2 (0.0029 mi^2, 1.9 acres) could be contaminated above 0.2 μCi/m^2.

4.1.5.4. Mission Risks

A summary of the mission risks is presented in Table 4-12. For the purpose of this DEIS, risk is defined as the expectation of health effects in a statistical sense (i.e., the product of total probability times the mean health effects resulting from a release and then summed over all conditions leading to a release). The risk of health effects in the

potentially exposed populations is determined for each mission phase and the overall mission. Since the health effects resulting from a release equals the sum of the probability of a health effect for each individual in the exposed population, risk can also be interpreted as the total probability of one health effect given the mission. The overall radiological risk from the instrument small source radioisotopes for the Mars 2020 mission is estimated to be $1.6x10^{-6}$. Thus, the total probability of one health effect for the Proposed Action (Alternative 1) resulting from the use of Cm-244 in a science instrument is about 1 in 690,000.

Table 4-12. Summary of Instrumentation Radioisotope Health Effect Mission Risks

Mission Phase [(a)]	Accident Probability	Conditional Probability of a Release	Total Probability of a Release	Mean Health Effects (given an release)	Mission Risks
0: Pre-Launch	Very Unlikely ($3.3x10^{-6}$)	0.56	Very Unlikely ($1.8x10^{-6}$)	0.00016	$3.0x10^{-10}$
1: Early Launch	Unlikely $3.1x10^{-3}$	0.19	Unlikely ($6.0x10^{-4}$)	$5.3x10^{-5}$	$3.2x10^{-8}$
2: Late Launch	Unlikely $3.6x10^{-3}$	0.032	Unlikely ($1.2x10^{-4}$)	0.00015	$1.7x10^{-8}$
3: Suborbital	$1.3x10^{-2}$	0.50	Unlikely ($6.6x10^{-3}$)	0.00015	$9.6x10^{-7}$
4: Orbital	Unlikely ($4.7x10^{-3}$)	0.90	Unlikely ($4.2X10^{-3}$)	0.00015	$6.1x10^{-7}$
5: Long-Term Reentry	Very Unlikely ($1.0x10^{-6}$)	1.00	Very Unlikely ($1.0x10^{-6}$)	0.00029	$2.9x10^{-10}$
Overall Mission	**$2.5x10^{-2}$**	**0.47**	**$1.2x10^{-2}$**	**0.00014**	**$1.6x10^{-6}$**

Source: SNL 2014

(a) A composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5. Accident probabilities are the average of individual values for the two vehicles. Based on the current state of knowledge, the specific accident probabilities for the accident conditions for each vehicle are expected to be similar.

Notes: Differences in multiplications and summations are due to rounding of results as reported in SNL 2014.
Probability categories (i.e., unlikely, very unlikely) as defined by NASA.

The risk contribution from Phase 3 accidents represents 59 percent of the radiological risk for the Mars 2020 mission. Phase 4 contributes 38 percent of the overall mission risk.

The global risks are due to accidents in all mission phases and, because Phases 3 and 4 are the dominant risk contributing phases, most of the risk is to the global area—over 98 percent. The contribution to risk within 100 km (62 mi) of the launch site is about 1.4 percent. The launch area risks are due entirely from accidents during Phases 0 and 1.

Individual Risks (Maximum Exposed Individual)

Individual risk can be interpreted as the probability of an individual in the exposed population incurring a fatal cancer. For an accident near the launch site, not everyone

within the regional area would be expected to receive a dose as a result of the accident. Due to meteorological conditions prevailing at the time of launch, only a portion of the total regional population is estimated to receive some measurable radiological exposure should an accident occur.

Even those individuals within the exposed population that receive the maximum individual dose would face very small risks. The risk to the maximally exposed individual within the launch area and global populations from the release of the instrumentation radioisotopes is estimated to be exceedingly small for the Mars 2020 mission (Table 4-13).

Table 4-13. Instrumentation Radioisotope Maximum Individual Risk

Mission Phase [(a)]	Release Probability	Maximum Individual Dose, (rem)	Maximum Individual Risk [(b), (c)]
0: Pre-Launch	Very Unlikely ($1.8x10^{-6}$)	$3.4x10^{-5}$	$3.7x10^{-14}$
1: Early Launch	Unlikely ($6.0x10^{-4}$)	$1.1x10^{-5}$	$4.0x10^{-12}$
2: Late Launch	Unlikely ($1.2x10^{-4}$)	$3.1x10^{-5}$	$2.2x10^{-12}$
3: Suborbital	Unlikely ($6.6x10^{-3}$)	$3.1x10^{-5}$	$1.2x10^{-10}$
4: Orbital	Unlikely ($4.2X10^{-3}$)	$3.1x10^{-5}$	$7.7x10^{-11}$
5: Long-Term Reentry	Very Unlikely ($1.0x10^{-6}$)	$6.1x10^{-5}$	$3.7x10^{-14}$

Source: SNL 2014

(a) A composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.

(b) Determined as the product of total probability of release, maximum individual dose (mean value), and a health effects estimator of $6x10^{-4}$ latent cancer fatalities per rem.

(c) The individuals associated with the maximum individual risk in Phase 0 and 1 are assumed to be the same individual, so the two risks are additive. The individuals associated with the maximum individual risk in Phases 3, 4, and 5 would not be the same individual due to different global regions potentially affected.

Note: Probability categories (i.e., unlikely, very unlikely) as defined by NASA.

4.1.6 Radiological Contingency Response Planning

Prior to launch of the Mars 2020 mission, a comprehensive set of plans would be developed by NASA to ensure that any launch accident could be met with a well-developed and tested response. NASA's plans would be developed in accordance with the National Response Framework (NRF) (DHS 2013) and the NRF Nuclear/ Radiological Incident Annex (DHS 2008) with the combined efforts of the U.S. Department of Homeland Security (DHS), DHS's Federal Emergency Management Agency, DOE, the U.S. Department of Defense (DoD), the U.S. Department of State (DOS), the U.S. Environmental Protection Agency (EPA), the state of Florida, Brevard County, and local organizations. These organizations and other Federal agencies, as appropriate, could be involved in response to a radiological emergency. The radiological contingency planning and implementation for a Mars 2020 mission would be expected to be similar to the process used for the 2011 MSL mission launch (Scott 2012).

The radiological emergency response plan would be exercised prior to launch to verify that the response interfaces, command channels, and field response-organizations

would be prepared to respond in the unlikely event of a launch accident. NASA would be the Coordinating Agency, and in the event of a declaration of an Incident of National Significance, would work with the DHS to coordinate the entire Federal response for launch accidents occurring within United States jurisdiction. Should a release of radioactive material occur in the launch area, the state of Florida, Brevard County, and local governments would determine an appropriate course of action for any regional areas (such as sheltering in place, evacuation, exclusion of people from contaminated land areas, or no action required) and would have full access to the coordinated Federal response. For accidents outside United States jurisdiction defined as Incidents of National Significance, NASA and DHS would assist the DOS in coordinating the United States' response via diplomatic channels and in deploying Federal resources as requested.

To manage the radiological contingency response, NASA would establish a radiological emergency response capability that would include a radiological assessment and command center, as well as field monitoring assets deployed prior to launch. The assessment and command center would be the focal point for NASA and DHS coordination efforts. This center would also be used to coordinate the initial Federal response to a radiological contingency until the Mars 2020 spacecraft has left Earth orbit. Pre-deployed assets to support a response to a potential launch accident would include representation from NASA, DHS, DOE, DoD, DOS, EPA, USAF, the National Oceanic and Atmospheric Administration (NOAA), the state of Florida, and Brevard County.

If impact of the Mars 2020 spacecraft occurs in the ocean following an accident, NASA would coordinate with the DHS, the U.S. Coast Guard, the U.S. Navy, and DOE to initiate security measures and assess the feasibility of search and retrieval operations. Efforts to recover the MMRTG or its components would be based on technical feasibility and consideration of any potential health hazards presented to recovery personnel and potential environmental impacts.

4.2 ENVIRONMENTAL IMPACTS OF ALTERNATIVE 2

With Alternative 2, NASA would discontinue preparations for the Proposed Action (Alternative 1) and implement an alternative Mars 2020 mission. The alternative Mars 2020 mission would include an autonomous rover that would perform science operations on the surface of Mars. Instead of an MMRTG, a solar array would provide the necessary electric power to operate the Mars 2020 rover and its science instruments.

The non-radiological impacts for this alternative would be identical to those described for Alternative 1 and are addressed in Sections 4.2.1 through 4.2.3.

4.2.1 Environmental Consequences of Preparing for Launch

With Alternative 2, the potential environmental consequences of preparing for launch would be the same as those described in Section 4.1.1 for the Proposed Action, with the exception that some spacecraft and launch vehicle integration personnel would not be exposed to radiation from the MMRTG during pre-launch testing and integration, since a

radioisotope power system, the MMRTG, would not be used as the source of electrical power for the Alternative 2 Mars 2020 rover.

4.2.2 Environmental Impacts of a Normal Launch

With Alternative 2, the primary environmental impacts of a normal launch of the Mars 2020 mission would be the same as those described in Section 4.1.2 for the Proposed Action (Alternative 1).

4.2.3 Non Radiological Environmental Impacts of Potential Accidents

With Alternative 2, the environmental non-radiological impacts of potential accidents would be the same as those described in Section 4.1.3 for the Proposed Action (Alternative 1).

4.2.4 Radiological Environmental Impacts of Potential Accidents

If the rover should be equipped with science instrumentation that incorporates small radioisotope sources, the radiological risks from the release of these materials during an accident would be identical to those presented in Section 4.1.5. These risks are applicable to any rover that is equipped with this instrumentation, regardless of whether the power supply is an MMRTG, a solar array, or a solar array augmented with LWRHUs.

4.3 ENVIRONMENTAL IMPACTS OF ALTERNATIVE 3

In Alternative 3, NASA would discontinue preparations for the Proposed Action (Alternative 1) and implement an alternative Mars 2020 mission. The alternative Mars 2020 mission would include an autonomous rover that would perform science operations on the surface of Mars. A solar array would provide the necessary electric power to operate the Mars 2020 rover and its science instruments. In addition, the power from the solar array would be augmented by up to 71 LWRHUs. These LWRHUs would be used to provide thermal power to maintain the internal temperature of the rover within the required limits to ensure equipment and instrumentation survivability.

The non-radiological impacts for this alternative would be identical to those identified for the Proposed Action (Alternative 1) and are addressed in Sections 4.3.1 through 4.3.3. Environmental impacts of potential accidents involving radiological material for the rover powered by a solar array augmented with LWRHUs are addressed in Section 4.3.4 and Section 4.1.5. The impacts discussed in Section 4.3.4 are those associated with the release of PuO_2 from the LWRHUs during an accident. If the rover should be equipped with science instrumentation that incorporates small radioisotope sources, the radiological risks from the release of these materials during an accident would be identical to those presented in Section 4.1.5. These risks would be applicable to any rover that is equipped with this instrumentation, regardless of whether the power supply is an MMRTG, a solar array, or a solar array augmented with LWRHUs.

4.3.1 Environmental Consequences of Preparing for Launch

With Alternative 3, the potential environmental consequences of preparing for launch would be the same as those described in Section 4.1.1 for the Proposed Action, with the

exception that some spacecraft and launch vehicle integration personnel would not be exposed to radiation from the MMRTG during pre-launch testing and integration, since a radioisotope power system, the MMRTG, would not be used as the source of electrical power for the Alternative 3 Mars 2020 rover.

4.3.2 Environmental Impacts of a Normal Launch

With Alternative 3, the primary environmental impacts of a normal launch of the Mars 2020 mission would be the same as those described in Section 4.1.2 for the Proposed Action (Alternative 1).

4.3.3 Non-radiological Environmental Impacts of Potential Accidents

With Alternative 3, the environmental non-radiological impacts of potential accidents would be the same as those described in Section 4.1.3 for the Proposed Action.

4.3.4 Radiological Environmental Impacts of Potential Accidents Involving Plutonium

NASA and the U.S. Department of Energy (DOE) have assessed the potential environmental impacts of launch accidents involving release of PuO_2. The likelihood that a malfunction or system failure would lead to launch accident is essentially the same for this alternative (a solar-powered rover with LWRHUs) as for Alternative 1 (an MMRTG powered rover).The analysis results indicate that the most likely outcome of implementing this alternative version of the Mars 2020 mission is a successful launch of the spacecraft toward Mars. If, however, a launch accident were to occur, the most probable outcome is an accident without a release of the PuO_2. Specifically:

- There is a 97.5% chance of a successful launch.
- There is a 2.5% chance of a launch accident.
- There is a 1 in 15,000 chance of a launch accident that would release plutonium dioxide.
    - There is a 1 in 16,000 chance of a launch accident that would result in a release of plutonium dioxide in the launch area.
    - There is a 1 in 420,000 chance of a launch accident that would result in a release of plutonium dioxide outside the launch area.
- No radiological fatalities would be expected to occur as a result of any accident.
- The average maximum dose to any member of the public would be equal to about 5 days of exposure to natural background radiation for a person living in the United States.

This section summarizes the results from the DOE's nuclear risk assessment (SNL 2014) for the solar-powered rover with LWRHUs.

4.3.4.1. Risk Assessment Methodology

The nuclear risk assessment for this alternative for the Mars 2020 mission was performed using the same methodology as that used for Alternative 1. The discussion of the methodology is contained in Section 4.1.4.1. The DOE risk analysis was performed assuming that 80 LWRHUs could be used on the Mars 2020 rover. This is slightly more

than the 71 LWRHUs that NASA anticipates could be used on the rover. The DOE analysis conservatively assumed more LWRHUs to address the possibility that design requirements could change requiring more thermal power to maintain the proper environment for rover equipment and instrumentation.

Safety testing and response analyses of the LWRHU to accident environments indicate that the protection provided by graphitic components and the platinum-30 rhodium (Pt-30Rh) clad encapsulating the PuO_2 fuel, makes releases unlikely due to purely mechanical damage, including overpressures and fragments. The primary release mechanism is from impact by very heavy LV fragments. Another release mode is from exposure to high-temperature burning solid-propellant fuel, which could lead to clad melting and partial vaporization of the PuO_2. Should the aeroshell and/or cladding be damaged or stripped, a greater amount of fuel could be vaporized. If the aeroshell remains intact, any vaporized fuel release would be limited to that which permeates through the graphitic components of the aeroshell, which would be a very small fraction (about 1/1000) of that vaporized fuel associated with a bare clad.

4.3.4.2. Launch Accidents and Accident Probabilities

Launch accidents and their associated probabilities were identified and developed using the methodology described in Section 4.1.4.2. As in the analysis for Alternative 1, the analysis considered two representative launch vehicles (the Atlas V 551 and the Delta IV Heavy) in developing the composite analysis results. The same six mission phases were identified for the analysis.

- Phase 0 - Pre-Launch,
- Phase 1 - Early Launch,
- Phase 2 - Late Launch,
- Phase 3 - Suborbital Reentry,
- Phase 4 - Orbit Reentry, and
- Phase 5 – Long-term Reentry.

The composite accident end-state probabilities for the launch vehicle are presented in Table 4-14. The only difference between these accident probabilities and those developed for Alternative 1 (Table 4-2) is in Phase 0. Because there is no MMRTG in this alternative, the accidents associated with loss of MMRTG cooling during Phase 0 are not applicable to this alternative. Therefore, the Phase 0 accident probability for the Mars 2020 mission using solar power augmented with LWRHUs is smaller (3.3×10^{-6} instead of 3.3×10^{-5}) than for the Mars 2020 MMRTG alternative.

Table 4-14. Alternative 3: Accident End-state Probabilities

Ground Impact Configuration	Phase 0	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Total Probability
On-Pad Explosion	$4.8x10^{-7}$	$9.8x10^{-5}$	-	-	-	-	$1.2x10^{-4}$
FSII	-	$2.2x10^{-5}$	-	-	-	-	$2.2x10^{-5}$
Stage 2/SV	-	$4.8x10^{-5}$	-	-	-	-	$4.8x10^{-5}$
SVII	$2.8x10^{-6}$	$6.3x10^{-7}$	-	-	-	-	$3.4x10^{-6}$
Low Altitude FTS	-	$2.9x10^{-3}$	-	-	-	-	$2.9x10^{-3}$
High Altitude FTS	-	-	$3.6x10^{-3}$	-	-	-	$3.6x10^{-3}$
Sub-Orbital Reentry	-	-	-	$1.3x10^{-2}$	-	-	$1.3x10^{-2}$
Orbital Reentry	-	-	-	-	$4.7x10^{-3}$	-	$4.7x10^{-3}$
Long Term	-	-	-	-	-	$1.0x10^{-6}$	$1.0x10^{-6}$
Total	**$3.3 x10^{-6}$**	**$3.1x10^{-3}$**	**$3.6x10^{-3}$**	**$1.3x10^{-2}$**	**$4.7x10^{-3}$**	**$1.0x10^{-6}$**	**$2.5x10^{-2}$**

Source: SNL 2014

Note: This is a composite of the accident end state probabilities for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.

For this DEIS, the initiating probabilities and total probabilities of an accident with a release of PuO2 are grouped into categories that allow for a descriptive characterization of the likelihood of each accident. The categories and their associated probability ranges are:

- unlikely: 10-2 to 10-4 (1 in 100 to 1 in 10 thousand);
- very unlikely: 10-4 to 10-6 (1 in 10 thousand to 1 in 1 million); and
- extremely unlikely: less than 10-6 (less than 1 in 1 million).

The potential accident environments associated with accidents include blast (explosion overpressure), fragments, thermal energy (burning liquid propellant and/or solid propellant), reentry conditions (aerodynamic loads and heating), and surface impact. A given accident could involve one or more sequential and/or simultaneously occurring accident environments. The nature and severity of such environments would be a function of the type of accident and its timing (relative to launch) of occurrence.

4.3.4.3. LWRHU Response to Accident Environments

Most launch accidents in Phases 0, 1, and 3 would lead to intact impact of various SV/launch vehicle configurations. The resulting impact could lead to mechanical damage of the LWRHU aeroshell, depending on the orientation at impact, and subsequent exposure to burning solid propellant. This, in turn, could potentially lead to PuO_2 releases from the fire. In addition, impact by large pieces of LV or SV debris could lead to some mechanical release of PuO_2.

Phase 2 results in water impact and no release. For Phases 4 and 5 of the mission, accidents could lead to reentry heating and ground impact environments. The LWRHU is designed to survive the reentry environments and subsequent surface impacts. No clad melt, eutectic formation with graphitics, or release is expected from impact following orbital or suborbital reentry.

4.3.4.4. Accident Probabilities and Source Terms

In the nuclear risk assessment, DOE evaluated each of the identified end states and estimated the accident environments to which the LWRHUs would likely be exposed. From that information, conditional probabilities that a release would occur and estimated source terms were developed based on the known response of LWRHUs to various accident conditions.

As discussed earlier, the probability of a launch accident involving any release of PuO_2 is very small, approximately 1 in 15,000. The most severe accident environments would occur during launch area accidents that might expose the LWRHUs to mechanical impacts, explosion overpressures and fragments, and fire environments from burning liquid and solid propellants.

A summary of the accident and source term probabilities by mission phase, along with mean and 99th percentile source terms, is presented in Table 4-15. For the purpose of this DEIS, "source term" is defined as that portion of the release that becomes airborne and could be transported downwind.

The 99th percentile source term is the value predicted to be exceeded with a probability of 0.01 (1 in 100), given a release in an accident. In this context, the 99th percentile value reflects the potential for higher radionuclide releases at lower probabilities. The 99th percentile releases are up to 36 times the mean estimates reported in this DEIS, but at probabilities of a factor of 100 lower than the mean probabilities. Essential features of the results are summarized below.

- **Phase 0 (Pre-Launch):** During the pre-launch period, prior to ignition of the Stage 1 liquid rocket engine, most initiating failures result in a mission abort. Those failures that result in on-pad accidents could result in a release at a total probability of 3.1×10^{-7} (1 in 3,200,000). The mean source term, given that an accident with a release has occurred, is estimated to be 3.0 Ci.
- **Phase 1 (Early Launch):** During Phase 1, during which land impacts, including near the launch complex, are likely, the accidents resulting in a release have a total probability estimate of 6.2×10^{-5} (or 1 in 16,000). The mean source term, given an accident with a release has occurred, is estimated to be 4.1 Ci.

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Table 4-15. Alternative 3: Summary of Accident Probabilities and LWRHU Source Terms

Mission Phase [(a)]	Accident Probability	Source Term, Ci (given an accident)		Conditional Probability of Release [(b)]	Total Probability of a Release	Source Term [(c)], Ci (given a release)	
		Mean	99th Percentile			Mean	99th Percentile
0: Pre-Launch	Very Unlikely ($3.3x10^{-6}$)	0.28	5.0	0.093	Extremely Unlikely ($3.1x10^{-7}$)	3.0	21
1: Early Launch							
On-Pad Explosion	Very Unlikely ($9.8x10^{-5}$)	0.16	2.7	0.12	Very Unlikely ($1.2x10^{-5}$)	1.3	3.2
FSII	Very Unlikely ($2.2x10^{-5}$)	8.1	270	0.13	Very Unlikely ($3.0x10^{-6}$)	60	380
Stage 2/SV	Very Unlikely ($4.8x10^{-5}$)	0.020	0.84	0.017	Extremely Unlikely ($8.0x10^{-7}$)	1.2	5.1
SVII	Extremely Unlikely ($6.3x10^{-7}$)	0.062	2.0	0.047	Extremely Unlikely ($2.9x10^{-8}$)	1.3	4.3
Low Altitude FTS	Unlikely ($2.9x10^{-3}$)	0.020	0.67	0.016	Very Unlikely ($4.6x10^{-5}$)	1.3	6.1
Overall Phase 1	Unlikely ($3.1x10^{-3}$)	0.082	0.89	0.020	Very Unlikely ($6.2x10^{-5}$)	4.1	76
2: Late Launch	$3.6x10^{-3}$	-	-	–	–	-	-
3: Suborbital	$1.3x10^{-2}$	0.00022	-	0.00018	Very Unlikely ($2.4x10^{-6}$)	1.2	4.6
4: Orbital	Unlikely ($4.7x10^{-3}$)	-	-	-	-	-	-
5: Long-term Reentry	Very Unlikely ($1.0x10^{-6}$)	-	-	-	-	-	-
Overall Mission [(d)]	**$2.5x10^{-2}$**	**0.011**	**-**	**0.0026**	**Very Unlikely ($6.5x10^{-5}$)**	**4.0**	**73**

Source: SNL 2014

(a) A composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.

(b) The conditional probability of a release of PuO2 given that an accident has occurred.

(c) Total source terms given. The source term is that portion of the release which becomes airborne would represent the amounts of PuO_2 released that are no more than 100 microns (100 micrometers) in diameter. Particles larger than this do not generally become airborne and would remain in the vicinity of the accident.

(d) Overall mission values are weighted by the total probability of release for each mission phase.

Notes: Differences in multiplications and summations are due to rounding of results as reported in SNL 2014.

Probability categories (i.e., unlikely, very unlikely) as defined by NASA.

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Most initiating failures occurring in Phase 1 would lead to activation of the FTS. The elements of the FTS are highly redundant and reliable. As a result, the expected outcome of a Phase 1 accident is ground impact of the spacecraft or portions thereof, including possibly the rover with LWRHUs. In this case, mechanical damage and, for an Atlas V 551 accident, potential exposure to burning solid propellant could occur. The probability for this impact configuration with a release is estimated to be 4.6×10^{-5} (or 1 in 22,000), with an estimated mean source term, given an accident with a release has occurred, is estimated to be 1.3 Ci).

A much less likely outcome of a Phase 1 accident involves failure of some or all of the FTS elements to perform properly. This could lead to ground impact of the spacecraft (with the LWRHUs inside) still attached to other launch vehicle stages (Stages 1 and 2, or Stage 2). Since this would require multiple failures of safety systems, such ground impact configurations leading to a release are very unlikely. However, because the LWRHUs could impact the ground within the spacecraft at higher velocities and with additional mass above the spacecraft due to the attached Stage(s), the potential for more severe mechanical damage is higher than with the expected accident conditions associated with normal activation of the FTS.

In the impact configurations leading to the largest estimated releases, such as the FSII, slightly larger estimated mean source terms, given an accident with a release, of 60 Ci. Both of these events would fall in the very unlikely range.

- **Phase 2 (Late Launch):** All accidents that could occur in Phase 2 lead to impact of debris in the Atlantic Ocean with no release of PuO_2.
- **Phase 3 (Suborbital):** Accidents during Phase 3 include suborbital reentries. Prior to the attainment of Earth park orbit these conditions could lead to prompt suborbital reentry within minutes. This could result in impacts of the intact SV entry vehicle and LWRHUs along the vehicle flight path over the Atlantic Ocean and Africa. Additional suborbital land impacts are possible after crossing over Africa, depending on the launch vehicle selected and its nominal mission timeline. Should the SV impact land, releases are possible. The total probability of release in Phase 3 is estimated to be 2.4×10^{-6} (or 1 in 420,000). The mean source term, given an accident with a release, is estimated to be 1.2 Ci.
- **Phase 4 (Orbital):** Accidents which occur after attaining parking orbit could result in orbital decay reentries from minutes to years after the accident, affecting Earth surfaces between approximately 29° north latitude and 29° south latitude. As previously stated, the LWRHU is designed to survive reentry environments and surface impacts. No releases are expected from accidents in this phase.
- **Phase 5 (Long-term Reentry):** The potential exists for an inadvertent long-term (hundreds to thousands of years) reentry should the SV be left in an Earth crossing orbit. Based on considerations of long-term inadvertent reentry for other missions, the probability of such an occurrence is estimated to be less than 1×10^{-6}. As previously stated, the LWRHU is designed to survive reentry

environments and surface impacts. No releases are expected from accidents in this phase.

The specific probability values presented in this DEIS are estimates and will likely differ from those that might ultimately be developed in the more detailed FSAR that would be prepared by DOE if this Alternative is selected. Some probabilities would likely increase while others may decrease. However, NASA expects the overall probability of an accidental release of radioactive material would not vary substantially from the values presented in this DEIS.

4.3.4.5. Radiological Consequences

The radiological consequences of a given accident that results in a radiological release have been calculated in terms of maximum individual dose, collective dose, health effects, and land area contaminated at or above specified levels. The radiological consequences have been determined from atmospheric transport and dispersion simulations incorporating both launch-site specific and worldwide meteorological and population data. Biological effects models, based on methods prescribed by the ISCORS, were applied to predict the number of health effects following a launch accident that results in a release of PuO_2. The analysis assumes that no mitigation measures (e.g., sheltering, evacuation, and decontamination) are taken to reduce the health impacts. Additional information on the behavior of plutonium in the environment (environmental transport and health impact mechanisms) can be found in Appendix B.

The maximum individual dose is the mean maximum dose delivered to a single individual for a given accident, considering the probability distribution over all release conditions. Collective dose is the sum of the radiation dose received by all individuals exposed to radiation from a given release in units of “person-rem.” Internal doses are determined using particle-size dependent dose conversion factors based on ICRP-60 (ICRP 1979) and ICRP-66/67 (ICRP 1993, ICRP 1994). The exposure pathways considered include direct inhalation, inhalation of re-suspended material, ingestion (e.g., vegetables, fruit, and seafood), and external exposure. Due to the insoluble nature of PuO_2, other secondary exposure pathways (e.g., meat and milk) would be far less important, and their contributions to dose would be negligible.

The health effects represent incremental cancer fatalities induced by releases, as determined by using the ISCORS estimates of $6x10^{-4}$ fatalities per person-rem for the general population (DOE 2002). The health effects estimators are based on a linear, non-threshold model relating health effects and effective dose. This means that health effects decrease as the dose decreases down to zero, rather than assuming a threshold dose below which there would be no health effects. When the probability of incurring a health effect is estimated for each individual in the exposed population and then the probabilities summed over the population, an estimate of the total health effects in the population results.

Table 4-16 presents a summary of DOE’s risk assessment of radiological consequences for each of the mission phases. The radiological consequences were estimated by mission phase in terms of both the mean and 99th percentile values. The 99th percentile radiological consequence is the value predicted to be exceeded 1

percent of the time for an accident with a release. In this context, the 99th percentile value reflects the potential for higher radiological consequences to the exposed population at lower probabilities. The 99th percentile consequences are one to less than 42 times the mean estimates reported in this DEIS, but at probabilities of a factor of 100 lower than the mean probabilities.

The radiological consequences summarized in Table 4-16 are proportional to the source terms listed in Table 4-15, except that the scaling factors vary with the type and nature of the release. Key factors include the particle size distribution of the release, release height, and energy of the release. The higher dose numbers are associated with very small particles that might be released if the PuO_2 were exposed to solid propellant fires. The radiological dose per curie released is about ten times higher with the PuO_2 exposed to solid propellant fires. Key results for the mean estimates are summarized below; the corresponding 99th percentile estimates can be found in Table 4-16.

- **Phase 0 (Pre-Launch):** The initiating failures that result in Phase 0 accident configurations are extremely unlikely, having very low probabilities of occurrence. The overall mean probability of a release is 3.1×10^{-7} (or 1 in 3,200,000) during Phase 0. Most problems that arise during Phase 0 can be successfully mitigated by safety systems and procedures leading to safe hold or termination of the launch countdown.

- If an accident were to occur during Phase 0, however, there is a potential for measurable releases and contamination. The probability of the LWRHUs being close to large pieces of burning solid propellant would be higher in Phase 0 accidents than in other phases. The mean maximum dose to an individual is estimated to be approximately 0.003 rem (3 millirem), about one percent of the dose an individual might receive annually from natural background radiation[19].
- Assuming no mitigation actions, such as sheltering and exclusion of people from contaminated land areas, the radiation doses to the potentially exposed population are predicted to result in 0.015 mean health effects among the potentially exposed population.
- For Phase 0 accidents with a release, the mean area contaminated above 0.2 microcuries per square meter ($\mu Ci/m^2$) (see Section 4.1.4.7) is estimated to be about 0.37 km^2 (about 0.14 mi^2). Detectable levels below 0.2 $\mu Ci/m^2$ would be expected over a larger area.

[19] An average of about 0.31 rem per year for an individual in the United States from natural sources. Man-made sources add an additional 0.060 to 0.31 rem. The dominant man-made contribution is from medical radiological diagnosis and therapy. See Section 3.2.6 for further information.

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Table 4-16. Summary of LWRHU Estimated Radiological Consequences

Mission Phase [a]	Total Probability of Release	Maximum Individual Dose, rem		Health Effects [b]		Land Contamination [c] km^2	
		Mean	99th Percentile	Mean	99th Percentile	Mean	99th Percentile [f]4.0
0: Pre-Launch	Extremely Unlikely ($3.1x10^{-7}$)	0.0030	0.022	0.015	0.10	0.37	2.6
Early Launch							
On-Pad Explosion	Very Unlikely ($1.2x10^{-5}$)	0.0013	0.0032	0.0063	0.016	0.16	0.39
FSII	Very Unlikely ($3.0x10^{-6}$)	0.062	0.38	0.30	1.8	7.5	47
Stage2/SV	Extremely Unlikely ($8.0x10^{-7}$)	0.0013	0.0052	0.0060	0.025	0.15	0.64
SVII	Extremely Unlikely ($2.9x10^{-8}$)	0.0014	0.0044	0.0066	0.021	0.17	0.54
Low Altitude FTS	Very Unlikely ($4.6x10^{-5}$)	0.0013	0.0062	0.0061	0.030	0.16	0.76
1: Overall Phase 1	Very Unlikely ($6.2x10^{-5}$)	0.0042	0.078	0.020	0.37	0.51	9.5
2: Late Launch	—	—	—	—	—	—	—
3: Suborbital	Very Unlikely ($2.4x10^{-6}$)	0.0013	0.0047	0.0060	0.022	0.15	0.57
4: Orbital	—	—	—	—	—	—	—
5: Long-term Reentry	—	—	—	—	—	—	—
Overall Mission [d]	**Very Unlikely ($6.5x10^{-5}$)**	**0.0041**	**0.075**	**0.020**	**0.36**	**0.50**	**9.1**

Source: SNL 2014

(a) A composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.
(b) Based on ISCOR health effects recommendation of $6x10^{-4}$ health effects per person-rem for the general population.
(c) Land area contaminated above 0.2 µCi/m2; 1 km2 = 0.386 mi2.
(d) Overall mission values weighted by total probability of release for each mission phase.
Notes: Differences in multiplications and summations are due to rounding of results as reported in SNL 2014. Probability categories (i.e., unlikely, very unlikely) as defined by NASA.

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- **Phase 1 (Early Launch):** The Phase 1 consequences consist of contributions from two types of accident scenarios. Most initiating failures occurring in Phase 1 would lead to activation of the FTS. The elements of the FTS are highly redundant and very reliable. As a result, the expected outcome of a Phase 1 accident is that the SV and LWRHUs or its components could fall free to the ground and would be subject to mechanical damage and potential exposure to burning solid propellant. The probability for this very unlikely impact configuration with a release is 4.6×10^{-5} (or 1 in 22,000). The mean maximum individual dose is estimated to be 0.0013 rem (1.3 millirem), less one percent of the dose an individual might receive annually from natural background radiation.

  Assuming no mitigation action, such as sheltering, the radiation dose to the potentially exposed population is predicted to result in 0.0062 mean health effects among the potentially exposed population over the long term.

  The risk assessment indicates that about 0.16 km^2 (about 0.062 mi^2) could be contaminated above 0.2 $\mu Ci/m^2$.

  A less likely outcome of a Phase 1 accident involves failure of some or all of the FTS elements to perform properly. This could lead to ground impact of the spacecraft (with the LWRHUs inside) still attached to other launch vehicle stages (Stages 1 and 2, or Stage 2). Since this would require multiple failures of safety systems, such ground impact configurations leading to a release are very unlikely. However, because the LWRHUs could impact the ground within the spacecraft at high speed, the potential for more severe mechanical damage and exposure to burning liquid and, possibly, solid propellant, could result in higher source terms.

  The more severe impact configurations, such as the FSII, would result in larger estimated mean releases. In the highest consequence case, identified in Table 4-16, mean exposures as high as about 0.062 rem (62 millirem) to the maximum exposed individual might occur with a total probability of 3.0×10^{-6} or 1 in 330,000. Assuming no mitigation action, such as sheltering, radiation doses to the potentially exposed population are predicted to result in an estimated 0.30 mean health effects. An estimated area of 7.5 km^2 (about 2.9 mi^2) might be contaminated above 0.2 $\mu Ci/m^2$. Detectable levels below 0.2 $\mu Ci/m^2$ would be expected over a larger area.

- **Phase 2 (Late Launch):** No radiological consequences would be expected from an accident that could occur during Phase 2 since any accident during this mission phase would lead to impact of debris in the Atlantic Ocean with no release of PuO_2 from the LWRHUs.

- **Phases 3 (Suborbital):** The total probability of a release in Phase 3, categorized as very unlikely, is estimated to be 2.4×10^{-6} (or 1 in 420,000). Mean consequences are estimated to be 0.0013 rem (1.3 millirem) for maximum individual dose, and a collective dose that results in 0.0060 health effects among the potentially exposed population. An estimated area of 0.15 km^2 (about 0.058 mi^2) might be contaminated above 0.2 $\mu Ci/m^2$.

- **Phase 4 (Orbital):** There are no radioactive releases during this phase and, therefore, no radiological consequences.
- **Phase 5 (Long-term Reentry):** There are no radioactive releases during this phase and, therefore, no radiological consequences.

4.3.4.6. Discussion of the Results

Maximum Individual Doses

The maximum individual dose is the maximum dose delivered to a single individual for each accident. During Phase 1, the predicted mean radiation dose to the maximally exposed individual ranges from about 0.0013 rem (1.3 millirem) for the on-pad explosion launch area accident up to about 0.062 rem (62 millirem) for a very unlikely FSII in combination with burning solid propellant. This maximum individual dose is the largest for any phase. No short-term radiological effects would be expected from any of these exposures. Each exposure would increase the statistical likelihood of a health effect. It should be noted that the prediction of doses to the maximally exposed individual is subject to large variations and uncertainties in the locations of individuals, meteorological conditions, periods of exposure, and dispersion modeling.

Population Exposures

Impacts to downwind populations that might be exposed to releases following an accident are estimated by first calculating the collective dose to that population. This is simply the sum of the radiation dose received by all individuals exposed to radiation from a given release. These collective doses are assumed to result in the potential for health effects among the potentially exposed population following an accident. The health effects induced by releases are calculated using the methods described above in Section 4.1.4.5. The consequences discussed below have been estimated considering impacts to both the local population and the global population. Because of a variety of factors, principally involving meteorological conditions at the time of launch and the amount and particle size distribution of any PuO_2 released, not all persons in the affected regions would be exposed to a release.

Prior to launch, most problems that could potentially lead to an accident would be mitigated by safety systems and procedures that would lead to safe hold or termination of the launch countdown. After launch, most significant problems would lead to activation of the FTS, which would result in the destruction of all of the vehicle stages. This would lead to the spacecraft or portions thereof, including possibly the rover with LWRHUs, falling to the ground, where it could be subject to ground impact mechanical damage and potential exposure to burning solid propellant. The probability for this scenario with a release is 4.6×10^{-5} (or 1 in 22,000). Assuming no mitigation actions, such as sheltering and exclusion of people from contaminated land areas, the radiation dose to the potentially exposed population is predicted to result in less than one additional health effect over the long term. The mean estimate for this release scenario is 0.0062 health effects.

Even for the very and extremely unlikely launch area accidents, mean releases are not significantly higher than for the most probable accident and release. Assuming no

mitigation actions, such as sheltering, estimated health effects range from a low of less than 0.0063 to a high of 0.30. As with the maximum individual dose, the largest population dose is associated with a Phase 1 FSII release.

In the event of a launch area accident, it is unlikely that any given racial, ethnic, or socioeconomic group of the population would bear a disproportionate share of the consequences.

Impacts of Radiological Releases on the Environment

The environmental impacts of the postulated accidents include the potential for PuO_2 to be released to the environment, resulting in land and surface water contamination. The affected environment, described in Section 3 of this DEIS, includes the regional area near CCAFS and the global area. Launch area accidents (Phases 0 and 1) would initially release material into the regional area, as defined in this DEIS, to be within 100 km (62 mi) of the launch pad. Since some of the accidents result in the release of very fine particles (less than a micron in diameter), a portion of such releases could be transported beyond 100 km (62 mi) and become well mixed in the troposphere, and thus affect the global environment. Releases during Phase 3 could involve reentering LWRHUs that could impact the ground in southern Africa. Releases during Phase 4 could affect the environment anywhere between 29° north and 29° south latitude.

The risk assessment for this DEIS uses the 0.2 $\mu Ci/m^2$ screening level (a screening level used in prior NASA environmental documentation (e.g., NASA 1989, NASA 1997, NASA 2002b, NASA 2005)) as an indicator of the extent of land area contaminated due to a release of PuO_2 from a potential launch accident. The results are summarized in Table 4-16.

DOE's risk assessment indicates that for the most likely type of launch area accidents with a release, the intentional destruction of all the vehicle stages would result in about 0.16 km^2 (about 0.062 mi^2) being contaminated above 0.2 $\mu Ci/m^2$. The risk assessment also indicates that in at least one very unlikely ground impact configuration—FSII with a total probability of release of 3.0×10^{-6} (or 1 in 330,000)—a mean area of 7.5 km^2 (about 2.9 mi^2) could be contaminated above 0.2 $\mu Ci/m^2$. Detectable levels below 0.2 $\mu Ci/m^2$ would be expected over an even larger area.

Land areas contaminated at levels above 0.2 $\mu Ci/m^2$ would potentially need further action, such as monitoring or cleanup. Costs associated with these efforts, as well as continued monitoring activities, could vary widely depending upon the characteristics of the contaminated area. Potential cost estimating factors for decontamination of various land types are summarized in Table 4-5. These cost factors address a wide variety of possible actions, including land acquisition, waste disposal, site restoration, and final surveys of remediated sites.

As indicated in Table 4-5 costs for farmland decontamination have been identified. In addition to the costs of decontamination, there is the potential that the contamination of crops would require additional mitigation measures. Actions could be required to prevent contaminated foodstuffs from being consumed by the public. As discussed in Section 4.1.4.6, DOE performed an assessment of the areas that might be

contaminated to the point that the FDA suggested DIL might be exceeded and mitigation measures may be required.

The results of this analysis indicated that for all phases and for all accidents, the area contaminated above the DIL is consistently more than 50 times lower than (less than 2 percent) the area contaminated at or above the 0.2 µCi/m^2 level that are shown in Table 4-16. For example, in assessing the Phase 1 accident with Low Altitude FTS, DOE calculated that the DIL value of 2.5 Bq/kg would be exceeded in an area of 0.0028 km^2 (0.0011 mi^2 or about 0.69 acres). This is the mean value for the cropland area where some mitigation measures could be required to limit the public health impact from the consumption of food contaminated by a release from this accident. The 99th percentile area would be 0.013 km^2 (0.0050 mi^2 or 3.2 acres). These values are less than 2% of the calculated land contamination area using the 0.2 µCi/m^2 criteria (Table 4-16) (SNL 2014).

The Price-Anderson Act of 1957, as an amendment to the Atomic Energy Act of 1954 (42 U.S.C. 2210), governs liability and compensation in the event of a nuclear incident arising out of the activities of the DOE. A "nuclear incident" is defined under the Atomic Energy Act as “any occurrence, including an extraordinary nuclear occurrence, within the United States causing, within or outside the United States, bodily injury, sickness, disease, or death, or loss of or damage to property, or loss of use of property, arising out of or resulting from the radioactive, toxic, explosive, other hazardous properties of source, special nuclear or byproduct material…" (42 U.S.C. 2014 (q)). In the case of the Mars 2020 mission, DOE retains title to the LWRHUs. The LWRHUs would, therefore, be subject to Price-Anderson Act provisions. In the unlikely event that an accident were to occur resulting in release of PuO_2, affected property owners would be eligible for reimbursement for loss of property due to contamination.

In addition to the potential direct costs of radiological surveys, monitoring, and potential cleanup following an accident, there are potential secondary societal costs associated with the decontamination and mitigation activities with the very unlikely, potentially higher consequence launch area accidents. Those costs could include, but may not be limited to:

- temporary or longer term relocation of residents;
- temporary or longer term loss of employment;
- destruction or quarantine of agricultural products, including citrus crops;
- land use restrictions (which could affect real estate values, tourism, and recreational activities);
- restriction or bans on commercial fishing; and
- public health effects and medical care.

4.3.4.7. Mission Risks

A summary of the mission risks is presented in Table 4-17. For the purpose of this DEIS, risk is defined as the expectation of health effects in a statistical sense (i.e., the product of total probability times the mean health effects resulting from a release, and then summed over all conditions leading to a release). The risk of health effects in the

potentially exposed populations is determined for each mission phase and the overall mission.

Table 4-17. Summary of LWRHU Health Effect Mission Risks

Mission Phase [(a)]	Accident Probability	Conditional Probability of a Release	Total Probability of a Release	Mean Health Effects (given a release)	Mission Risks
0: Pre-Launch	$3.3x10^{-6}$	0.093	Extremely Unlikely ($3.1x10^{-7}$)	0.015	$4.4x10^{-9}$
1: Early Launch	$3.1x10^{-3}$	0.020	Very Unlikely ($6.2x10^{-5}$)	0.020	$1.3x10^{-6}$
2: Late Launch	$3.6x10^{-2}$	–	–	—	—
3: Suborbital	$1.3x10^{-2}$	0.00018	Very Unlikely ($2.4x10^{-6}$)	0.0060	$1.4x10^{-8}$
4: Orbital	$4.7x10^{-3}$	-	-	-	-
5: Long-term Reentry	$1.0x10^{-6}$	-	-	-	-
Overall Mission	**$2.5x10^{-2}$**	**0.0026**	**Very Unlikely ($6.5x10^{-5}$)**	**0.020**	**$1.3x10^{-6}$**

Source: SNL 2014

(a) A composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5. Accident probabilities are the average of individual values for the two vehicles. Based on the current state of knowledge, the specific accident probabilities for the accident conditions for each vehicle are expected to be similar.

Differences in multiplications and summations are due to rounding of results as reported in SNL 2014.

Probability categories (i.e., unlikely, very unlikely) as defined by NASA.

Since the health effects resulting from a release equals the sum of the probability of a health effect for each individual in the exposed population, risk can also be interpreted as the total probability of one health effect given the mission. The overall radiological risk for the solar powered rover with LWRHUs Mars 2020 mission is estimated to be $1.3x10^{-6}$. Thus, the total probability of one health effect for the Alternative 3 (with LWRHUs) is about 1 in 790,000.

The risk contribution from Phase 1 accidents, $1.3x10^{-6}$ (or a probability of about 1 in 800,000 that a health effect will occur), represents nearly all of the radiological risk for the Mars 2020 mission. The primary contributors to the Phase 1 risk in order of significance are (1) FSII, (2) Low Altitude FTS, and (3) On-Pad Explosion.

The contributions to risk within 100 km (62 mi) of the launch site and in the global area are summarized in Table 4-18. The launch area risk is about 64 percent of the overall mission risk, while the risk to global areas is 36 percent. The launch area risks are due entirely from accidents during Phases 0 and 1, with Phase 1 being the primary contributor. The global risks are due to accidents in all mission phases, with Phase 1 being the primary contributor due to the atmospheric transport of small particles beyond 100 km from the launch site.

Table 4-18. LWRHU Health Effect Mission Risk Contributions by Affected Region

Mission Phase [(a)]	Mission Risks		
	Launch Area [(b)]	Global [(c)]	Total
0: Pre-Launch	2.7×10^{-9}	1.8×10^{-9}	4.4×10^{-9}
1: Early Launch	8.1×10^{-7}	4.4×10^{-7}	1.3×10^{-6}
2: Late Launch	—	—	—
3: Suborbital	—	1.4×10^{-8}	1.4×10^{-8}
4: Orbital	—	—	-
5: Long-term Reentry	—	—	-
Overall Mission	**8.2×10^{-7}**	**4.6×10^{-7}**	**1.3×10^{-6}**

Source: SNL 2014

(a) A composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5

(b) Phases 0 and 1: within 100 km (62 mi) of the launch site.

(c) Phase 3: southern Africa; Phase 4: land impacts between 29° north and 29° south latitude.

Note: Differences in summations may be due to rounding

Individual Risks

Individual risk can be interpreted as the probability of an individual in the exposed population incurring a fatal cancer. For an accident near the launch site, not everyone within the regional area would be expected to receive a dose as a result of the accident. Due to meteorological conditions prevailing at the time of launch, only a portion of the total regional population is estimated to receive some measurable radiological exposure should an accident occur.

Even those individuals within the exposed population, such as those very close to the launch area that might receive the highest exposures, would face very small risks. The risk to the maximally exposed individual within the launch area and global populations (Table 4-19) is estimated to be much less than 1 in 10,000,000 for Alternative 3 (with LWRHUs) of the Mars 2020 mission. Most people in the potentially exposed population would have much lower risks.

The individual risk estimates are small compared to other risks. For example, Table 4-9 presents information on annual individual fatality risks to residents of the United States due to various types of hazards. This data indicates that in 2010 the average individual risk of accidental death in the United States was about 1 in 2,600 per year, while the average individual risk of death due to any disease, including cancer, was about 1 in 140.

Table 4-19. LWRHU Maximum Individual Risk

Mission Phase [(a)]	Release Probability	Maximum Individual Dose, (rem)	Maximum Individual Risk [(b), (c)]
0: Pre-Launch	Extremely Unlikely ($3.1x10^{-7}$)	0.0030	$5.6x10^{-13}$
1: Early Launch	Very Unlikely ($6.2x10^{-5}$)	0.0042	$1.6x10^{-10}$
2: Late Launch	–	—	—
3: Suborbital	Very Unlikely ($2.4x10^{-6}$)	0.0013	$1.8x10^{-12}$
4: Orbital	-	—	—
5: Long-term Reentry	-	—	—

Source: SNL 2014

(a) A composite of the results for the Atlas V 551 and the Delta IV Heavy, determined by taking the probability-weighted value of the two sets of results, treating the conditional probability of having a given launch vehicle as 0.5.

(b) Determined as the product of total probability of release, maximum individual dose (mean value) and a health effects estimator of $6x10^{-4}$ latent cancer fatalities per rem.

(c) The individuals associated with the maximum individual risk in Phase 0 and 1 are assumed to be the same individual, so the two risks are additive. The individuals associated with the maximum individual risk in Phases 3, 4, and 5 would not be the same individual due to different global regions potentially affected.

Note: Probability categories, i.e., unlikely, very unlikely, defined by NASA.

4.3.4.8. Uncertainty

An uncertainty analysis to estimate uncertainties in probabilities, source terms, radiological consequences, and mission risks has not been performed as part of this report. Based on experience with uncertainty analyses in the preliminary risk assessment of previous missions (e.g., for the Cassini, Mars Exploration Rover, New Horizons, and Mars Science Laboratory missions), the uncertainty in the estimated mission risk for the Mars 2020 mission can be approximated. The FSAR analysis for those missions indicate that the uncertainty is dominated by the uncertainty associated with the launch vehicle accident probabilities. The 5th and 95th percentile accident probabilities are about a factor of 25 lower and higher, respectively, than the accident median probabilities. The mission risk estimate for Alternative 3 (with LWRHUs) of $1.3x10^{-6}$ (or a probability of about 1 in 790,000 that a health effect will occur) can be treated as the median of the uncertainty probability distribution (i.e., it is equally probable that the mission risk could be higher or lower than this value). The mission risks at the 5th and 95th percent confidence levels are then estimated to be $5.1x10^{-8}$ (or a probability of about 1 in 19,000,000 that a health effect will occur) and $3.2x10^{-5}$ (or a probability of about 1 in 32,000 that a health effect will occur), respectively.

4.3.5 Radiological Contingency Response Planning

Radiological contingency response planning for any configuration of the Mars 2020 mission that contains plutonium (either an MMRTG or LWRHUs) would be similar, and has been described in Section 4.1.6.

4.4 ENVIRONMENTAL IMPACTS OF THE NO ACTION ALTERNATIVE

Under the No Action Alternative, preparations for the proposed Mars 2020 mission would be discontinued and the mission would not be implemented. Environmental impacts associated with preparation of the proposed Mars 2020 spacecraft and the processing of the launch vehicle would not occur. There would be no local or global launch-related environmental impacts.

As a result of the No Action Alternative, NASA could decide to utilize the 2020 launch opportunity to Mars for a different mission, which could address some of the objectives of the proposed Mars 2020 mission or could have completely different objectives. In either case, such a mission would be outside the scope of this DEIS and new environmental documentation would be prepared.

4.5 CUMULATIVE IMPACTS

NEPA analyses conducted under the NEPA and its implementing regulations (CEQ, 1992), must include the evaluation of direct, indirect, and cumulative environmental impacts associated with a proposed action (40 CFR 1508.7). A cumulative impact is the "...impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions..." (32 CFR 651).

The potential cumulative impacts associated with use of the launch vehicles and facilities addressed within this DEIS have been assessed using currently available information. Implementing either the Proposed Action (Alternative 1), Alternative 2, or Alternative 3 (i.e., launch of the Mars 2020 mission) would not increase the number of either Atlas V or Delta IV launches beyond the scope of previously approved programs for CCAFS (USAF 1998, USAF 2000).

Various components of the spacecraft and launch vehicle for the proposed Mars 2020 mission would be manufactured at different sites in the United States, with final integration of the components occurring at KSC and CCAFS. Each of these sites would be required to follow applicable Federal, state, and local regulations governing these areas such as air pollution, noise ordinances, wastewater disposal, pollution prevention, disposal of hazardous waste, and worker safety and health (see Section 4.9). Spacecraft and launch vehicle manufacturing are specialized activities with only a very limited number of units manufactured each year. While such activities could generate air pollutants, noise, and hazardous waste, any quantities would be small compared to major industrial activities and subject to the appropriate Federal, state, and local environmental laws and regulations pertinent to the individual manufacturing facilities.

The MMRTG hardware has already been manufactured and assembled by industry under contract to DOE; those flight units are in bonded storage at the contractor facility. Testing and fueling of the MMRTGs would be done by DOE at existing facilities. The plutonium needed to fuel the MMRTG is currently in storage at a DOE facility. Production efforts would meet all current DOE safety and environmental requirements. The programmatic environmental impacts associated with MMRTG production were

addressed by the DOE for the Mars 2020 mission in existing DOE NEPA documents (DOE 1993, 2000, 2002, 2002b, 2008, 2013).

The use of the facilities at KSC and CCAFS for processing the Mars 2020 spacecraft, launch vehicle components, and for launch of the mission would be consistent with existing land uses at each site. No new processing facilities for the Mars 2020 mission are expected at either KSC or CCAFS, and any impacts from the use of existing facilities are expected to be within the scope of previously approved programs (e.g., USAF 1998, USAF 2000, NASA 2002, NASA 2011). Implementing the Mars 2020 mission would unlikely add new jobs to the workforce at either site.

Launching the Mars 2020 spacecraft would principally contribute to exhaust emission impacts on and near SLC-37, LC-39A, or SLC-41 at CCAFS/KSC, depending on the launch vehicle. The USAF has monitored numerous launches from CCAFS (USAF 1998). Launch could result in scorched vegetation and partially or completely defoliated trees near the launch complex from flame and acidic deposition. Deposition could also impact nearby bodies of water, resulting in temporary elevation of acidity levels. While these impacts may persist with continued use of either launch complex, they are probably not irreversible. At KSC, NASA found that in affected areas near the Space Shuttle launch pads, vegetation reestablished itself after the launches stopped (Schmalzer, et al. 1998).

On a short-term basis, the Mars 2020 launch would contribute negligible amounts of ozone-depleting chemical compounds to the stratosphere. The USAF has estimated that the total contribution from large expendable launch vehicles with SRBs to the average annual depletion of ozone would be small (approximately 0.014 percent per year). By comparison, a 3 percent to 7 percent annual decrease in ozone at mid-latitudes occurs as a result of the current accumulation of all ozone-depleting substances in the stratosphere (USAF 2000). Moreover, the ozone depletion trail from a launch vehicle has been estimated to be largely temporary, and would be self-healing within a few hours of the vehicle's passage (AIAA 1991). Furthermore, because launches at CCAFS are always separated by at least a few days, combined impacts in the sense of holes in the ozone layer combining or reinforcing one another would not occur (USAF 2000).

Rocket launches result in the emission of greenhouse gases (CO_2, trace emissions of NO_X emitted by the SRBs). The exhaust cloud would also contain CO, most of which, under the high temperatures of the SRB's exhaust, would quickly react with oxygen in the atmosphere to form CO_2. The principal source of carbon emissions that could be associated with spacecraft launches would be from NASA's energy use in support of the launches. The following annual greenhouse gas emissions were reported for 2011 in the U.S.: 5,612.9 million metric tons (mt) (6.187 billion tons) of CO_2 equivalent, 12.8 million mt (14.2 million tons) of NO_X, and 65.1 million mt (71.8 million tons) of CO (EPA 2013, EPA 2014).

Concerning cumulative ozone depletion impacts, while present day ozone loss caused by rocket emissions may be small, future ozone changes may not be; potential increases in rocket launch rates due to space tourism or by geoengineering measures in space should be considered. In addition, rocket-induced ozone loss might become

more significant in the future when the anthropogenic stratospheric halogen loading decreases due to implementation of the Montreal Protocol (Murray et. al. 2013).

Since the Mars 2020 mission would not increase the previously analyzed launch rates, launch of the mission would not be anticipated to contribute further to the accumulation of greenhouse gases from expendable launch vehicles, there would not be any substantial increase in cumulative impacts for payload processing and launch. Therefore, the long-term, cumulative effects to the local and regional environment by the Proposed Action (Alternative 1), Alternative 2, or Alternative 3 would not be substantial (NASA 2011).Other activities on or near CCAFS that are not connected with the Mars 2020 mission that could occur during this timeframe include the proposed development and construction of the KSC Exploration Park (formerly the International Space Research Park (ISRP)) located on 160 hectares (400 acres) of KSC and the proposed development and construction of a commercial space launch facility, the Shiloh Launch Complex (FAA 2013b). NASA intends to expand the launch capability of the Shuttle Launch Complex (LC-39A and 39B) to include the ability to launch several vehicles including the Space Launch System and commercial launch vehicles. These and other potential construction activities at and in the vicinity of CCAFS could potentially contribute to increases in noise, particulates and dust, solid waste disposal, and the potential for involving wetlands and endangered species. An EIS for the ISRP has been prepared (NASA 2004). It is anticipated that, should NASA approve this project, phased construction would occur over the next 20 to 25 years. NASA has prepared an EIS for the expansion of SL 39A and B (NASA 2013). FAA is preparing an EIS for the Shiloh Launch Complex.

No cumulative impacts would occur under the No Action Alternative.

4.6 ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED

At lift-off and during ascent, the main engine and SRBs of the Atlas V would produce Al_2O_3, CO, HCl, and relatively smaller amounts of CO_2, NO_X, hydrogen, nitrogen, chlorine, and water. The main engines of the Delta IV would produce primarily water vapor and water. The exhaust cloud would be concentrated near the launch pad during the first moments of launch. Thereafter, the exhaust cloud would be transported downwind and upward, eventually dissipating to background concentrations.

Biota in the immediate vicinity of the Atlas V launch pad at SLC-41, the Delta IV launch pad at SLC-37, or the Falcon Heavy launch pad at LC-39A could be damaged or killed by the intense heat and HCl deposition (at SLC-41) from the exhaust cloud. No long-term adverse effects to biota would be anticipated. Al_2O_3 particulates from the Atlas V SRBs would also be deposited on soils and nearby surface waters at the launch site as the exhaust cloud travels downwind.

4.7 INCOMPLETE OR UNAVAILABLE INFORMATION

This DEIS has been developed before final preparations would be completed for the proposed Mars 2020 mission. The final mission and spacecraft designs would be subject to refinement and modification as the detailed mission planning and spacecraft design processes proceed. The results of this development process are not anticipated

to substantively affect the environmental evaluations presented in this DEIS. However, should substantial change occur in the environmental impact analyses, NASA would evaluate the need for additional environmental analysis and documentation.

The launch vehicle to be used on the Mars 2020 mission has not been selected. Candidate vehicles include two versions of the Atlas V (the 541 and 551), the Delta IV Heavy, and the Falcon Heavy. The Falcon Heavy is under development and has not yet been flown. Some of the information presented in this DEIS regarding this launch vehicle is based upon the design and operation of the Falcon 9. In particular, launch vehicle preparation for the Falcon Heavy is based on preparation activities for the Falcon 9. The description of the launch complex assumed to be used for Falcon Heavy launches (LC-39A) is the description of the complex as it is now and does not include any modifications necessary to support Falcon Heavy launches.

The suite of science instruments to be used on the Mars 2020 rover have not been selected as of the preparation of this DEIS. It is possible that some of the instruments may use small quantities of radioisotopes for various functions (e.g., calibration). The risk assessment performed by the DOE addressed the possible use of this material through the use of a representative radioisotope and quantity in the NRA (SNL 2014).

The risk assessment for the Mars 2020 mission prepared by DOE evaluates postulated launch accidents that could potentially result in a release of PuO_2 from the MMRTG. DOE's risk assessment has made use of the techniques developed in risk analyses for previous NASA missions.

DOE's risk analysis makes use of the results of extensive testing for the response of plutonium dioxide to the environments associated with accident conditions. In addition, DOE has developed sophisticated computer models to predict the detailed sequences of events that might result in the release of plutonium dioxide to the environment under these accident conditions. These techniques represent state-of-the-art plutonium accident modeling. Several technical issues that could impact the results presented in this DEIS would undergo continuing evaluation as a part of a more detailed safety analysis should NASA proceed with the Proposed Action (Alternative 1) or the LWRHU-based Alternative 3. Issues that continue to be evaluated include:

- the solid propellant fire environment and its potential effect on the release of PuO_2 from the MMRTG; and
- the mechanical response of the MMRTG or LWRHUs for the mission-specific configuration of the Mars 2020 mission.

Recent solid fire propellant tests indicate that DOE's analysis is conservative, but the results of any future test programs could impact the modeling of the fire environment and its effects on the MMRTG. Therefore, this issue continues to be evaluated. The Mars 2020 mission, while using an MSL heritage design, would be expected to have some differences in the spacecraft and rover configurations. These differences could alter the conditional probabilities of MMRTG damage and PuO_2 release. As indicated below, a safety analysis (which would include another risk assessment) that incorporates more detailed configuration information will be performed for this mission.

Under Presidential Directive/National Security Council Memorandum 25, a separate nuclear launch safety review of the Mars 2020 mission would be conducted by NASA, DOE, DoD and EPA should NASA proceed with the Proposed Action (Alternative 1) or Alternative 3. As part of this process, DOE would prepare a Final Safety Analysis Report (FSAR) that would include a complete, detailed risk analysis. In preparing the FSAR, DOE would follow procedures and use techniques similar to those used in the risk analyses performed for earlier NASA missions using radioisotope devices. An Interagency Nuclear Safety Review Panel (INSRP) would be formed for the Mars 2020 mission, and would review this safety analysis. Should the FSAR present risk estimates that differ significantly from those presented in this DEIS, NASA would consider the new information, and determine the need for additional environmental analysis and documentation.

A detailed uncertainty analysis has not been performed as part of the risk assessment prepared for this DEIS. Based on uncertainty analyses performed for previous mission risk assessments (e.g., for the Cassini, Mars Exploration Rover, New Horizons, and Mars Science Laboratory missions), parameter and model uncertainties associated with estimating radiological consequences could result in risk estimates that vary from one to two orders of magnitude at the 5 percent and 95 percent confidence levels. The Mars 2020 FSAR would include the results of a formal uncertainty analysis based on the Mars 2020 risk analysis.

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

4.8.1 Short-Term Uses

Under Proposed Action (Alternative 1), Alternative 2, or Alternative 3, the Mars 2020 mission would be launched from CCAFS or KSC. The short-term affected environment would include the launch complex and surrounding areas. At CCAFS and KSC, short-term uses include commercial, NASA and USAF operations, urban communities, a fish and wildlife refuge, citrus groves, residential communities, and recreational areas. The proposed Mars 2020 mission would be conducted in accordance with past and ongoing NASA and USAF procedures for operations at CCAFS and KSC. Should an accident occur under the Proposed Action causing a radiological release, short-term uses of contaminated areas could be curtailed, pending mitigation.

4.8.2 Long-Term Productivity

No change to land use at CCAFS or KSC and the surrounding region is anticipated due to either the Proposed Action (Alternative 1), Alternative 2, or Alternative 3. The region would continue to support human habitation and activities; wildlife habitats; citrus groves; grazing and agricultural land; and cultural, historic, and archaeological areas. No long-term effects on these uses are anticipated because of any of these 3 alternatives. However, should an accident occur under the Proposed Action causing a radiological release, the long-term productivity of contaminated land areas could be impacted, pending mitigation.

The successful completion of the proposed Mars 2020 mission would benefit science and the United States space program, which is important to the economic stability of the area. In addition to the localized economic benefits from the proactive small and small disadvantaged business plan, implementing this mission has broader socioeconomic benefits. These include technology spin-offs, such as low-power digital receivers, to industry and other space missions, maintaining the unique capability of the United States to conduct complex planetary missions by a large number of scientists and engineers, and supporting the continued scientific development of graduate students in a number of universities and colleges. Furthermore, comprehensive formal and informal education programs would be conducted as education and public outreach efforts, and proactive small business plans would be available to provide opportunities for small businesses, small disadvantaged businesses, and woman-owned small businesses; and historically black colleges and universities. Data and images acquired by the Mars 2020 mission would be made available to the general public, schools, and other institutions via a broad variety of media, including the Internet. In short, the mission would maintain and foster the nation's human engineering and science expertize.

4.9 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

An irretrievable resource commitment results when a spent resource cannot be replaced within a reasonable period of time. For the Proposed Action (Alternative 1), Alternative 2, and Alternative 3, quantities of various resources, including energy, fuels, and other materials, would be irreversibly and irretrievably committed. The use of these resources would be associated with the fabrication, launch, and operation of all elements of the proposed Mars 2020 mission.

4.9.1 Energy and Fuels

Fabrication of the Mars 2020 spacecraft and its launch vehicle would use electrical and fossil-fuel energy. This use constitutes an irretrievable commitment of resources but would not impose any significant energy impacts. The launch and operation of the spacecraft would consume solid and liquid propellant and related fluids. The solid propellant ingredients for the Atlas V SRBs would be ammonium perchlorate, aluminum powder, and HTPB binder. The liquid propellants would include RP-1 (for the Atlas V), hydrazine, LH_2, and LOx. Typical quantities that would be used are summarized in Section 2.1.5.

4.9.2 Other Materials

The total quantities of other materials used in the proposed Mars 2020 mission that would be irreversibly and irretrievable committed are relatively minor. Typically, these materials include steel, aluminum, titanium, iron, molybdenum, plastic, glass, graphite, nickel, chromium, lead, zinc, and copper. Small quantities of plutonium (for the MMRTG of the Proposed Action (Alternative 1) and even smaller quantity for the LWRHUs of Alternative 3) would be used. Less common materials may include small quantities of silver, mercury, gold, rhodium, gallium, germanium, hafnium, niobium, platinum, iridium, tantalum, and beryllium.

4.10 ENVIRONMENTAL COMPLIANCE AT CCAFS AND KSC

This section presents an overview of environmental laws, regulations, reviews and consultation requirements applicable to operations at CCAFS and KSC, and includes permits, licenses, and approvals. The information presented is summarized from the *Final Environmental Impact Statement for the Evolved Expendable Launch Vehicle Program* (USAF 1998), the *Final Supplemental Environmental Impact Statement for the Evolved Expendable Launch Vehicle Program* (USAF 2000), NASA's *Final Environmental Assessment for Launch of NASA Routine Payloads on Expendable Launch Vehicles,* (NASA 2011), and the KSC *Environmental Resources Document* (NASA 2010).

The referenced NEPA documents present the relevant discussions, analyses, potential environmental impacts, and applicable mitigation plans within each topic of concern. Launch services for the Mars 2020 mission would be provided by a commercial NLS contractor that would be required to adhere to facility permits and regulatory requirements. USAF requirements are cited for some of the environmental resource areas noted below as examples of the documentation the NLS contractor would need to implement. Launch of the Mars 2020 mission from CCAFS or KSC would follow all applicable environmental and health and safety regulatory requirements. No modifications to existing permits are anticipated for the Delta or Atlas launch vehicles. If the Falcon Heavy is selected as the launch vehicle, applicable permits will be obtained and/or existing permits will be modified accordingly.

4.10.1 Air Resources

Air permits are required for activities considered as stationary sources, such as launch support activities (e.g., vehicle preparation, assembly, propellant loading), having the potential to release threshold amounts of air pollutants but are not required for emissions from mobile sources such as launch vehicles during liftoff and ascent. Existing equipment and services would be used for preparation and launch of the selected launch vehicle.

CCAFS and KSC are classified as major sources because emissions are above major source thresholds. In this regard, CCAFS and KSC have both been issued Title V permits by the Florida Department of Environmental Protection (FDEP) and currently operate under their respective Title V permits. The NLS contractors are required to comply with all applicable Clean Air Act requirements for their launch service operations.

4.10.2 Water Resources

The Clean Water Act (CWA) of 1977, as amended (33 U.S.C. 1251 et seq.), provides regulatory guidelines for water quality.

Wastewater at CCAFS and KSC is discharged in accordance with its respective National Pollutant Discharge Elimination System (NPDES) permit conditions. Water used during launch would be discharged under the CCAFS/KSC NPDES permit issued by the Florida Department of Environmental Protection or generated wastewater would be tested and properly disposed of by a certified contractor.

4.10.3 Floodplains and Wetlands

Executive Order (EO) 11988, *Floodplain Management*, and EO 11990, *Protection of Wetlands*, would be followed. Most wetlands are considered waters of the U.S. and are under the jurisdiction of the CWA. A number of Federal agencies regulate and administer programs that can potentially affect wetlands and their likelihood for utilization including but not limited to the Army Corps of Engineers, Florida Department of Environmental Protection, U.S. Fish and Wildlife Service, Department of the Interior, and the Environmental Protection Agency.

No added impacts to floodplains and wetlands beyond those normally associated with typical launches would be anticipated. The proposed Mars 2020 launch would not be anticipated to add substantial impacts beyond those normally associated with a launch vehicle.

4.10.4 Hazardous Material Management

Hazardous materials are regulated under Federal laws such as the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended (42 U.S.C. 9601 et seq.); the Toxic Substances Control Act of 1986, as amended (15 U.S.C. 2601 et seq.); and the Hazardous Material Transportation Act of 1970, as amended (49 U.S.C. 1803 et seq.). In addition, Air Force Instruction (AFI) 32-7086, *Hazardous Material Management*, provides guidance for managing hazardous materials at all Air Force installations, including CCAFS.

As required by contract, all hazardous material would be procured and managed by the NSL contractor in accordance with all applicable Federal, state, and local requirements.

4.10.5 Hazardous Waste Management

The Resource Conservation and Recovery Act of 1976, as amended (42 U.S.C. 6901 et seq.), corresponding state law, and associated Federal and state regulations establish regulatory requirements for managing hazardous wastes. For example, Air Force Instruction AFI 32-7042, *Solid and Hazardous Waste Compliance*, and the 45th Space Wing Operations Plan 19-14, *Petroleum Products and Hazardous Waste Management Plan,* provide guidance on managing hazardous waste. Hazardous wastes must be collected, labeled appropriately, and stored in hazardous waste collection areas prior to disposal.

Hazardous wastes would be managed by the NLS contractor in accordance with all applicable Federal, state, and local requirements.

4.10.6 Pollution Prevention

The Pollution Prevention Act of 1990, as amended (42 U.S.C. 13101 et seq.), provides the regulatory framework for reducing pollution. For example, Department of Defense Directive 4210.15, *Hazardous Material Pollution Prevention*; USAF Policy Directive AFPD 32-70, *Environmental Quality*; and AFI 32-7080, *Pollution Prevention Program*, provide pollution prevention guidelines. NASA participates in a partnership with the military services called the Joint Group on Pollution Prevention to reduce or eliminate hazardous material or processes.

Pollution prevention guidelines are provided, for example, by the 45th Space Wing *Pollution Prevention Program Guide and Pollution Prevention Management Action Plan*.

4.10.7 Spill Prevention

Oil pollution prevention regulations in 40 CFR 112 require preparation and implementation of spill prevention, control, and countermeasures (SPCC) plans for all non-transportation-related facilities that store oil in excess of specific quantities [an aggregate aboveground container capacity greater than 1,320 gals (only containers greater than or equal to 55 gals are counted), or completely buried storage capacity greater than 42,000 gals] and that have discharged or could reasonably be expected to discharge oil into navigable waters of the U.S. or its adjoining shorelines. Since both CCAFS and KSC store more than 1,320 gals of oil above ground and, because a spill could reach a navigable U.S. waterway, the facilities are subject to the SPCC regulations (NASA 2010).

The NSL contractor would be responsible for prevention of spills or releases of hazardous material, and, in most cases, be responsible for cleanup of any released hazardous material in accordance with all applicable Federal, state, and local requirements. When a spill of a Federally-listed oil or petroleum occurs, the substance would be collected and removed for disposal by a certified contractor.

4.10.8 Biological Resources

Federal mandates for the conservation of biological resources include, but are not limited to, the Endangered Species Act of (ESA) 1973, as amended (16 U.S.C. 1531 et seq.); the Marine Mammal Protection Act of 1972, as amended (16 U.S.C. 1361 et seq.); and the Migratory Bird Treaty Act of 1918, as amended (16 U.S.C. 703 et seq.), Both CCAFS and KSC have ESA-listed (endangered or threatened) species. USAF and KSC consultations with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service are in place or in process. Established standard practices (e.g., complying with the light management plan for nesting sea turtles and hatchlings) would be observed to minimize impacts to these resources.

Any consultation agreements would be modified, if necessary and as applicable, to address the Falcon Heavy launch vehicle if this vehicle is selected for launch of the Mars 2020 rover.

4.10.9 Coastal Zone Management

The regulatory framework for coastal zone management is provided by the Federal Coastal Zone Management Act of 1972, as amended (16 U.S.C. 1451 et seq.), which establishes a national policy to preserve, protect, develop, restore, and enhance the resources of the nation's coastal zone. CCAFS and KSC would follow the state of Florida's coastal zone management requirements. No added impacts beyond those normally associated with launches would be anticipated.

4.10.10 Cultural and Historic Resources

Directives of Section 106 of the National Historic Preservation Act of 1966, as amended (16 U.S.C. 470 et seq.), would be followed. The State Historic Preservation Officer and

the Federal Advisory Council on Historic Preservation would be consulted if the USAF or KSC believe that the Mars 2020 mission might adversely affect cultural or historic resources, although no such adverse effects are anticipated at this time.

4.10.11 Noise

Regulations and guidelines prescribed by the Noise Control Act of 1972, as amended (42 U.S.C. 4901 et seq.); the Occupational Safety and Health Administration; and the National Institute of Occupational Safety and Health would be followed at both CCAFS and KSC.

4.10.12 Worker and Public Safety and Health

OSHA regulations would be followed to ensure worker and public safety and health from excessive noise, exposure to hazardous materials and hazardous wastes, and ingestion of toxic fumes from operations such as fueling. The 45th Space Wing at CCAFS has the responsibility to follow Range Safety guidelines as outlined in the *Range Safety User Requirements Manual* (USAF 2004). MMRTG handling at the launch site would be performed following applicable regulations as outlined in KHB 1860.1, *KSC Ionizing Radiation Protection Program* (NASA 2001) and in accordance with the DOE safety rules and regulations as summarized in a Mars 2020-specific Documented Safety Analysis that would be prepared by the DOE prior to activities in support of a Mars 2020 launch.

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5. LIST OF PREPARERS

This Draft Environmental Impact Statement (DEIS) for the Mars 2020 mission was prepared by the Science Mission Directorate, National Aeronautics and Space Administration (NASA). As a cooperating agency, the U.S. Department of Energy (DOE) has contributed expertise in the preparation of this DEIS. The organizations and individuals listed below contributed to the overall effort in the preparation of this document.

National Aeronautics and Space Administration	
George Tahu *M.S., Systems Engineering* Years of Experience: 22	Program Executive, Mars 2020 Mission Science Mission Directorate
Tina Norwood *M.S., Ecology* Years of Experience: 29	NASA NEPA Coordinator Environmental Management Division
Ken Kumor *JD* Years of Experience: 34	NASA NEPA Analyst
Thomas Hayes *JD* Years of Experience: 20	NASA Office of General Counsel

California Institute of Technology - Jet Propulsion Laboratory (Contractor to NASA)	
Reed Wilcox *M.S., City and Regional Planning* Years of Experience: 28	Manager, Project Support Office
J. Mark Phillips *B.S., Biology* Years of Experience: 33	Manager, Mars Exploration Program Launch Approval
Jonathan Stabb *M.A., Mathematics* Years of Experience: 25	Launch Approval Engineer
Victoria Ryan *MS, Environmental Engineering* Years of Experience: 13	Group Supervisor, Launch Approval Engineering
Paul VanDamme *M.S., Public Policy* Years of Experience: 22	Deputy Manager, Launch Approval Engineering
Douglas Bernard PhD, Aeronautics and Astronautics Years of Experience: 31	Project System Engineering Manager
Michael Wilson *MS, Aerospace* Years of Experience: 31	Mission System Manager

California Institute of Technology - Jet Propulsion Laboratory (Contractor to NASA)	
Deborah Bass *PhD* Years of Experience: 21	Deputy Project Scientist
Douglas Isbell *MS, Journalism* Years of Experience: 24	Risk Communication Coordinator

U.S. Department of Energy	
Ryan Bechtel *M.S., Nuclear Engineering, Civil Engineering* Years of Experience: *5*	Space Nuclear Power Systems Safety Program Manager

Sandia National Laboratories (Contractor to DOE)	
Ronald Lipinski *PhD, Nuclear Engineering* Years of Experience: 37	Manager, Radioisotope Power Systems Launch Safety
Daniel Clayton *PhD, Chemical Engineering* Years of Experience: 11	Source Team Leader
John Bignell *PhD, Civil Engineering* Years of Experience: 8	Blast and Impact Team Leader
Tim Bartell *PhD, Engineering Physics* Years of Experience: 30	Fire and Thermal Team Leader
Don Potter *MS, Mechanical & Aerospace Engineering* Years of Experience: 33	Reentry Team Leader
Nate Bixler *PhD, Chemical Engineering* Years of Experience: 31	Consequence Analysis Team Leader

Cornell Technical Services, LLC (Contractor to NASA)	
Michael Cadena *B.S., Economics* Years of Experience: 23	CTS Task Manager
Jayme Melofchik *B.S., Biology* Years of Experience: 26	Meeting Facilitator, Senior Environmental Scientist

Leidos (Contractor to Cornell Technical Services)	
Douglas Outlaw *PhD, Nuclear Physics* Years of Experience: 37	EIS Project Manager, Radiological Risks and Impacts
Daniel Gallagher *M.E., Nuclear Engineering* Years of Experience: 34	Chapters 1 and 2 Manager, Risk Analyst Reliability and Risk Engineer
Suzanne Crede *B.S., Chemistry Education* Years of Experience: 22	Environmental Analyst
Scott Heiser *M.S., Engineering Management* Years of Experience: 22	Deputy Project Manager
Sydel Cavanaugh *B.A., Interdisciplinary Studies-Personnel and Sociology* Years of Experience: 17	Public Meetings Coordinator

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6. AGENCIES, ORGANIZATIONS, AND INDIVIDUALS CONSULTED

6.1 INTRODUCTION

The National Environmental Policy Act (NEPA) states, “There shall be an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to the proposed action.” As such, NASA has engaged stakeholders and the general public in the preparation of this DEIS. Stakeholders include Federal, state, and local governments; business interests; landowners; residents; and environmental organizations.

This chapter of the *Draft Environmental Impact Statement for the Mars 2020 Mission* summarizes the public and agency outreach program NASA has undertaken in support of its Mars Exploration Program and the Mars 2020 mission.

In preparing the DEIS, NASA has actively solicited input from a broad range of interested parties. In addition to publication in the Federal Register of a Notice Of Intent (NOI) (78 FR 55672) for the DEIS, NASA mailed on September 23, 2013 an introductory letter directly to agencies, organizations, and individuals who may have interest in environmental impacts and alternatives associated with the Mars 2020 mission.

6.2 COOPERATING AGENCY

As defined in Title 40 CFR 1508.5, and further clarified in subsequent Council of Environmental Quality (CEQ) guidance memoranda, a cooperating agency can be any Federal, state, tribal, or local government that has jurisdiction by law or special expertise regarding any environmental impact involved in a proposal or a reasonable alternative.

NASA is the Federal agency that funds the launch of the Mars 2020 mission and is therefore the lead agency for preparation of this DEIS. The DOE is participating as a cooperating agency because they possess both regulatory authority and specialized expertise regarding the environmental context of the use of plutonium.

6.3 SCOPING PROCESS

On April 12, 2005, NASA published a Notice of Availability of the Final Programmatic Environmental Impact Statement for the Mars Exploration Program (PEIS MEP) (NASA 2005a, 70 FR 19102). The Record of Decision for the PEIS MEP was signed on June 22, 2005, enabling continued planning for the MEP, which represents NASA’s overall plans for the robotic exploration of Mars through 2020. The PEIS MEP encompasses the launch of at least one spacecraft to Mars during each favorable launch opportunity, which occurs approximately every 26 months. Overall environmental compliance in support of the MEP is addressed in the PEIS MEP, and allows planning to continue for the Mars 2020 mission.

On September 11, 2013, NASA published a NOI in the Federal Register (78 FR 55762) to prepare a DEIS and conduct scoping for the Mars 2020 mission. Public input and

comments on alternatives, potential environmental impacts, and concerns associated with the proposed Mars 2020 mission were requested.

NASA held scoping meetings on October 9 and 10, 2013, to solicit written and oral comments on the scope of the Mars 2020 Mission DEIS. Two scoping meetings were held in the vicinity of Kennedy Space Center (KSC). An open house, town hall meeting format was used for the scoping meetings. This format enabled meeting participants to familiarize themselves with the proposed Mars 2020 mission and DEIS, as well as the NEPA process during the open house, followed by an opportunity to provide formal comments on the scope of the Mars 2020 Mission DEIS.

The open house portion of the scoping meetings included displays of a variety of posters and printed material that supported the DEIS and NEPA process. Technical experts were available to interact with the public at the various displays. In addition, there were several “floater” experts that provided additional technical expertise where needed. Each display was augmented with supporting written materials such as a fact sheet.

The town hall session followed the open house. After introductory remarks, presentations were made including videotaped presentations by the NASA HQ Mars 2020 Program Executive and the NASA HQ NEPA Manager, and followed by presentations by other team members that were in attendance. In anticipation of the government shutdown, the NASA HQ Mars 2020 Program Executive and the NASA HQ NEPA Manager recorded their presentations at NASA TV in Washington, DC. At the conclusion of the presentations, the facilitator took direction of the meeting, guiding individuals through the comment process. During the formal scoping comment portion, one member of the public asked questions on the science portion of the mission but did not provide comments on the scope of the DEIS. Written scoping comments were received by one individual representing a college class (Turner 2013). The scoping period ended on October 30, 2013.

6.4 WEBSITE

Throughout the duration of the *Mars 2020 Mission* NEPA process, NASA will maintain a website that provides the public with the most up-to-date project information, including electronic copies of the EIS, as they are made available. The website may be accessed at *http://www.nasa.gov/agency/nepa/mars2020eis*

6.5 REVIEW OF DRAFT EIS

The public will be notified of the opportunity to review and comment on this *Draft Mars 2020 Mission EIS* by announcements in the Federal Register and local news media. This Mars 2020 Mission DEIS will be available for public review at the following locations:

NASA Headquarters Library

300 E Street SW, Suite 1J20
Washington, DC 20546
Phone: (202) 358-0168

Jet Propulsion Laboratory

Visitors Lobby, Building 249, 4800 Oak Grove Drive
Pasadena, CA 91109
Phone: (818-354-5179).

Kennedy Space Center Area

Central Brevard Library and Reference Center
308 Forrest Ave.
Cocoa, FL 32922
Phone: (321-633-179).

6.6 DRAFT EIS DISTRIBUTION

This *Draft Mars 2020 Mission EIS* is available for review and comment by Federal, state, and local agencies and the public. The public review and comment period will close 45 days from the publication of the U.S. Environmental Protection Agency's (EPA's) Federal Register notice of availability (NOA) or NASA's NOA, whichever is later. Timely comments will be considered during the preparation of the Final EIS.

As announced in the NOA, the DEIS is available for review and download at the NASA web site: *http://www.nasa.gov/agency/nepa/index.html#.UzQr1IEVF8M*

NASA has mailed copies of the DEIS directly to the agencies, organizations, and individuals who have requested a printed copy or CD of the document. In addition, NASA has sent copies of the NOA via mail or email to the stakeholders listed below:

Federal Agencies

Council on Environmental Quality
Advisory Council on Historic Preservation
Council on Environmental Quality
National Aeronautics and Space Administration
- NASA Headquarters
- NASA Ames Research Center FOIA Customer Service Center
- NASA Dryden Flight Research Center FOIA Customer Service Center
- NASA Goddard Space Flight Center FOIA Customer Service Center
- NASA Johnson Space Center FOIA Customer Service Center
- NASA Kennedy Space Center FOIA Customer Service Center
- NASA Langley Research Center FOIA Customer Service Center
- NASA Marshall Space Flight Center FOIA Customer Service Center
- NASA Stennis Space Center FOIA Customer Service Center
- NASA Glenn Research Center FOIA Customer Service Center
- NASA Jet Propulsion Laboratory FOIA Customer Service Center
- NASA Shared Services Center FOIA Customer Service Center

National Science Foundation
Office of Management and Budget
U.S. Department of Agriculture
U.S. Department of the Air Force
- Patrick Air Force Base

U.S. Department of the Army
U.S. Department of Commerce
    National Oceanic and Atmospheric Administration
    National Marine Fisheries Service (NOAA Fisheries)
U.S. Department of Energy
U.S. Department of Health and Human Services
    Centers for Disease Control and Prevention
    Food and Drug Administration
    National Cancer Institute
U.S. Department of Homeland Security
    Federal Emergency Management Agency, Region 4
    Transportation Security Administration
    U.S. Coast Guard
U.S. Department of the Interior
    Bureau of Safety and Environmental Enforcement
    Fish and Wildlife Service
    National Park Service
U.S. Department of State
U.S. Department of Transportation
    Federal Aviation Administration
    Office of Safety, Energy and Environment
    Research and Innovative Technology Administration
U.S. Environmental Protection Agency
    Office of Enforcement and Compliance Assurance
    USEPA, Region 4
U.S. House of Representatives
    Representatives of Congressional Districts within the area of potential impacts
U.S. Senate
    Senator Bill Nelson
    Senator Marco Rubio
U.S. Nuclear Regulatory Commission

State Agencies

East Central Florida Regional Planning Council
Florida Division of Emergency Management
Florida Department of Environmental Protection
    Florida State Clearinghouse
State of Florida
    Office of Governor
    Office of Lt. Governor
State of Florida Senate
    Representatives of Districts within the area of potential impacts
State of Florida House of Representatives
    Representatives of Districts within the area of potential impacts

County Agencies

Brevard County
- Board of Commissioners
- Natural Resources Management Office
- Office of Emergency Management
- Planning and Zoning Office

Lake County Board of Commissioners
Orange County Board of Commissioners
Osceola County Board of Commissioners
Seminole County Board of Commissioners
Volusia County
- County Chair
- County Manager

Local Agencies

Port Canaveral Commissioners, Chairman, District 1
City of Cape Canaveral, Office of the Mayor
City of Cocoa, Office of the Mayor
City of Cocoa Beach, Office of the Mayor
City of Kissimmee, Office of the Mayor
City of Melbourne, Office of the Mayor
City of New Smyrna Beach, Office of the Mayor
City of Orlando, Office of the Mayor
City of West Melbourne, City Manager
City of St. Cloud, Office of the Mayor
City of Titusville, Office of the Mayor

Organizations

Aerospace Industries Association
The American Association for the Advancement of Science
American Astronomical Society
American Institute of Aeronautics and Astronautics
American Society of Mechanical Engineers
Audubon of Florida
- Space Coast Audubon Society
- Pelican Island Audubon Society

Economic Development Commission of Florida's Space Coast
Environmental Defense Fund
Environmental Defense Institute, Inc.
Federation of American Scientists
Florida Coalition for Peace and Justice
Friends of the Earth
Global Network Against Weapons and Nuclear Power in Space
Global Security.org
Greenpeace International
Innovative Health Applications, LLC

International Committee Against Mars Sample Return
Mars Society
National Audubon Society
National Congress of American Indians
National Hispanic Environmental Council
National Space Society
National Tribal Environmental Council
National Fish and Wildlife Federation
Natural Resources Defense Council
The Nature Conservancy
Partnership for a Sustainable Future, Inc.
Physicians for Social Responsibility
The Planetary Society
Sierra Club National Headquarters
Southwest Network for Environmental and Economic Justice
The Space Foundation
Union of Concerned Scientists

Public Libraries

NASA Headquarters Library
Central Brevard Library and Reference Center

Individuals

Franz Aischovann
Christopher Almquist
Sebnem Aynur
Brian Berber
Walter Blair
Dr. Katherine Burkart
Peter Carson
Sandip Chatterjee
Lois Clark
Kevin Clendaniel
James Dean – Florida Today
Premilla Dixit
Margaret Dutton
Dr. Murray Felsher
Rosemary Galli
Nancy Goodspeed
Daniel Gruenbaum
Jane Hanna
Russell D. Hoffman
Karl Johanson
Leah R. Karpen
Helene Knox, PhD.
Deborah Kreis

Chris Kridler
Sarah Lasenby
Heidi Ledford
Dr. John F. Martin
Natacsha Mayers
Ross McCluney
Gary Moore – Webster University
Shirley Morrison
Robert Osband
Richard Paczynski, MD
L. Peterson
Andrew Pesce
John Plotnicky
Mary Ann Powell
Wilfred Phillips
Ralph E. Renno, III
Dr. David Rigby
Charles Ryan, Jr.
Lilly Ryterski
Gregory Sakala
Dr. Judith Schmidt
Alan H. Scoville
William Sell
Jean Stewart
Bryan Thomas
Eric Turner
Matt Van Kleunen
Caroll Webber
Linda West
Claire Whitehill
Faith Molly Wilcox
Tim Yep
William Young
Sylvia Z. Zisman

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APPENDIX A
GLOSSARY OF TERMS

99th percentile—An expression of an outcome that would not occur in more than 1 percent of all statistical samples (that is, 1 percent of the outcomes would be greater than the 99th percentile level); the 99th percentile is derived from the distribution of outcomes on which the mean value is based.

accident environment—Conditions resulting from an accident, such as blast overpressure, fragments, and fire.

affected environment—A description of the existing environment that could be affected by the Proposed Action or its alternatives.

ambient air—The surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures. (It is not the air in the immediate proximity of an emission source.)

astrobiology—The science that studies the question of whether life exists on other planets and encompasses the study of the origin, evolution, distribution, and future of life in the universe.

Atlas—A family of launch vehicles originally developed by the Lockheed Martin Space Systems Company and currently manufactured by the United Launch Alliance, a joint venture between Lockheed Martin and The Boeing Company.

attainment—An area is designated as being in attainment by the U.S. Environmental Protection Agency if it meets the National Ambient Air Quality Standards (NAAQS) for a given criteria pollutant. Non-attainment areas are areas in which any one of the NAAQS have been exceeded, maintenance areas are areas previously designated non-attainment and subsequently re-designated as attainment, and unclassifiable areas are areas that cannot be classified on the basis of available information as meeting or not meeting the NAAQS for any one criteria pollutant.

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

biosignature—Any substance that provides evidence of past or present life. A biosignature may be an element, molecule, or any observable occurrence that provides signs of life.

chromatography—A method of determining the chemical composition of a substance by passing a gas or liquid over a solid or gel and using the different adsorption characteristics between the substance and solid to separate the chemicals in the substance being examined.

conditional probability—Within the context of this Environmental Impact Statement (EIS), the probability that a release of radioactive material could occur given an initiating accident (that is, the accident has occurred).

confidence level—In statistics, the degree of desired trust or assurance in a given result. A confidence level is always associated with some assertion and measures the probability that a given assertion is true.

criteria pollutants—The Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to set air quality standards for common and widespread pollutants after preparing criteria documents summarizing scientific knowledge on their health effects. Currently, there are standards in effect for six criteria pollutants: sulfur dioxide, carbon monoxide (CO), particulate matter equal to or less than 10 microns in diameter (PM_{10}), nitrogen dioxide, ozone, and lead.

cultural resources—The prehistoric and historic districts, sites, buildings, objects, or any other physical activity considered important to a culture, subculture, or a community for scientific, traditional, religious, or any other reason.

cumulative impact—The impact on the environment which results 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 other such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

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

decibel (dB)—A logarithmic measurement unit that describes a particular sound pressure level compared to a standard reference value. The threshold of human hearing is approximately 0 dB, and the threshold of discomfort or pain is around 120 dB. A-weighted decibels (dBA) refer to measured decibels whose frequencies have been adjusted to correspond to the highest sensitivity of human hearing, which is typically in the frequency range of 1,000 to 4,000 hertz.

Delta—A family of space launch vehicles originally developed by The Boeing Company and currently manufactured by United Launch Alliance, a joint venture between Lockheed Martin and The Boeing Company.

derived intervention level (DIL)—Guidance levels for radionuclide activity concentration in food established by the U.S. Food and Drug Administration to determine whether food in interstate commerce or offered for import presents a safety concern.

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

essential fish habitat—The United States Congress defined essential fish habitat for federally managed fish species as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity” (16 U.S.C. 1802(10)). The conservation of essential fish habitat is an important component of building and maintaining sustainable fisheries.

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

Falcon—A family of space launch vehicles manufactured by SpaceX.

first stage—The launch vehicle stage that provides thrust at lift-off.

full stack intact impact (FSII)—For the purpose of this Environmental Impact Statement, a postulated accident in which the entire launch vehicle (that is, all stages, other vehicle elements, and the payload) impacts the ground in an intact configuration due to a failure at or very shortly after lift-off.

General Conformity Rule—The General Conformity Rule is applicable to non-attainment or maintenance areas (see **attainment**) as designated by the EPA, and ensures that federal actions conform to each State Implementation Plan for air quality. These plans, approved by the EPA, are each State's individual plan to achieve the NAAQS as required by the Clean Air Act. The EPA is required to promulgate a Federal Implementation Plan if a state defaults on its implementation plan. A conformity requirement determination for the action is made from influencing factors, including, but not limited to, non-attainment or maintenance status of the area, types of emissions and emission levels resulting from the action, and local impacts on air quality.

General Purpose Heat Source (GPHS)—A passive device that produces heat from the radioactive decay of plutonium (in a ceramic form of plutonium dioxide consisting mostly of plutonium-238, a non-weapons grade isotope). This heat can then be converted into usable electrical power.

geology—The study or science of the Earth (or any solid celestial body), its history, and its life as recorded in the rocks.

health effects—Within the context of this EIS, health effects are defined as the number of additional latent cancer fatalities due to a radioactive release (that is, the number of cancer fatalities resulting from this release that are in excess of those cancer fatalities which the general population would normally experience from other causes).

hydrazine—A toxic, colorless liquid fuel that is hypergolic (able to burn spontaneously on contact) when mixed with an oxidizer such as nitrogen tetroxide (N_2O_4) or placed in contact with a catalyst. Vapors may form explosive mixtures with air.

initiating probability—The probability that an identified accident and associated adverse conditions (accident environments) will occur.

ionosphere—An upper atmospheric region where ionization of atmospheric gases occurs.

isotope—Any of two or more species of atoms of a chemical element with the same atomic number and nearly identical chemical behavior, but with different atomic mass (due to different number of neutrons) or mass number and different nuclear properties.

latent cancer fatalities—Estimation of latent cancer fatalities assumes that 1) exposures to the radioactive material released to the environment occur over a 50-year period, and 2) the internal dose resulting from such exposure are 50-year committed doses, meaning that following inhalation or ingestion of the radioactive material, the resulting internal doses are based on tracking the material in the body for a 50-year period. The time period over which latent cancer fatalities occur is undefined, and could occur well after 50 years following the release.

launch azimuth—The initial angle, measured clockwise from North, which a launch vehicle takes as it begins to ascend.

Light Weight Radioisotope Heater Unit (LWRHU)— A radioactive heat source that provides heat for temperature-sensitive spacecraft components. Each LWRHU provides about one (1) watt of heat derived from the radioactive decay of about 2.7 grams (0.1 ounce) of plutonium dioxide, having approximately 33.2 curies of activity.

mass spectrometry—An analytical technique for the identification of the chemical composition of a substance. Using an electrical or magnetic field the mass spectrometer creates gaseous ions from the substance being examined and sorts and identifies the ions.

maximally exposed individual (MEI)—A hypothetical person that would receive the maximum predicted dose following an accident with a release of radioactive material.

mean—The outcome (source term, dose, health effects, or land contamination as used in this EIS) that would be anticipated if an accident which released radioactive material were to occur; the mean is a statistical expression of probability-weighted values (source terms or radiological consequences).

Multi-Mission Radioisotope Thermoelectric Generator (MMRTG)—An evolutionary power source derived from the GPHS-RTG that converts the heat from the radioactive decay of plutonium (in a ceramic form of plutonium dioxide consisting mostly of plutonium-238, a non-weapons grade isotope) contained in eight GPHS modules into usable electrical energy.

National Ambient Air Quality Standards (NAAQS)—Section 109 of the Clean Air Act requires the EPA to set nationwide standards—the NAAQS—for widespread air pollutants. Currently, six pollutants are regulated by primary and secondary NAAQS (see criteria pollutants).

nominal—In the context of this EIS, default, typical, or planned conditions or operations; functioning normally or acceptably.

oxides of nitrogen (NOx)—Gases formed primarily by fuel combustion, which contribute to the formation of acid rain. Hydrocarbons and oxides of nitrogen combine in the presence of sunlight to form ozone, a major constituent of smog.

parking orbit—A temporary low-altitude Earth orbit in which a spacecraft with its second or third launch vehicle stage waits until it is in the proper position to continue toward its next or final destination.

payload—The element(s) that a launch vehicle or spacecraft carries over and above what is necessary for the operation of the vehicle. For a launch vehicle, the spacecraft being launched is the payload; for a scientific spacecraft, the suite of science instruments is the payload.

payload fairing (PLF)—The protective shell on a launch vehicle that encapsulates the spacecraft through atmospheric ascent.

Prebiotic—occurring or existing before the development of life

pyrolitic graphite— A man-made form of graphite, created by heating graphite and allowing it to cool into a crystalline form. This type of graphite has enhanced thermal conduction properties compared to ordinary graphite.

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

radiation dose—The amount of energy from ionizing radiation deposited within tissues of the body; it is a time-integrated measure of potential damage to tissues from exposure to radiation and, as such, is related to health-based consequences.

radioactive half-life—The time required for one half of the atoms in a radioactive isotope to decay.

rem—The unit dose representing the amount of ionizing radiation needed to produce the same biological effects as one roentgen of high-penetration x-rays (about 200,000 electron volts). The biological effects of 1 rem are presumed to be independent of the type of radiation.

risk—Within the context of this EIS, risk is defined as the expectation of health effects in a statistical sense (that is, the product of total probability times the mean health effects resulting from a release of plutonium dioxide, and then summed over all conditions leading to a release).

second stage—The launch vehicle stage that continues to provide thrust during ascent after the vehicle's first stage has depleted its propellant and been jettisoned.

solar longitude (of Mars)—The apparent longitude of the sun seen on a celestial sphere whose equator is defined by the plane of Mars' orbit about the sun. The transition from winter to spring in the northern hemisphere on Mars defines zero degrees solar longitude.

source term—Typically the quantities of materials released during an accident to air or water pathways and the characteristics of the releases (for example, particle size distribution); used for determining accident consequences. The DOE Nuclear Risk Assessment identifies the quantities of material released that can become airborne as the source term.

spectrometer—A device used to identify the chemical composition of a substance. The mass spectrometer uses an electrical or magnetic field to create gaseous ions from the substance being examined and sorts and identifies the ions.

Strategic Knowledge Gap—Gaps in knowledge or information required to reduce risk, increase effectiveness, and improve the design of robotic and human space exploration missions.

stratosphere—An upper portion of the atmosphere above the troposphere reaching a maximum height of 50 kilometers (31 miles) above the Earth's surface. The temperature is relatively constant in the lower stratosphere and gradually increases with altitude. The stratosphere is the Earth's main ozone producing region.

take—To pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to pursue, hunt, shoot, wound, kill, trap, capture, or collect (50 CFR 10.12).

tropopause—The boundary between the troposphere and stratosphere, usually characterized by an abrupt change of lapse rate; the change is in the direction of increased atmospheric stability from regions below to regions above the tropopause; its height varies from 15 kilometers (9 miles) in the tropics to about 10 kilometers (6 miles) in polar regions.

troposphere—The portion of the atmosphere next to the Earth's surface in which the temperature rapidly decreases with altitude, clouds form, and convection is active. The troposphere begins at ground level and extends to an altitude of 10 to 12 kilometers (6 to 8 miles) above the Earth's surface.

unavoidable adverse effects—Effects that cannot be avoided due to constraints in alternatives. These effects must be disclosed, discussed and mitigated, if practicable.

APPENDIX B
EFFECTS OF PLUTONIUM ON THE ENVIRONMENT

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APPENDIX B
EFFECTS OF PLUTONIUM ON THE ENVIRONMENT

B-1 INTRODUCTION

This appendix addresses the potential impacts from a radioactive source containing plutonium (Pu)-238 released to the environment, which could occur in any of the low-probability accidents described in Chapter 4 of this Environmental Impact Statement (EIS). In Alternative 1, the Proposed Action, the Mars 2020 rover would carry one Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) containing approximately 4.8 kilograms (10.6 pounds) of plutonium dioxide (PuO_2) (consisting mostly of Pu-238), with a total activity of about 60,000 curies. Additionally, in Alternative 3, the Mars 2020 rover would include light weight radioisotope heater units (LWRHUs) to keep avionics and communication systems within thermal limits. The rover could include up to 71 LWRHUs, each containing approximately 2.7 grams (0.095 oz) of PuO_2 (consisting mostly of Pu-238), with a total activity of about 33.2 curies. Should 71 LWRHUs be used the total activity would be about 2,400 curies. The health and environmental risks associated with Pu-238 have been previously addressed in the National Aeronautics and Space Administration's (NASA's) EISs for the Galileo, Ulysses, Cassini, Mars Exploration Rovers, New Horizons, and Mars Science Laboratory missions (NASA 1989, NASA 1990, NASA 1995, NASA 1997, NASA 2002b, NASA 2005 and NASA 2006).

Because radiation exposure and its consequences are of interest to the general public, Section B.2 provides information about the nature of radiation and explains basic concepts used to evaluate radiation health effects. Section B.3 discusses the behavior of plutonium in the environment, including how it interacts with the human body.

B-2 RADIOLOGICAL HUMAN HEALTH IMPACTS

This appendix presents numerical information using scientific, or exponential, notation. For example, the number 100,000 can also be expressed as 1×10^5. The number 0.001 can be expressed as 1×10^{-3}. The following chart defines the equivalent numerical notations that may be used in this appendix.

Fractions and Multiples of Units			
Multiple	**Decimal Equivalent**	**Prefix**	**Symbol**
1×10^6	1,000,000	mega-	M
1×10^3	1,000	kilo-	k
1×10^2	100	hecto-	h
1×10	10	deka-	da
1×10^{-1}	0.1	deci-	d
1×10^{-2}	0.01	centi-	c
1×10^{-3}	0.001	milli-	m
1×10^{-6}	0.000001	micro-	μ

B-2.1 NATURE OF RADIATION AND ITS EFFECTS ON HUMANS

What Is Radiation?

Radiation is energy transferred in the form of particles or waves. Globally, human beings are exposed constantly to radiation from the solar system and the Earth's rocks and soil. This radiation contributes to the natural background radiation that always surrounds us. Manmade sources of radiation also exist, including medical and dental x-rays and household smoke detectors.

All matter in the universe is composed of atoms. Radiation comes from the activity of tiny particles within an atom. An atom consists of a positively charged nucleus (central part of an atom) with a number of negatively charged electron particles in various orbits around the nucleus. There are two types of particles in the nucleus: neutrons that are electrically neutral, and protons that are positively charged. Atoms are categorized as different stable elements based on the number of protons in the nucleus. There are more than 100 natural and manmade elements. An element has equal numbers of electrons and protons. When atoms of an element differ in their number of neutrons, they are called isotopes. All elements have three or more isotopes, some or all of which could be unstable.

Unstable isotopes undergo spontaneous change, known as radioactive disintegration or radioactive decay. The process of continuously undergoing spontaneous disintegration is called radioactivity. The radioactivity of a material decreases with time. The time it takes a material to lose half of its original radioactivity is its half-life. An isotope's half-life is a measure of its decay rate. For example, an isotope with a half-life of 8 days will lose one-half of its radioactivity in that amount of time. In 8 more days, one-half of the remaining radioactivity will be lost, and so on. Each radioactive element has a characteristic half-life. The half-lives of various radioactive elements may vary from millionths of a second to billions of years.

As unstable isotopes change into more stable forms, they emit particles and/or energy. An emitted particle may be an alpha particle (a helium nucleus), a beta particle (an electron), or a neutron, with various levels of kinetic energy. Sometimes these particles are emitted in conjunction with gamma rays. The particles and gamma rays are referred to as "ionizing radiation." Ionizing radiation refers to the fact that the radiation can ionize, or electrically charge, an atom by stripping off one or more of its electrons. Gamma rays, even though they do not carry an electric charge, can ionize atoms as they pass through an element by ejecting electrons. Ionizing radiation can cause a change in the chemical composition of many things, including living tissue (organs), which can affect the way they function.

When a radioactive isotope of an element emits a particle, it changes to an entirely different element or isotope, one that may or may not be radioactive. Eventually, a stable element is formed. This transformation, which may take several steps, is known as a decay chain. For example, the isotope plutonium-238, has a half-life of 87.7 years. It emits an alpha particle and becomes the isotope uranium-234, a radioactive isotope with a half-life of 246,000 years. The decay products will build up and eventually die away as time progresses.

Characteristics of various forms of ionizing radiation are briefly described in the following text and in the table below.

Radiation Type	Typical Travel Distance in Air	Barrier
α	Few centimeters	Sheet of paper or skin's surface
β	Few meters	Thin sheet of aluminum foil or glass
γ	Very large	Thick wall of concrete, lead, or steel
n	Very large	Water, paraffin, graphite

Alpha (α) – Alpha particles are the heaviest type of ionizing radiation, consisting of two protons and two neutrons. They can travel only a few centimeters in air. Alpha particles lose their energy almost as soon as they collide with anything. They can be stopped easily by a sheet of paper or by the skin's surface.

Beta (β) – Beta particles, consisting of an electron, are 7,330 times lighter than alpha particles and can travel a longer distance in the air. A high-energy beta particle can travel a few meters in the air. Beta particles can pass through a sheet of paper, but can be stopped by a thin sheet of aluminum foil or glass.

Gamma (γ) – Gamma rays (and x-rays), unlike alpha or beta particles, are waves of pure energy. Gamma rays travel at the speed of light. Gamma radiation is very penetrating and requires a large mass, such as a thick wall of concrete, lead, or steel, to be stopped.

Neutrons (n) – Neutrons produce ionizing radiation indirectly by collision with hydrogen nuclei (protons) and when gamma rays and alpha particles are emitted following neutron capture in matter. A neutron has about one-quarter the weight of an alpha particle. It will travel in the air until it is absorbed in another nucleus. The most prolific source of neutrons is a nuclear reactor.

Radiation Measuring Units

During the early days of radiological experimentation, there was no precise unit for radiation measure. Therefore, a variety of units were used to measure radiation. These units determined the amount, type, and intensity of radiation. Just as heat can be measured in terms of its intensity or effects using units of calories or degrees, amounts of radiation or its effects can be measured in units of curies, radiation absorbed dose (rad), or dose equivalent (roentgen equivalent in man, or rem). The following text summarizes these units.

Curie – The curie, named after scientists Marie and Pierre Curie, describes the intensity of a sample of radioactive material. The decay rate of 1 gram of radium was the original basis of this unit of measure. Because the measured decay rate kept changing slightly as measurement techniques became more accurate, the curie was subsequently defined as exactly 3.7×10^{10} disintegrations (decays) per second.

Radiation Units and Conversions to International System of Units	
1 curie	= 3.7×10^{10} disintegrations per second
	= 3.7×10^{10} becquerels
1 becquerel	= 1 disintegration per second
1 rad	= 0.01 gray
1 rem	= 0.01 sievert
1 gray	= 1 joule per kilogram

Rad – The rad is the unit of measurement for the physical absorption of radiation. The total energy absorbed per unit quantity of tissue is referred to as “absorbed dose” (or simply “dose”). As sunlight heats pavement by giving up an amount of energy to it, radiation similarly gives up energy to objects in its path. One rad is equal to the amount of radiation that leads to the deposition of 0.01 joule of energy per kilogram of absorbing material.

Rem – The rem is a measurement of the dose equivalent from radiation based on its biological effects. The rem is used in measuring effects of radiation on the body. One rem of one type of radiation is presumed to have the same biological effects as one rem of any other kind of radiation. This allows comparison of the biological effects of radionuclides that emit different types of radiation. One-thousandth of a rem is called a millirem.

Person-rem – The term used for reporting the collective dose, the sum of individual doses received in a given time period by a specified population from exposure to a specified radiation source.

The corresponding units of radiation measure in the International System of Units are: becquerel (a measure of source intensity), gray (a measure of absorbed dose), and sievert (a measure of dose equivalent).

An individual may be exposed to ionizing radiation externally (from a radioactive source outside the body) or internally (from ingesting or inhaling radioactive material). The external dose is different from the internal dose because an external dose is delivered only during the actual time of exposure to the external radiation source, while an internal dose continues to be delivered as long as the radioactive source is in the body. The dose from internal exposure is calculated over 50 years following the initial exposure. Both radioactive decay and elimination of the radionuclide by ordinary metabolic processes decrease the dose rate with the passage of time.

B-2.2 RADIATION SOURCES

The average American receives a total of approximately 620 millirem per year from all radiation sources—both natural and manmade—of which approximately 310 millirem per year are from natural sources. Radiation sources can be divided into six different categories: (1) cosmic radiation, (2) terrestrial radiation, (3) internal radiation, (4)

consumer products, (5) medical diagnosis and therapy, and (6) other sources (NCRP 1987, NRC 2011). These categories are discussed in the following paragraphs.

Cosmic Radiation – Cosmic radiation is ionizing radiation resulting from energetic charged particles from space continuously hitting Earth's atmosphere where they create secondary particles and photons (primarily gamma rays and x-rays). These particles, and the secondary particles and photons they create, compose cosmic radiation. Because the atmosphere provides some shielding against cosmic radiation, the intensity of this radiation increases with the altitude above sea level. The average dose to people in the United States from this source is approximately 32 millirem per year.

External Terrestrial Radiation – External terrestrial radiation is radiation emitted from radioactive materials in Earth's rocks and soils. The average individual dose from external terrestrial radiation is approximately 19 millirem per year.

Internal Radiation – Internal radiation results from the human body metabolizing natural radioactive material that has entered the body by inhalation or ingestion. Natural radionuclides in the body include isotopes of uranium, thorium, radium, radon, polonium, bismuth, potassium, rubidium, and carbon. The major contributors to the annual dose equivalent for internal radioactivity are the short-lived decay products of radon, which contribute approximately 229 millirem per year. The average individual dose from other internal radionuclides is approximately 31 millirem per year.

Consumer Products – Consumer products also contain sources of ionizing radiation. In some products, such as smoke detectors and airport x-ray machines, the radiation source is essential to the product's operation. In other products, such as televisions and tobacco, radiation occurs as the products function. The average dose from consumer products is approximately 12 millirem per year.

Medical Diagnosis and Therapy – Radiation is an important diagnostic medical tool and cancer treatment. Nuclear medical procedures result in an average exposure of about 297 millirem per year—a significant increase over the14 millirem per year exposure estimated in the recent past. This increase is due primarily to the expanded use of computed tomography and the use of nuclear medication in therapy. Individual exposures vary widely since not all individuals undergo the same medical procedures.

Other Sources – There are a few additional sources of radiation that contribute minor doses to individuals in the United States. The average dose from nuclear fuel cycle facilities (e.g., uranium mines, mills, and fuel processing plants) and nuclear power plants has been estimated to be less than 1 millirem per year. Radioactive fallout from atmospheric atomic bomb tests, emissions from certain mineral extraction facilities, and transportation of radioactive materials contribute less than 1 millirem per year to the average dose to an individual. Air travel contributes approximately 1 millirem per year to the average dose.

B-2.3 EXPOSURE PATHWAYS

As stated earlier, an individual may be exposed to ionizing radiation both externally and internally. The different ways that could result in radiation exposure to an individual are

called exposure pathways. Each type of exposure is discussed separately in the following paragraphs.

External Exposure – External radiation exposure can result from several different pathways, including exposure to a cloud of radioactive particles passing over the receptor (an exposed individual), standing on ground contaminated with radioactivity, and swimming or boating in contaminated water. If the receptor leaves the source of radiation exposure, the dose rate will be reduced, if not eliminated. Dose from external radiation is based on time spent exposed to a radiation source. The appropriate dose measure is called the effective dose equivalent (EDE).

Internal Exposure – Internal exposure results from a radiation source entering the human body through either inhalation of contaminated air or ingestion of contaminated food or water. In contrast to external exposure, once a radiation source enters the body, it remains there for a period of time that varies, depending on decay and biological half-life.[1] The absorbed dose to each organ of the body is calculated for a period of 50 years following intake. The calculated absorbed dose is called the committed dose equivalent. Various organs have different susceptibilities to damage from radiation. The committed EDE takes these different susceptibilities into account and provides a broad indicator of the health risk to an individual from radiation. The committed EDE is a weighted sum of the committed dose equivalent in each major organ or tissue. The concept of the committed EDE applies only to internal pathways.

B-2.4 RADIATION PROTECTION GUIDES

Several organizations have issued radiation protection guides. Responsibilities of the main radiation safety organizations, particularly those that affect policies in the United States, are summarized in the following text.

International Commission on Radiological Protection (ICRP) – ICRP has responsibility for providing guidance in matters of radiation safety. ICRP's operating policy is to prepare recommendations to address basic principles of radiation protection, leaving the various national protection committees to introduce detailed technical regulations, recommendations, or codes of practice best suited to the needs of their countries.

National Council on Radiation Protection and Measurements – In the United States, this council has responsibility for adapting and providing detailed technical guidelines for implementing ICRP recommendations. The Council consists of expert radiation protection specialists and scientists.

National Research Council and National Academy of Sciences – The National Research Council, which provides science and policy research supporting the National Academy of Sciences, associates the broad science and technology community with the Academy's purposes of furthering knowledge and advising the Federal Government. The Council's Nuclear Radiation Studies Board prepares reports to advise the Federal

[1] Biological half-life is the time for one-half of a radioactive source that has entered the body to be removed from the body by natural processes.

Government on issues related to radiation protection and radioactive materials. The Committee on the Biological Effects of Ionizing Radiation (BEIR), which has issued a number of studies on radiation exposure health conveyances, operates under the Nuclear Radiation Studies Board.

U.S. Environmental Protection Agency (EPA) – EPA has published a series of documents, *Radiation Protection Guidance to Federal Agencies,* used as a regulatory benchmark by a number of Federal agencies to limit public and occupational workforce exposures to the greatest extent possible.

The Interagency Steering Committee on Radiation Standards (ISCORS) – ISCORS technical reports serve as guidance for Federal agencies to assist them in preparing and reporting analysis results and implementing radiation protection standards in a consistent and uniform manner. ISCORS issued a technical report entitled *A Method for Estimating Radiation Risk from TEDE* (DOE 2002). This report provides dose-to-risk conversion factors using total effective dose equivalent (TEDE) to estimate dose. It is recommended for use by DOE personnel and contractors when computing potential radiation risk from calculated radiation dose for comparison purposes. Alternatively, for radiation risk assessments required in risk management decisions, DOE recommends that the radionuclide-specific risk coefficients in EPA's Federal Guidance Report No. 13, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides* (EPA 1999) should be used.

B-2.5 RADIATION EXPOSURE LIMITS

Exposure limits for members of the public and radiation workers are generally consistent with ICRP recommendations. EPA also considers National Council on Radiation Protection and Measurements and ICRP recommendations, and sets specific annual exposure limits (usually less than those recommended by ICRP) in *Radiation Protection Guidance to Federal Agencies* documents. Each regulatory organization then establishes its own set of radiation standards. Examples of exposure limits set by DOE, EPA, and the U.S. Nuclear Regulatory Commission (NRC), for members of the public are shown in Table B-1.

Table B-1. Exposure Limits for Members of the Public

Guidance Criteria (Organization)	Public Exposure Limits at the Site Boundary
40 CFR Part 61 (EPA)	0.01 rem per year (all air pathways)
40 CFR Part 141 (EPA)	0.004 rem per year (drinking water pathways)
DOE Order 5400.5 (DOE)	0.01 rem per year (all air pathways) 0.004 rem per year (drinking water pathway) 0.1 rem per year (all pathway)
10 CFR 20.1301 (NRC)	0.1 rem per year (all pathways)

B-2.6 HEALTH EFFECTS

To provide background information for discussions of radiation exposure impacts, this section explains basic concepts used to evaluate radiation effects.

Radiation can cause a variety of damaging health effects in humans. The most significant effects are induced cancer fatalities. These effects are referred to as “latent cancer fatalities” because the cancer may take many years to develop. In the discussions that follow, all fatal cancers are considered latent; therefore, the terms “latent cancer fatalities” and “fatal cancers” are used interchangeably in this appendix.

The National Research Council’s Committee on the BEIR has prepared a series of reports to advise the Federal Government on radiation exposure health consequences. *Health Effects of Exposure to Low Levels of Ionizing Radiation*, BEIR V (NRC 1990), provides current estimates for excess mortality from leukemia and other cancers expected to result from exposure to ionizing radiation.

Models and risk coefficients in BEIR V were derived through analyses of relevant epidemiologic data that included the Japanese atomic bomb survivors, ankylosing spondylitis (spinal arthritis) patients, Canadian and Massachusetts fluoroscopy (breast cancer) patients, New York postpartum mastitis (breast cancer) patients, Israeli tinea capitis (thyroid cancer) patients, and Rochester, New York, thymus (thyroid cancer) patients. Models for leukemia, respiratory cancer, digestive cancer, and other cancers used only the atomic bomb survivor data, although the ankylosis spondylitis patient analysis results were considered. Atomic bomb survivor analyses were based on revised dosimetry, with an assumed relative biological effectiveness of 20 for neutrons, and were restricted to doses less than 400 rad. Estimates of fatal cancer (other than leukemia) risks were obtained by totaling estimates for breast, respiratory, digestive, and other cancers.

The National Council on Radiation Protection and Measurements, based on radiation risk estimates provided in BEIR V and ICRP Publication 60 recommendations (ICRP 1991), estimated the total detriment resulting from low-dose or low-dose-rate exposure to ionizing radiation to be 0.0007 per rem for the general population (NCRP 1993). The total detriment includes fatal and nonfatal cancers, as well as severe hereditary (genetic) effects. The major contribution to the total detriment is from fatal cancer, estimated to be 0.0005 per rem for the general population. The risk estimator breakdowns for the general population are shown in Table B-2. (Risk estimators are lifetime probabilities that an individual would develop a fatal cancer per rem of radiation received.) Nonfatal cancers and genetic effects are less probable radiation exposure consequences.

Table B-2. Nominal Health Risk Estimators Associated with Exposure to 1 Rem of Ionizing Radiation

Exposed Individual	Fatal Cancer [a]	Nonfatal Cancer [b]	Genetic Disorders [b]	Total
Public	0.0005	0.0001	0.00013	0.00073

Source: NCRP 1993.

(a) For fatal cancer, the health effect coefficient is the same as the probability coefficient. When applied to an individual, the unit is the lifetime probability of a cancer fatality per rem of radiation dose. When applied to a population of individuals, the unit is the excess number of fatal cancers per person-rem of radiation dose.

(b) In determining a means of assessing radiation exposure health effects, the ICRP has developed a weighting method for nonfatal cancers and genetic effects.

The EPA, in coordination with other Federal agencies involved in radiation protection, issued the September 1999 Federal Guidance Report No. 13, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides* (EPA 1999). This document is a compilation of risk factors for doses from external gamma radiation and internal intake of radionuclides. Federal Guidance Report No. 13 is the basis of radionuclide risk coefficients used in the EPA *Health Effects Assessment Summary Tables* (EPA 2001) and in computer dose codes, such as the DOE Argonne Residual Radiation code. However, DOE and other agencies regularly conduct dose assessments with models and codes that calculate radiation dose from exposure or intake using dose conversion factors and do not compute risk directly. In these cases, where it is necessary or desirable to estimate risk for comparative purposes (e.g., comparing risk associated with alternative actions), it is common practice to simply multiply the calculated TEDE by a risk-to-dose factor. ISCORS recommends that agencies use a conversion factor of 6×10^{-4} fatal cancers per TEDE (rem) for mortality and 8×10^{-4} cancers per rem for morbidity when making qualitative or semi-quantitative estimates of radiation exposure risk to members of the general public[2] (DOE 2002). The TEDE-to-risk factor provided in *Estimating Radiation Risk from Total Effective Dose Equivalent (TEDE),* ISCORS Technical Report No. 1, is based upon a static population with characteristics consistent with the U.S. population.

The ISCORS report notes that the recommended risk coefficients used with TEDE dose estimates generally produce conservative radiation risk estimates (i.e., they overestimate risk).[3] For the ingestion pathway of 11 radionuclides compared, risks would be overestimated compared with Federal Guidance Report No. 13 values for about 8 radionuclides, and significantly overestimated (by up to a factor of 6) for 4 of the 8. The DOE Office of Environmental Policy and Guidance also compared the risks obtained using the risk conversion factor with the risks in Federal Guidance Report No. 13 for the inhalation pathway, and found a bias toward overestimation of risk, although it was not as severe as for ingestion. For 16 radionuclides/chemical states evaluated, 7 were significantly overestimated (by more than a factor of 2), 5 were significantly underestimated, and the remainder agreed within about a factor of 2. Generally, these differences are within the uncertainty of transport and uptake portions of dose or risk modeling and, therefore, the approach recommended is fully acceptable for comparative assessments. That notwithstanding, it is strongly recommended that, wherever possible, the more rigorous approach with Federal Guidance Report No. 13 cancer risk coefficients be used (DOE 2002).

The values in Table B-2 are “nominal” cancer and genetic disorder probability coefficients. They are based on an idealized population receiving a uniform whole-body dose. Recent EPA studies, based on age-dependent dose coefficients for members of

[2]Such estimates should not be stated with more than 1 significant digit.

[3]This statement presumes that using the radionuclide-specific risk factors in Federal Guidance Report No. 13 would be a more accurate measure of potential risk than multiplying the TEDE by a single average risk factor.

the public, indicate that the product of the effective dose and the probability coefficient could over- or underestimate radiological risk (EPA 1999). In support of risk results provided in Federal Guidance Report No. 13, EPA performed an uncertainty analysis on uniform whole-body exposure effects. The analysis resulted in an estimated nominal risk coefficient increase from 0.051 fatal cancers per gray (0.00051 fatal cancers per rad) to 0.0575 fatal cancers per gray (0.000575 fatal cancers per rad) (EPA 1999a). This result indicates a nominal risk coefficient increase of about 20 percent over that provided in *Risk Estimates for Radiation Protection* (NCRP 1993) for the public.

Based on review of recent EPA reports, ISCORS recommended that a risk factor of 0.0006 fatal cancers per rem be used for estimating risks when using calculated dose (DOE 2002).

Numerical fatal cancer estimates presented in this EIS were obtained using a linear no-threshold extrapolation from the nominal risk estimated for lifetime total cancer mortality. Other methods of extrapolation to the low-dose region could yield higher or lower numerical fatal cancer estimates. Studies of human populations exposed to low doses are inadequate to demonstrate the actual risk level. There is scientific uncertainty about cancer risk in the low-dose region below the range of epidemiologic observation, and the possibility of no risk cannot be excluded (CIRRPC 1992). The National Research Council in its report on the Biological Effects of Ionizing Radiation (BEIR) states that the available scientific information is consistent with a linear dose model for low exposure levels and that, in their judgment, it is unlikely that a threshold exists (NRC 2006). Therefore, the risk factor of 0.0006 fatal cancers per rem was used as the conversion factor for all radiological exposures due to accidents, including those in the low-dose region.

B-2.7 EIS HEALTH EFFECT RISK ESTIMATORS

Health impacts of radiation exposure, whether from external or internal sources, generally are identified as somatic (i.e., affecting the exposed individual) or genetic (i.e., affecting descendants of the exposed individual). Radiation is more likely to produce somatic than genetic effects. The somatic risks of most importance are induced cancers. Except for leukemia, which can have an induction period (time between exposure to the carcinogen and cancer diagnosis) of as little as 2 to 7 years, most cancers have an induction period of more than 20 years.

For uniform irradiation of the body, cancer incidence varies among organs and tissues; the thyroid and skin demonstrate a greater sensitivity than other organs. Such cancers, however, also produce relatively low mortality rates because they are relatively amenable to medical treatment. Because fatal cancer is the most serious effect of environmental and occupational radiation exposures, estimates of cancer fatalities, rather than cancer incidence, are presented in this appendix. The numbers of fatal cancers can be used to compare risks among the various alternatives.

Based on the preceding discussion, the number of fatal cancers to workers and the general public for postulated accidents in which individual doses are less than 20 rem is calculated using a health risk estimator of 0.0006 per person-rem. The risk estimator

associated with total cancer incidence among the public is 0.0008 per person-rem (DOE 2002).

The fatal cancer estimators are used to calculate the statistical expectation of the effects of exposing a population to radiation. For example, if 100,000 people were each exposed to a one-time radiation dose of 100 millirem (0.1 rem), the collective dose would be 10,000 person-rem. The exposed population would then be expected to experience six additional cancer fatalities from the radiation (10,000 person-rem × 0.0006 lifetime probability of cancer fatalities per person-rem = 6 cancer fatalities).

Calculations of the number of excess fatal cancers associated with radiation exposure do not always yield whole numbers. These calculations may yield numbers less than one, especially in environmental impact applications. For example, if a population of 100,000 were exposed to a total dose of only 0.001 rem per person, the collective dose would be 100 person-rem (100,000 persons × 0.001 rem = 100 person-rem). The corresponding estimated number of cancer fatalities would be 0.06 (100 person-rem × 0.0006 cancer fatalities per person-rem = 0.06 cancer fatalities). The 0.06 means that there is 1 chance in 16.6 that the exposed population would experience 1 fatal cancer. In other words, 0.06 cancer fatalities are the *expected* number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people. In most groups, no person would incur a fatal cancer from the 0.001 rem dose each member received. In a small fraction of the groups, one cancer fatality would result; in exceptionally few groups, two or more cancer fatalities would occur. The *average* expected number of deaths over all the groups would be 0.06 cancer fatalities (just as the average of 0, 0, 0, and 1 is ¼, or 0.25). The most likely outcome is no cancer fatalities.

The same concept is applied to estimate radiation exposure effects on an individual member of the public. Consider the effects of an individual's exposure to a 300-millirem (0.30-rem) annual dose from all natural radiation sources. The probability that the individual would develop a fatal cancer from continuous exposure to this radiation over an average life of 72 years (presumed) is 0.013 (one person × 0.30 rem per year × 72 years × 0.0006 cancer fatalities per person-rem = 0.013). This corresponds to 1 chance in 77.

B-3 EFFECTS OF PLUTONIUM ON THE ENVIRONMENT

B-3.1 INTRODUCTION

The purpose of this section is to describe qualitatively the factors that influence the movement of PuO_2 through the environment and into the human body in the event that there is an accidental release of PuO_2 from the spacecraft's MMRTG or LWRHUs.

B-3.2 CHEMICAL AND PHYSICAL PROPERTIES THAT ARE IMPORTANT FOR BEHAVIOR IN THE ENVIRONMENT AND THE HUMAN BODY

In this section, the following important characteristics are discussed:

- Chemical form;
- Particle size distribution;

- Solubility;
- Half-life; and
- Decay modes.

Chemical Form

In the MMRTG for the Mars 2020 mission, the Pu-238 is present as plutonium dioxide in ceramic form. The predominant risk pathways are those in which this material is released as the result of ground impact and fire. It is therefore assumed that the plutonium remains oxidized. This is important because the chemical form influences the solubility, which, in turn, strongly influences such factors as bioaccumulation and uptake in the human body.

Particle Size Distribution

It is also important to understand the physical form of the material, in particular the particle size distribution, which influences: whether the material will fall to the ground in the immediate vicinity of the accident or will be transported over long distances; the initial deposition and subsequent resuspension of particles in both air and water; solubility in water and in biological fluids; and whether or not the material can be inhaled and where it will be deposited and retained within the human respiratory system. Generally speaking, larger particles have less potential for suspension and resuspension; as the particle size decreases, particles are more easily kept in suspension.

The initial particle size distribution is a function of the conditions of the accident. For example, the launch area source terms could initially be in the form of vapor as a result of exposure to fire. The vapors would contain not only the radionuclides but also various structural materials. The radionuclides would tend to condense with and agglomerate with these other materials, which would then predominantly determine the characteristics of the aerosol. The potential for uptake of inhaled particles is critically dependent on the size of the particles (respirable particles are generally considered to be 10 microns (10 micrometers) or less, although larger sizes can be deposited in the upper respiratory tract).

Solubility

A number of factors affect the solubility of PuO_2 in water. Physical parameters most important to the solubility of PuO_2 are the reactive surface area and oxidation state of plutonium and the water chemistry, including pH, reduction/oxidation potential, and temperature. The mass to surface area ratios of particles affect the reactivity and solubility, with solubility being inversely related to particle size. In general, PuO_2 is insoluble.

Because PuO_2 is so insoluble, movement through the environment depends on physical processes. PuO_2 may be carried into the soil by a number of routes, including the percolation of rainfall and subsequent leaching of particles into the soil, animal burrowing activity, and plowing or other disturbance of the soil by humans. Migration of

the PuO_2 into the soil column is of concern, primarily because of the potential for PuO_2 to reach groundwater aquifers used as drinking water suppliers. Once deposited on soil, however, PuO_2 appears to be extremely stable. Soil profile studies have shown that generally more than 95 percent of the PuO_2 from nuclear weapons fallout remained in the top 5 centimeters (2 inches) of surface soil (in undisturbed areas) for 10 to 20 years following deposition (DOE 1987).

Half-Life

The half-life of Pu-238 is 87.7 years. This half-life is particularly important for chronic exposure pathways (inhalation and ingestion). Over a human lifetime (nominally 70 years), the amount of Pu-238 in the body is reduced by less than a factor of 2 due to radioactive decay.

Decay Modes

Pu-238 is an alpha particle emitter with decay energies of about 5 million electron volts. Its radioactive decay products are also alpha-emitters with about the same decay energy. These alpha particles are what predominantly determine the effects on the human body. Pu-238 can also undergo extremely unlikely spontaneous fission, but with significantly smaller effects.

B-3.3 THE TRANSPORT OF PLUTONIUM OXIDES THROUGH THE ENVIRONMENT

This Section discusses the various ways in which plutonium can be transported through the environment to the point at which it is taken into or irradiates the human body. The modeling for the Mars 2020 mission encompasses both short-term (during plume passage) and long-term (chronic exposure) pathways.

Plutonium is one of the most widely studied elements in terms of chemistry and environmental behavior. Although its chemistry and oxidation states are quite diverse, the element's environmental mobility is very limited (INSRP 1989). The pathways and the generalized behavior of plutonium in the environment are described in the literature (e.g., Aarkrog 1977, Pinder and Doswell 1985, Pinder et al. 1987, Yang and Nelson 1984). The extent and magnitude of potential environmental impacts caused by PuO_2 releases depend on the mobility and availability of PuO_2 and are directly controlled by a number of physical and chemical parameters, including particle size, potential for suspension, deposition and resuspension, solubility, and oxidation state of any dissolved plutonium.

During Plume Passage

The predominant pathway during the passage of the airborne plume is inhalation. The important parameters in this calculation are the rate of dilution of the plume as it travels downwind, the deposition mechanisms that deplete the plume and leave radioactive material on the ground, and the rate of inhalation. All of these parameters and mechanisms are independent of the fact that the radionuclide in question is Pu-238. For example, the small particle sizes arising from agglomeration onto aluminum oxide particles (see Section B.3.2) mean that gravitational settling is not important. It is therefore appropriate to use a standard Gaussian model for the atmospheric dispersion.

Similarly, the small particle size means that, once it is transported to a human receptor, it is inhaled. Work done for previous EISs shows that inhalation of the particles in the passing plume and of resuspended particles are the two most important contributors to the radiation dose accumulated by human receptors.

The other pathway that is potentially important during plume passage is cloud shine—the irradiation of the human body by neutrons and gamma rays emitted by the passing plume of radioactive material. However, because Pu-238 emits predominantly alpha particles, this irradiation pathway is not a significant contributor to doses resulting from potential accidents associated with the Mars 2020 Mission.

Chronic Exposure Pathways

This section considers contributions due to resuspension, ingestion of vegetables, external exposure, seafood ingestion, and contamination of drinking water.

Resuspension

For launch area accidents, the resuspension model used in the analysis starts with an initial resuspension factor that decreases exponentially to a constant long-term resuspension factor (Momeni et al. 1979; Strenge and Bander 1981). For materials deposited after traveling more than 100 kilometers (62 miles) from the source of a release, or released high in the atmosphere, the resuspension factor is at all times typically similar to the long-term resuspension factor (Bennett 1976, UNSCEAR 1982). The work done in previous EISs shows that resuspension is the most significant of the chronic exposure pathways and is comparable to or larger in its effects on humans than is the direct inhalation pathway.

Vegetable Ingestion

Parameters used for estimating the uptake from harvesting and consumption of agricultural products has been measured (Baes et al. 1984, Rupp 1980, Yang and Nelson 1984). These and similar agricultural and food consumption parameters and plutonium ingestion parameters (ICRP 1979) are used as the basis for estimating human doses via ingestion. For example, an analysis of Pu-238 contamination of orange trees shows that a total of only 1 percent of the plutonium actually aerially deposited on the plants would be transported on fruit from field to market during the 12 months following harvesting (Pinder et al. 1987). Most of this plutonium would adhere to the fruit's peel and would be removed prior to ingestion; uptake to the orange itself would be extremely small or nonexistent.

Four mechanisms of vegetable ingestion were taken into account, as described below.

1. ***Initial deposition immediately following the accident:*** The amount initially deposited per curie released depends on non-PuO_2 specific factors such as particle size distribution and characteristics of the vegetation. The predicted amount of radioactive material ingested by humans then depends on assumptions about physical mechanisms and vegetable distribution, such as: the removal half-life for leaf-deposited material, a leaf interception factor, and a vegetable density. Additionally, harvesting (whether continuous, delayed, or crops are destroyed) and

consumption assumptions would affect the predicted amount of radioactive material ingested by humans.

2. ***Continuous redeposition on the vegetables due to resuspension over the first 50 years following the accident:*** The amount ingested by individuals is controlled by the resuspension mechanism (see above), the assumed dry deposition velocity, and assumptions about harvesting and distribution.

3. ***Root uptake:*** This mechanism is, in principle, highly radionuclide and vegetable-specific and depends on such factors as solubility, radionuclide chemistry, and vegetable chemistry. In general, PuO_2 is insoluble and is poorly transported in terrestrial environments. Most forms of plutonium, including PuO_2, are removed from biological pathways by processes such as fixation in soil. Only small amounts of material would be concentrated by biological accumulation into grazing animals and vegetables.

4. ***Rain splashup:*** This mechanism depends in part on the characteristics of the soil and the rainfall.

For Pu-238, radiation doses arising via these pathways are a small fraction of those arising from the inhalation pathways.

External Radiation

External radiation from material deposited on the ground and resuspended material is calculated using standard methods for cloudshine and groundshine. Because Pu-238 is predominantly an alpha emitter, this exposure pathway is relatively unimportant.

Seafood and Fish Pathway

Radiation doses can result from the bioaccumulation of plutonium deposited on the surfaces of inland waters or oceans. The predicted radiation doses arising from this pathway depend on a number of assumptions and physical and chemical processes, including how the deposited radionuclides are diluted in the water, how the radionuclides are partitioned between water and sediment, and how radionuclides are accumulated in different types of fish, crustaceans and mollusks.

In marine and aquatic systems, larger particles would quickly settle to the bottom sediments; smaller silt-size particles may remain in suspension within the water column for extended periods of time. Smaller particles may not even break the water surface (due to surface tension), forming a thin layer on the water surface that is subsequently transported to the shoreline by wind and wave action. Resuspension of smaller particles from the bottom could occur due to physical disturbance of the sediments by wave action and recreational uses of the water bodies (e.g., swimming, boating, and fishing), as well as by the feeding activity of various marine and aquatic species. Particles of PuO_2, as a component of the bottom sediments, may also be transported toward and along the shoreline by wave action and currents in near-shore environments (NASA 1990).

Studies have indicated that bioaccumulation in marine organisms can vary widely depending on the type and population densities of seafood species impacted (e.g.,

freshwater fish, saltwater fish, mollusks), the amount and particle size distribution of radioactive material released, and the deposition area.

PuO_2 entering into a water/sediment system would be preferentially taken out of solution and bound in saturated sediments in amounts on the order of 100,000 times greater than the amounts that would remain in the associated water column (NASA 1990).

Clays, organics, and other anionic constituents tend to bind most of the PuO_2 particles in the sediment column. The binding of PuO_2 usually occurs in the first few centimeters of sediment, greatly reducing the concentration of this constituent with depth.

Overall, the seafood pathway is insignificant for PuO_2. This is due to a combination of considerable dilution in the water, overwhelming partition into sediment, and small bioaccumulation factors.

Contamination of Drinking Water

It is possible that surface water runoff containing PuO_2 could directly contaminate drinking water supplies that originate from surface water bodies, because this type of contamination is primarily due to suspended PuO_2 particles and not from dissolved PuO_2. Filtering the surface water before chemical treatment would reduce the concentration of total plutonium to very low levels (NASA 1990).

B-3.4 TRANSPORT AND DEPOSITION OF RADIONUCLIDES IN THE HUMAN BODY

The International Commission on Radiological Protection (ICRP) has developed accepted models for the distribution of inhaled and ingested radionuclides in the body. The ultimate fate of these radionuclides depends on such factors as particle size distribution, solubility, and chemistry. The ICRP models require knowledge of numerous parameters, most of which are obtained empirically (e.g., there is no theoretical model for determining what fraction of ingested plutonium enters the bloodstream). The required parameters are obtained from animal experiments and, if available, from human studies concerning the effects of nuclear weapons and of nuclear fallout. Of the transuranium elements, plutonium is by far the most widely studied.

PuO_2 that enters the human body by inhalation or ingestion has many possible fates, all of which have been studied in detail (ICRP 1979; ICRP 1986). The inhalation route is found to be approximately 1,000 times as effective as ingestion in transporting plutonium to the blood, due to the short time of residency, the chemical properties of plutonium, and the physiological environment of the gastro-intestinal tract (ICRP 1979).

Ingested PuO_2 would quickly pass through the digestive system and be excreted with only a small quantity being absorbed via the mucosa into the bloodstream. The fractional absorption of PuO_2 is estimated to average about 1 part in 100,000 ingested (ICRP 1979; ICRP 1986) – that is, in ICRP terminology, the f_1 factor for ingestion is 10^{-5}. The fractional absorption is based on the average individual. Note that PuO_2 in the environment could become more soluble with time due to the use of fertilizers in gardening, chlorination in drinking water, and conversion to soluble forms in seawater.

Dietary and physiological factors, such as fasting, dietary calcium deficiency, disease or intake of medications, may also change the fractional absorption (ICRP 1986).

Inhaled PuO_2 would be transported to one or more portions of the respiratory system depending on the particle size. Generally, most particles larger than 5 to 10 microns would be intercepted in the nasopharyngeal region and either expelled or swallowed to pass through the digestive tract; what is not absorbed would then be excreted. Particles smaller than about 5 microns would be transported to and remain in the trachea, bronchi, or deep lung regions. Particles reaching the deep lung would be cleared from the body much more slowly than those not entering the lung. For example, approximate micrometer-size PuO_2 particles would typically be cleared from the pulmonary area of the lung at the rate of 40 percent in the first day, and the remaining 60 percent cleared in 500 days (ICRP 1979). Particles captured in the mucous lining of the upper respiratory tract would be moved more rapidly to the pharynx, where they would be swallowed. Once swallowed, they would behave as if ingested.

Plutonium dioxide remaining in the lung would continuously irradiate lung tissue, and a small fraction would be transported over time directly to the blood or to lymph nodes and then to the blood. The estimated fraction of plutonium transferred directly from pulmonary lung tissues to the blood would be about 1 percent of the amount retained in the lungs, depending on the size distribution of ultra-fine particles. Smaller particles are likely to form over time from larger particles due to the natural fragmentation processes associated with radioactive decay and may also be transferred to the blood. Over a period of years, approximately 15 percent of the PuO_2 initially deposited in the lungs would be transferred to the lymph nodes. Of that, up to 90 percent would likely be retained in the lymph node with a 1,000 day half-life before being transferred to the blood (ICRP 1986). Overall, the PuO_2 f_1 factor for inhalation is the same as that for ingestion, i.e., 10^{-5}.

Once PuO_2 has entered the blood via ingestion or inhalation, it would circulate and be deposited primarily in the liver and skeletal system. It is currently accepted that plutonium transported by the blood is distributed to the following organs: 45 percent in the liver, 45 percent in the skeletal system, 0.035 percent in the testes, and 0.011 percent in the ovaries, with a non-measurable amount crossing the placenta and available for uptake by the fetus. The remaining 10 percent of the activity in the blood is excreted through the kidneys and colon or deposited in other tissues (ICRP 1979, ICRP 1986).

The estimated residence times in the liver, skeletal system, and gonads are quite long. Current estimates for 50 percent removal times for plutonium are 20 years for the liver, 50 years for the skeleton, and permanent retention for the gonads.

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APPENDIX C
ENVIRONMENTAL JUSTICE ANALYSIS

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APPENDIX C
ENVIRONMENTAL JUSTICE ANALYSIS

C-1 INTRODUCTION

Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, directs Federal agencies to identify and address, as appropriate, the disproportionately high and adverse health or environmental effects of their programs, policies, and activities on minority populations and low-income populations.

The Council on Environmental Quality (CEQ) has oversight responsibility for documentation prepared in compliance with the National Environmental Policy Act (NEPA) of 1969, as amended (42 U.S.C. 4321 et seq.). In December 1997, the CEQ released its guidance on Environmental Justice (CEQ 1997). The CEQ's guidance was adopted as the basis for the information provided in this Environmental Impact Statement (EIS) for the proposed Mars 2020 mission. The launch opportunity for the proposed Mars 2020 mission occurs during July – August 2020 and the next opportunity occurs 26 months later.

This appendix provides data necessary to assess the potential for disproportionately high and adverse human health or environmental effects on minority and low-income populations that may be associated with implementation of the Mars 2020 mission. The areas examined in this appendix include the counties for which any part of the county is within 100 kilometers (km) (62 miles (mi)) of either Space Launch Complex 41 (SLC-41) located in the northernmost section of Cape Canaveral Air Force Station (CCAFS), Brevard County, Florida, Space Launch Complex 37 (SLC-37), located on the northeastern section of CCAFS Brevard County Florida; or Launch Complex 39A (LC-39A) located on KSC, Brevard County, Florida north and east of SLC-41 and SLC-37. The counties that lie within 100 km (62 mi) of LC-39A and SLC-40 include Brevard, Indian River, Orange, Osceola, Seminole, Volusia, and small portions of Flagler, Lake, and Polk (Figure C-1). The counties that lie within 100 km (62 mi) of SLC-37 include those listed above with the exclusion of Flagler.

C-2 DEFINITIONS AND APPROACH

C-2.1 MINORITY POPULATIONS

During the Census of 2010, the U.S. Bureau of the Census (USBC) collected population data in compliance with guidance adopted by the Office of Management and Budget (62 FR 58782). The following definitions of minority individuals and population are used in this analysis of environmental justice:

Minority Individuals: Persons who are members of any of the following population groups: Hispanic or Latino of any race, American Indian or Alaska Native, Asian, Black or African-American, Native Hawaiian or Other Pacific Islander, or Multiracial (and at least one race, which is a minority race under CEQ guidance of 1997).

Figure C-1. The Area within 100 km (62 mi) of SLC-41, LC-39A and SLC-37

Minority Population: The total number of minority individuals residing within a potentially affected area.

Persons self-designated as Hispanic or Latino are included in the Hispanic or Latino population regardless of race. For example, Asians self-designated as Hispanic or Latino are included in both the Hispanic or Latino population and in the Asian population. Data used to characterize minority populations in the years 2010 and 2012 was extracted from the American Fact Finder portion of the U.S. Census Bureau 2010 census website (USBC 2013c) containing Census 2010 demographic data. Data used for the projection of population groups in Florida for the year 2020 was projected from the USBC's 2010 and 2012 (projected) census data for the nine surrounding counties.

C-2.2 LOW-INCOME POPULATIONS

Poverty thresholds are used to identify "low-income" individuals and populations (CEQ 1997). The following definitions of low-income individuals and population are used in this analysis:

Low-Income Individuals: Persons whose self-reported income is less than the poverty threshold for a given year.

Low-Income Population: The total number of low-income individuals residing within a potentially affected area.

Data used to characterize low-income populations in the year 2010 was extracted from the American Fact Finder portion of the U.S. Census Bureau 2010 census website (USBC 2013c) containing Census 2010 demographic data.

C-2.3 DISPROPORTIONATELY HIGH AND ADVERSE HUMAN HEALTH EFFECTS

Disproportionately high and adverse health effects are those that are significant (40 CFR1508.27) or above generally accepted norms, and for which the risk of adverse impacts to minority populations or low-income populations appreciably exceeds the risk to the general population.

C.2-4 DISPROPORTIONATELY HIGH AND ADVERSE ENVIRONMENTAL EFFECTS

Disproportionately high and adverse environmental effects are those that are significant (40 CFR 1508.27), and that would adversely impact minority populations or low-income populations appreciably more than the general population.

C-3 METHODOLOGY

C-3-1 SPATIAL RESOLUTION

For the purposes of enumeration and analysis, the USBC has defined a variety of aerial units (USBC 2001; USBC 1992). Aerial units of concern in this document include (in order of increasing spatial resolution) states, counties, census tracts, block groups, and blocks. The block is the smallest of these entities and offers the finest spatial resolution. This term refers to a relatively small geographical area bounded on all sides by visible features such as streets and streams, or by invisible boundaries such as city limits and property lines. In the analysis below, the county level data was used in the analysis of minority impacts.

C-3-2 PROJECTIONS OF POPULATIONS

The U.S. Census estimates for population groups living in the nine counties of interest closest to KSC for the years 2010 and 2012 are shown in Table C-1. Estimates for the 2020 populations living in the nine counties were obtained as linear projections of resident populations for the years 2010 and 2012.

C-3.3 ENVIRONMENTAL JUSTICE ASSESSMENT

The purpose of this analysis is to (1) identify minority populations and low-income populations residing within the identified area that would be potentially affected by

implementation of the Proposed Action (Alternative 1) or Alternatives 2 and 3, and determine if implementation of the Proposed Action or Alternatives would result in disproportionately high and adverse effects on these populations. In the event that radiological or other human health risks resulting from the implementation of the Proposed Action or Alternatives are found to be significant, then the health risks to minority populations and low-income populations will be evaluated to determine if they are disproportionately high.

C-4 CHARACTERIZATION OF POTENTIALLY AFFECTED POPULATIONS

The land area within the nine counties surrounding KSC includes approximately 2.2 million hectares (5.4 million acres) of central Florida's eastern coast. Approximately 4.0 million persons lived within the nine counties in the year 2010 (Table C-1). Between 2010 and 2012, the minority population within this area declined slightly and in 2012, minority persons comprised approximately 24 percent of the total population. By the year 2020, the total population is projected to increase to nearly 4.6 million persons, and minorities are projected to comprise approximately 24 percent of the total population.

In 2010, approximately 40 percent of the total and minority populations lived in Orange County.

Hispanic or Latino and Black or African-American populations were the largest minority groups living within the nine counties surrounding KSC in 2010. Blacks or African-Americans are the largest resident minority group in Brevard and Flagler counties; Hispanic or Latino the largest in the remaining seven counties. Hispanics or Latinos comprise the largest group of minority residents in the total area.

Data from Census 2010 (USBC 2013c) shows that 13.7 percent of the population living within the nine counties reported incomes below the poverty threshold; lower percentages than reported by Florida (14.7 percent) and the United States (14.3 percent).

Table C-1. Composition of the Population in the KSC Area

Population	Region		
	2010	2012	2020a
Total	4,008,199	4,123,015	4,633,191
White alone	3,000,817	3,150,914	3,517,600
Black or African American alone	563,524	597,053	682,502.3
American Indian and Alaska Native alone	16,119	10,080	11,225
Asian alone	117,240	123,613	142,107
Native Hawaiian and Other Pacific Islander alone	3,221	3,584	3,741
Some other race alone	194,124	134,859	158,873
Two or more races	113,154	102,912	117,142
Hispanic or Latino	768,264	840,134	979,685
Percent Minority	25.1%	23.6%	24.1%
Percent Low Income	13.7%	—	—

(a) Projected based on increase in total population by county between 2010 and 2012

Population	Brevard County			Flagler County			Indian River County		
	2010	2012	2020a	2010	2012	2020a	2010	2012	2020a
Total	543,376	547,307	563,317	95,696	98,359	109,773	138,028	140,567	151,199
White alone	450,927	456,906	470,272	78,710	77,874	86,911	116,346	120,669	129,796
Black or African American alone	54,799	55,223	56,838	10,884	11,999	13,391	12,397	12,825	13,795
American Indian and Alaska Native alone	2,118	1,146	1,180	267	0	0	408	0	0
Asian alone	11,349	12,279	12,638	2,046	2,174	2,426	1,666	1,807	1,944
Native Hawaiian and Other Pacific Islander alone	514	2,519	2,593	59	64	71	51	0	0
Some other race alone	9,299	5,658	5,824	1,544	4,058	4,529	4,909	3,080	3,313
Two or more races	14,370	13,576	13,973	2,186	2,190	2,444	2,251	2,186	2,351
Hispanic or Latino	43,943	47,891	49,292	8,251	8,705	9,715	15,465	15,970	17,178
Percent Minority	17.0%	16.5%	16.5%	17.7%	20.8%	20.8%	15.7%	14.2%	14.2%
Percent Low Income	13.7%	—	—	13.30%	-	-	13.40%	-	-

Population	Lake County			Orange County			Osceola County		
	2010	2012	2020a	2010	2012	2020a	2010	2012	2020a
Total	297,052	303,186	329,015	1,145,956	1,202,234	1,456,375	268,685	287,416	376,341
White alone	243,624	254,060	275,704	728,795	777,502	941,859	190,641	215,200	281,781
Black or African American alone	29,103	30,197	32,770	238,241	256,542	310,773	30,369	34,793	45,558
American Indian and Alaska Native alone	1,472	993	1,078	4,532	1,874	2,270	1,452	978	1,281
Asian alone	5,173	4,525	4,910	56,581	57,438	69,580	7,406	8,402	11,002
Native Hawaiian and Other Pacific Islander alone	215	267	290	1,266	100	121	294	0	0
Some other race alone	10,778	5,945	6,451	77,216	72,607	87,955	27,623	18,795	24,610
Two or more races	6,687	7,199	7,812	39,325	36,171	43,817	10,900	9,248	12,109
Hispanic or Latino	36,009	39,299	42,647	308,244	339,202	410,906	122,146	137,250	179,714
Percent Minority	18.0%	16.2%	16.2%	36.4%	35.3%	35.3%	29.0%	25.1%	25.1%
Percent Low Income	11.40%	-	-	14.90%	-	-	13.90%	-	-

Population	Polk County			Seminole County			Volusia County		
	2010	2012	2020a	2010	2012	2020a	2010	2012	2020a
Total	602,095	616,158	675,772	422,718	430,838	464,908	494,593	496,950	506,491
White alone	452,854	486,415	533,476	330,664	348,662	376,234	408,256	413,626	421,567
Black or African American alone	88,833	93,201	102,218	47,107	48,809	52,669	51,791	53,464	54,490
American Indian and Alaska Native alone	2,706	1,878	2,060	1,386	1,422	1,534	1,778	1,789	1,823
Asian alone	9,760	10,458	11,470	15,692	18,345	19,796	7,567	8,185	8,342
Native Hawaiian and Other Pacific Islander alone	360	213	234	258	58	63	204	363	370
Some other race alone	32,847	8,954	9,820	15,421	5,099	5,502	14,487	10,663	10,868
Two or more races	14,735	15,039	16,494	12,190	8,443	9,111	10,510	8,860	9,030
Hispanic or Latino	106,532	114,459	125,533	72,457	78,568	84,781	55,217	58,790	59,919
Percent Minority	24.8%	21.1%	21.1%	21.8%	19.1%	19.1%	17.5%	16.8%	16.8%
Percent Low Income	16.40%	-	-	10.00%	-	-	15.00%	-	-

C-5 IMPACTS ON MINORITY AND LOW-INCOME POPULATIONS

As discussed in Chapter 4 of this EIS, accidents during launch of the proposed Mars 2020 mission could result in human exposure to radioactive and other hazardous materials. Plutonium-238 is the primary radioactive material of concern. Potential radiological releases could affect populations residing both within and beyond 100 km (62 mi) of the launch complex. As shown in Tables 4-5, 4-12, and 4-17 of Chapter 4, if either Alternative 1, 2, or 3 is implemented, and if an accidental release of radioactive material were to occur during any mission phase, on average no latent cancer fatalities would be expected to occur.

Mission risks (consequences that would occur in the event of a radioactive release multiplied by the probability of a release) are also small. As shown in Table 4-6, should Alternative 1 be selected, the likelihood of an accident resulting in a release of radioactive material from the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) during the pre-launch and early launch phases combined is 9.9×10^{-5} (approximately 1 in 10,000). The corresponding risk to the local population (persons residing within 100 km (62 mi) of the launch facilities) of a latent cancer fatality resulting from an accident in pre-launch or early launch is 1.7×10^{-5} (approximately 1 in 59,000) (Table 4-7). The risk to the global population (persons residing more than 100 km (62 mi) from the launch site) of a latent cancer fatality resulting from an accident during the Mars 2020 mission is 1.3×10^{-5} (approximately 1 in 77,000).

As shown in Table 4-17, should Alternative 3 be selected, the likelihood of an accident resulting in a release of radioactive material from the Light Weight Radioisotope Heater Units (LWRHUs) during the pre-launch and early launch phases combined is 6.2×10^{-5} (approximately 1 in 16,000). The corresponding risk to the local population (persons residing within 100 km (62 mi) of the launch facilities) of a latent cancer fatality resulting from an accident in pre-launch or early launch is 8.2×10^{-7} (approximately 1 in 1,200,000) (Table 4-18). The risk to the global population (persons residing more than 100 km (62 mi) from the launch site) of a latent cancer fatality resulting from an accident during the Mars 2020 mission is 4.6×10^{-7} (approximately 1 in 2,200,000).

As shown in Table 4-13, should Alternatives 1, 2, or 3 be selected, the likelihood of an accident resulting in a release of radioactive material from the instrumentation small quantity source terms during the pre-launch and early launch phases combined is 6.0×10^{-4} (approximately 1 in 1,600). The corresponding risk to the affected population of a latent cancer fatality resulting from an accident in pre-launch or early launch is 3.2×10^{-8} (approximately 1 in 31,000,000) (Table 4-13). The risk to the affected population of a latent cancer fatality resulting from an accident during the Mars 2020 mission is 1.6×10^{-6} (approximately 1 in 600,000).

As discussed in Section 4.1.3, non-radiological accidents also pose no significant risks to the public. Toxic effects that could result from a liquid propellant spill during fueling operations would not extend beyond the immediate vicinity of the launch pad. Members of the public are excluded from the area at risk during fueling operations. A fuel explosion on the launch pad or during the first few seconds of flight could (if the Atlas V is selected as the launch vehicle) temporarily increase carbon monoxide (CO), hydrochloric acid (HCl), and aluminum oxide levels near the CCAFS boundary. One-

hour average concentrations of hazardous emissions from such an explosion are less than the emergency response guidelines recommended by the American Industrial Hygiene Association and the National Research Council for the Department of Defense (USAF 1998).

Thus, implementation of the Proposed Action or the Alternatives would pose no significant radiological or non-radiological risks to the public, including minority and low-income groups within the potentially affected population.

C-6 REFERENCES FOR APPENDIX C

CEQ 1997. Council on Environmental Quality. *Environmental Justice: Guidance under the National Environmental Policy Act.* Executive Office of the President. Washington, DC. December 10, 1997. Available at *http://www.epa.gov/compliance/ej/resources/policy/ej_guidance_nepa_ceq1297.pdf*

USAF 1998. U.S. Air Force. *Final Environmental Impact Statement – Evolved Expendable Launch Vehicle Program*. HQ USAF/ILEVP, 1260 Air Force Pentagon, Washington, DC. April 1998. Available at handle.dtic.mil/100.2/ADA413417

USBC 2013c. U.S. Census Bureau. *2010 Census, American Fact Finder.* November 2013. Available at *http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml*