2 ALTERNATIVES INCLUDING THE PROPOSED ACTION

The purpose of the Mars Exploration Rover–2003 (MER–2003) project would be to place two mobile science laboratories (rovers) on the surface of Mars to characterize rocks and soils that may hold clues to the possible presence of water on Mars.

This Final Environmental Impact Statement (FEIS) for the MER–2003 project evaluates the following alternatives:

- Proposed Action. NASA proposes to continue preparations for and to implement the MER–2003 project to Mars. The MER–2003 project involves two launches (the MER–A mission and MER–B mission) of identical spacecraft from Cape Canaveral Air Force Station (CCAFS), Florida, in 2003. The MER–A launch, aboard a Delta II 7925, would occur during May or June, 2003. The MER–B launch would occur during June or July, 2003, aboard a Delta II 7925 Heavy (7925H). The Proposed Action is described in Section 2.1.
- No Action. Under the No Action Alternative, NASA would discontinue preparations for and would not implement the MER–2003 project. The No Action Alternative is described in Section 2.2.

2.1 DESCRIPTION OF THE PROPOSED ACTION

NASA proposes to continue preparations for and to implement the MER–2003 project to Mars. The MER–2003 project would consist of two missions to send two identical rovers to two different sites on the surface of Mars to conduct *in situ* (local) mineralogy and geochemistry investigations and characterize a diversity of rocks and soils which may hold clues about past water activity. Each rover would explore to a distance of at least 600 meters (m) (1,968 feet (ft)) from its landing site (with a goal of one kilometer (km) (0.62 mile (mi))), and surface operations would be expected to last at least 90 Martian days (sols[1]). The rovers would investigate up to a total of eight separate locations in the vicinity of two diverse landing sites. The two rovers would operate simultaneously for at least 30 sols.

A Delta II 7925 with a Star 48B solid-rocket upper (third) stage would be used to inject the first spacecraft (MER–A) into an Earth-Mars trajectory during May or June 2003, with arrival at Mars in January 2004. A Delta II 7925H with a Star 48B third stage would be required to inject the second spacecraft (MER–B) into an Earth-Mars trajectory in June or July 2003 for arrival at Mars in January 2004. (Due to the later launch opportunity, the MER–B mission can only be achieved with the Delta II 7925H.) NASA has not selected specific landing sites yet but is currently considering potential sites between 15° South and 5° North for the MER–A mission, and between 10° South and 10° North for the MER–B mission.

Achieving all of the mission objectives would require launching two rovers as proposed. However, programmatic issues (*e.g.*, changes in NASA priorities or unforeseen

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

circumstances) could necessitate modification to the mission objectives and timing. Such modifications could result in the need to launch one mission in 2003, and a second mission at a later launch opportunity or not at all. If any of these events were to occur, NASA would evaluate the need to prepare additional environmental documentation.

2.1.1 Spacecraft Description

The summary description of the MER–2003 spacecraft presented in this section is based upon the detailed design information available at the time of publication of this FEIS. This information, in the *Mars Exploration Rover Project Final Delta II 7925/7925H EIS Databook* (NASA 2001), is subject to further refinement as the design process proceeds.

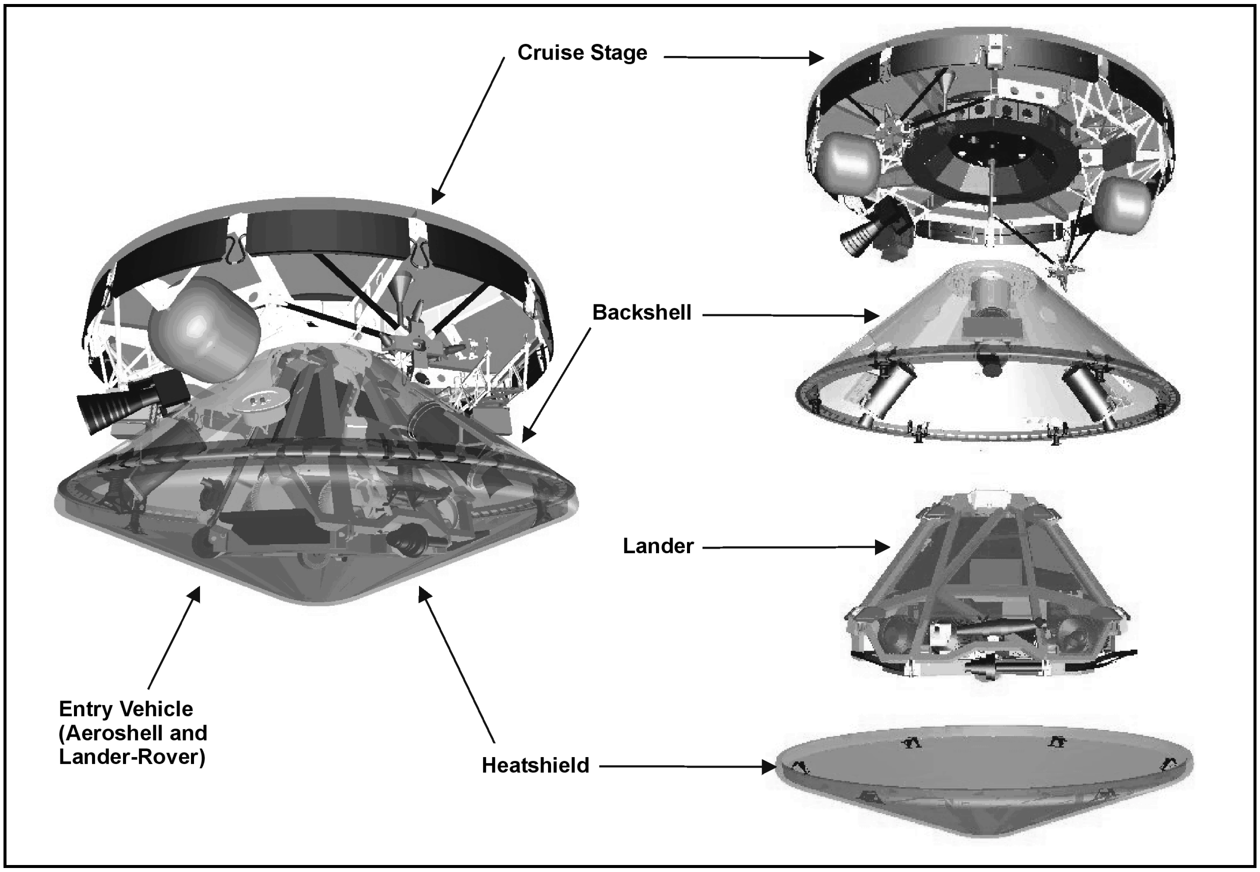
Each identical MER–2003 spacecraft (see Figure 2-1) would consist of a cruise stage and an entry, descent, and landing (EDL) stage, which would include an aeroshell, backshell, parachute, and airbags. A lander containing a large rover would be enclosed within the EDL stage. The primary function of the EDL stage would be to convey its lander-rover safely to the surface of the planet. Each rover would carry all science instruments and communications equipment for transmitting to and receiving data from Earth, either by using an existing Mars orbiting spacecraft or by communicating directly with Earth. The mass for each spacecraft is expected to be 1,063 kilograms (kg) (2,343 pounds (lb)).

After launch, each spacecraft would cruise to Mars for approximately seven to eight months. During final approach, the cruise stage would be jettisoned from the EDL stage, and the vehicle would enter the Martian atmosphere. The MER–2003 missions would employ a technique similar to that demonstrated by the 1996 Mars Pathfinder mission to ensure a safe landing on the surface of Mars. This technique would employ a heatshield, small solid retro-rockets, and a parachute to decelerate the lander as it passes through the Martian atmosphere. A system of airbags would then be used to cushion and protect the lander upon contact with the Martian surface. Once each lander comes to rest the airbags would deflate and the lander petals would unfold. Each rover would then drive off of its lander platform and begin exploring the landing site.

2.1.1.1 Cruise Stage

The cruise stage (see Figure 2-1) would contain the components that are used only during the cruise to Mars. It would provide the interface with the launch vehicle and upon command would separate from the launch vehicle upper stage. The cruise stage would provide the propulsion system for attitude control, trajectory correction maneuvers, and final Mars entry attitude alignment. It also would carry equipment for solar power generation during flight to Mars, and for telecommunications, attitude determination and navigation during cruise.

The cruise stage propulsion system would include two lightweight composite-wrapped aluminum-lined tanks, each designed to carry up to 35 kg (77 lb) of hydrazine (N_2H_4) propellant. Solar cells for electrical power generation would be fixed to the cruise stage along a disc-shaped substrate. A star tracker and sun-sensors would provide data for attitude determination. Telecommunications and navigation tracking would be provided by medium and low gain antennas.



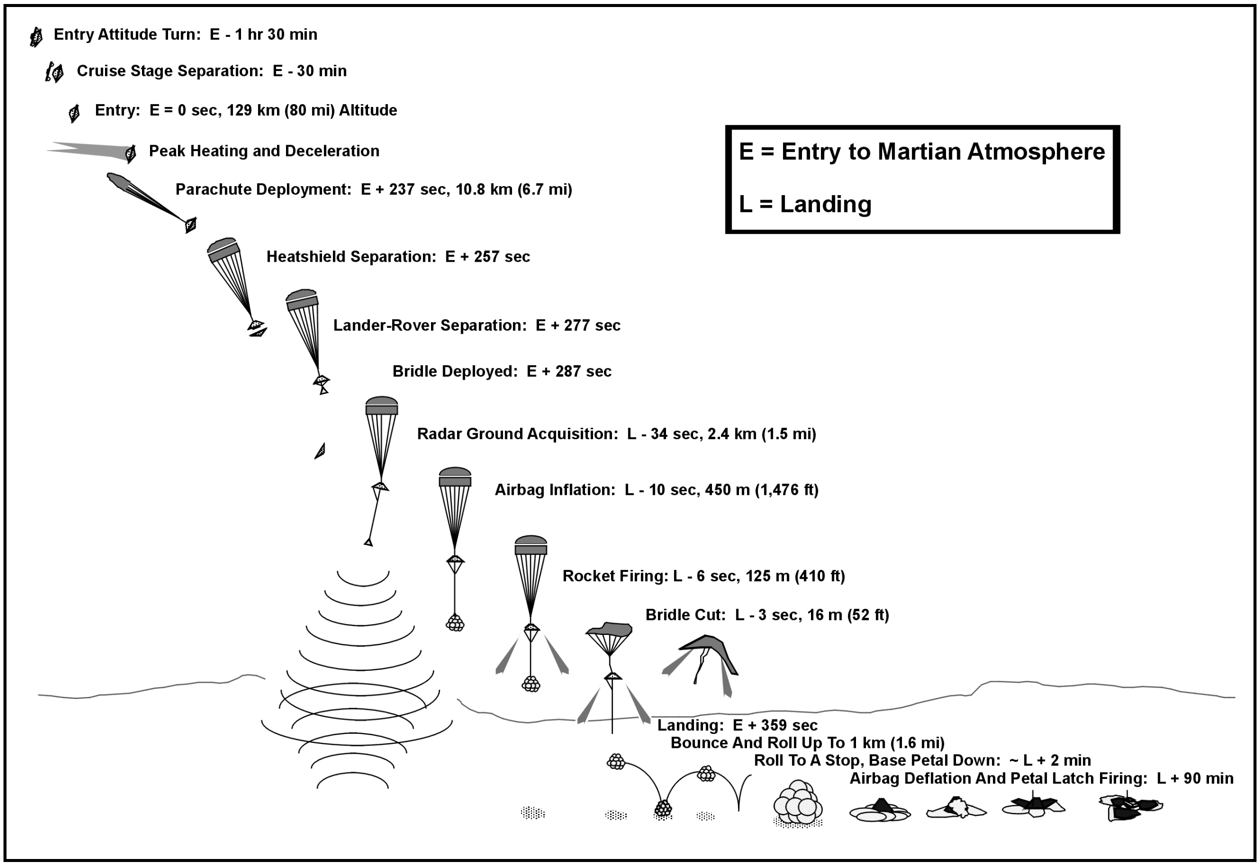
Source: Adapted from NASA 2001

Figure 2-1. Illustration of the MER–2003 Spacecraft

2.1.1.2 Entry Vehicle

The entry vehicle (see Figure 2-1) would contain the lander-rover vehicle in an aeroshell made up of a heatshield and a backshell. The entry vehicle would constitute the EDL stage of the MER–2003 spacecraft. The aeroshell would consist of the heatshield and backshell, a parachute, inflatable airbags, and small solid rocket motors. It would protect the lander-rover during entry through the Martian atmosphere via the thermal protection system on the heatshield. The heatshield would be shaped in a 70° half-cone, similar to that used for Mars Pathfinder.

The entry vehicle would separate from the cruise stage about 30 minutes prior to entering Mars' atmosphere. The vehicle would enter the atmosphere directly from its interplanetary trajectory without first being captured into an orbit about Mars. Between four and five minutes after entering Mars' atmosphere, the parachute would be deployed, the heatshield would be jettisoned, and the lander's radar altimeter would be turned on. The lander would descend on a tether suspended from the backshell. At approximately 450 m (1,476 ft) above the surface the airbags would be inflated. The small solid rocket motors would then fire at about 125 m (410 ft) above the surface. A few seconds after that the parachute bridle would be cut and the lander would descend in free-fall the remaining distance to the surface and bounce and roll to a stop. Figure 2-2 illustrates the landing sequence.



Source: Adapted from NASA 2001

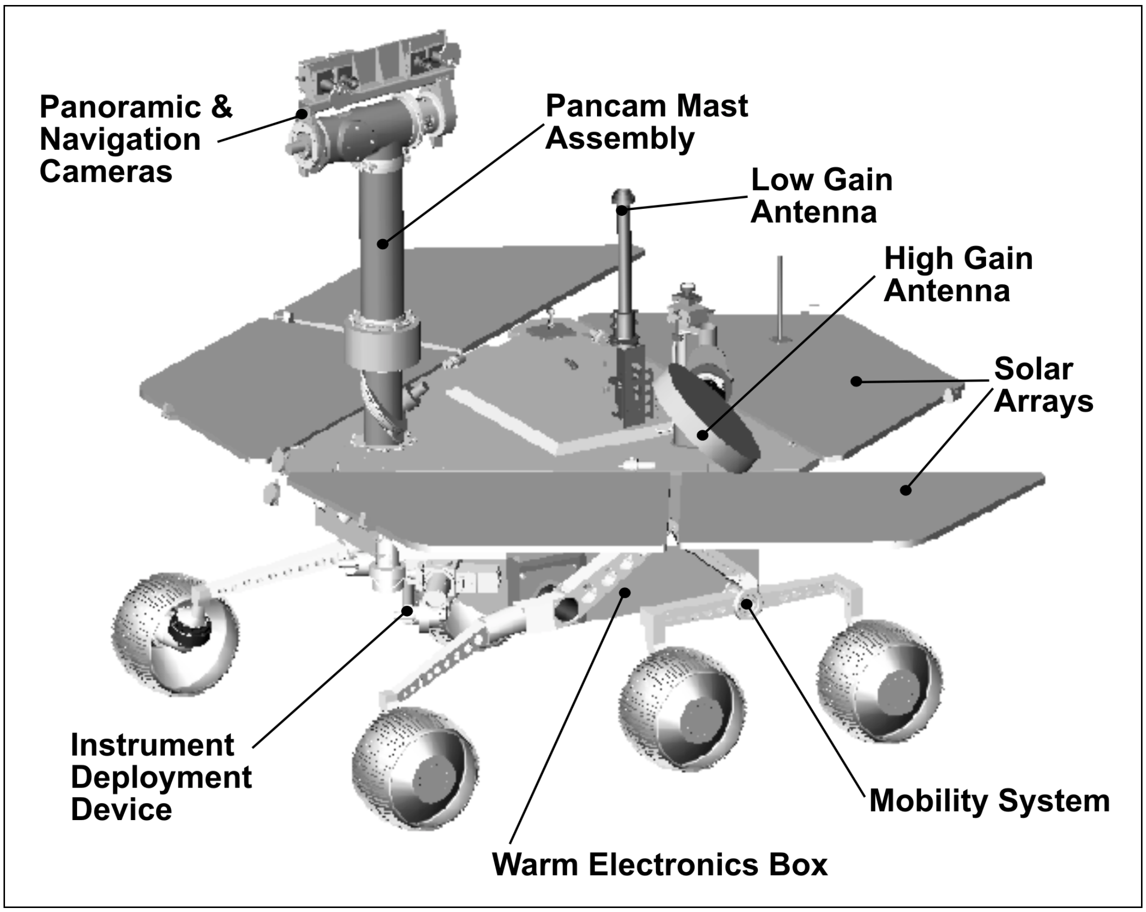
Figure 2-2. MER–2003 Entry, Descent and Landing Sequence

2.1.1.3 Lander

The lander (see Figure 2-1) would be a four-petal tetrahedron of composite structure with external aluminum sheet cladding for protection from rocks. The lander would carry the airbags and their associated inflation and retraction actuators, and the actuators that open the lander petals and right the lander. The lander would also carry the batteries to provide power through the first day of deployment activities, and electronics modules for pyrotechnic switching and primary battery control, and the lander radar altimeters. The base of the lander would contain the rover lift mechanism to support rover deployment after petal opening. Following entry, descent and landing, the lander would retract the airbags, deploy its petals, right itself if necessary, and erect the rover.

2.1.1.4 Rover

The MER–2003 rover (see Figure 2-3) would be substantially larger and more capable than the *Sojourner* rover of the Mars Pathfinder mission. The MER–2003 rover would have a mass of nearly 185 kg (408 lb) and a range of up to 40 m (about 131 ft) per Martian day. The rover's wheel base would measure 1.4 m (4.6 ft) and it would have a track width of 1.06 m (3.5 ft). The total height of the rover would be 1.5 m (4.8 ft) and the ground clearance beneath the rover would be 0.29 m (11.2 inches (in)).



Source: Adapted from NASA 2001

Figure 2-3. Illustration of the MER–2003 Rover

Immediately after landing and system check-out, each rover would begin reconnaissance of its landing site by taking a 360° visible color and infrared panorama image. It would then drive off its lander to begin its exploration, and may drive to up to four different sites during its planned 90-sol mission. The rover would perform remote science, taking images with the Panoramic Camera (Pancam) mounted on the Pancam

Mast Assembly (PMA). The PMA also would serve as the optical path for infrared images collected by the Miniature Thermal Emission Spectrometer (Mini-TES). The rover would perform *in situ* science using available cameras, and, on selected targets, would use the Instrument Deployment Device (IDD) to position the *in situ* instrument suite. This would include the Alpha Particle X-Ray Spectrometer (APXS), the Mössbauer Spectrometer, the Rock Abrasion Tool, and the Microscopic Imager. Table 2-1 lists the science instruments proposed for each MER–2003 rover and summarizes their measurement objectives.

Table 2-1. MER–2003 Project Science Instruments And Objectives

Instrument	Objectives
Panoramic Camera (Pancam) [a]	• Provide high spatial resolution information on nearby rocks and local geologic features. • Provide information on the mineralogy of materials by using the multispectral imaging capability. • Observe the full Martian sky to provide information about atmospheric dust particles.
Miniature Thermal Emission Spectrometer (Mini-TES) [a]	• Detect the presence of salts containing silicates, carbonates, hydroxides, phosphates, sulfates, and oxides. • Provide high-resolution temperature profiles of the Martian atmosphere. • Determine the thermal inertia of Martian surface materials over diurnal cycles.
Alpha Particle X-ray Spectrometer (APXS) [b]	• Determine the elemental chemistry of rocks and soils.
Rock Abrasion Tool [b]	• Remove dust and weathered surfaces of selected rock specimens to reveal the underlying material.
Microscopic Imager [b]	• Provide detailed images of rocks and minerals. • Provide information about sedimentary rocks that may have been deposited during former wetter environments on Mars. • Observe small-scale features of rocks formed by volcanic activity or meteorite impacts.
Mössbauer Spectrometer [b]	• Determine the iron oxidation state of rock and soil samples. • Measure the magnetic phases of the soil samples.

a. Mounted on the Pancam Mast Assembly (PMA)

b. Mounted on the Instrument Deployment Device (IDD)

The Pancam is a high-resolution stereo color imager with 14 color filters and would provide panoramic images and information on geologic context, rock and soil texture, and detection of iron-bearing minerals. The Mini-TES is an infrared spectrometer and would be used to recognize carbonates, silicates, organic molecules, and minerals formed in water. In addition to determining mineral composition of Martian surface materials, the Mini-TES would be pointed upward to make the first ever high-resolution temperature profiles through the Martian atmosphere's boundary layer. The Pancam and Mini-TES would survey the scene around the rover and look for the most interesting rocks and soils for *in situ* analysis.

The Mössbauer Spectrometer would identify the mineralogy of all iron-bearing minerals and would also be capable of examining the magnetic properties of surface materials and identifying minerals formed in hot, watery environments. The APXS would perform elemental analyses of Martian rock or soil. Analyzing the elemental make-up of Martian surface materials would provide information about crust formation, weathering processes, and water activity on Mars.

The Rock Abrasion Tool is a surface preparation tool that would be used to expose fresh rock surface for study by the other sensors. The Microscopic Imager is a combination of a microscope and a camera that would produce extreme close-up views of rocks and soils examined by other instruments on the IDD, providing visual context for the interpretation of mineral and element composition data.

The rover would use a Navigational Camera, mounted on the PMA, to provide low-resolution black and white stereo images for traverse planning. Two pairs of Hazard Avoidance Cameras, mounted on the front and back of the rover's main body, would provide black and white range maps for obstacle avoidance during traverses.

Batteries and solar panels would be used to power the various electronics within the rover. Onboard systems would be used to manage the thermal environment for the rover's batteries. Lightweight radioisotope heater units (RHUs) would be used to help maintain the thermal environment requirements of the batteries, which have a relatively narrow operating temperature range (-20° Celsius (C) to +30° C (-4° Fahrenheit (F) to +86° F)), and to minimize the use of electrical heaters during the Martian night. The battery box would be isolated from the rover's equipment module. If RHUs were not used, the thermostatically-controlled battery heaters would draw excessive battery energy to the point of total discharge during the Martian night and consequently not be able to keep any of the electronics functioning properly. Initial thermal analyses for Mars surface operations indicated up to eleven (11) RHUs could be required for each rover. As the mission design matures, ongoing thermal analyses for surface operation of the rovers may indicate a requirement for fewer RHUs. The RHUs would be mounted in three locations inside each rover: within holders mounted at each end on top of the battery assembly in the rear of the thermally-insulated Warm Electronics Box, and within a holder mounted to the rear face of the rover electronics module.

2.1.1.5 Small-Quantity Radioactive Sources

Two of the science instruments on the rovers would use small quantities of radioactive material for instrument calibration or science experiments. The Mössbauer Spectrometer would contain two cobalt-57 (Co-57) sources, with a total activity that would not exceed 350 millicuries (mCi). The APXS would contain six curium-244 (Cm-244) sources with a total activity that would not exceed 50 mCi. Both the Mössbauer Spectrometer and the APXS detector heads would be located on the Science Instrument Turret, at the end of the IDD.

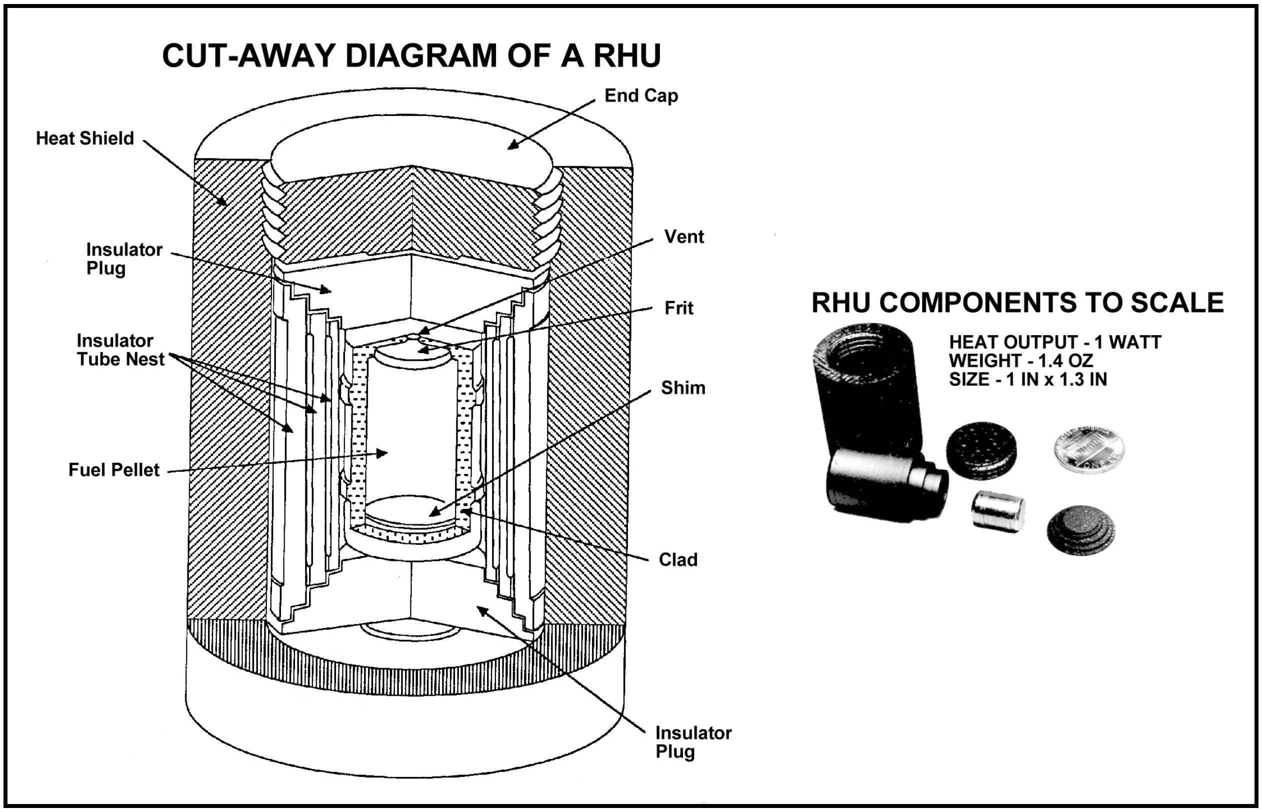
The Mössbauer Spectrometer is a unique analytical device which would identify the mineralogy of all iron-bearing minerals and would also be capable of examining the magnetic properties of surface materials and identifying minerals formed in hot, watery environments. No other instrument with similar mass and volume characteristics can determine *in situ* iron mineralogy with the same sensitivity. Analyzing iron mineralogy in a laboratory on Earth, if not done with a Mössbauer Spectrometer, can require multiple instruments, ranging from a saw and microscopes to create and observe thin sections of rock, to grinding tools and X-ray machines or concentrated acids for analytical wet chemistry. None of these methods have yet been made sufficiently compact or robust to be mounted on the end of a robotic arm and sent to Mars for analyzing rocks in place. While the Mini-TES instrument on the MER–2003 rover can determine the presence of some iron minerals, it cannot distinguish all iron minerals, and does not have the Mössbauer Spectrometer's ability to discriminate between minerals occurring at low concentrations. The Mössbauer Spectrometer is the best-suited instrument for conducting the iron mineralogy required for the project science objectives.

The APXS is also a unique instrument for analyzing the elemental composition of surface materials that would provide information about crust formation, weathering processes, and water activity on Mars. From its position on the IDD, the APXS would perform *in situ* analysis of both the light and heavy elemental composition of a substance (*e.g.*, soil, a rock, the calibration target). An active X-ray fluorescence instrument similar to that used on the 1975 Viking Landers could perform a similar elemental analysis. However, such analysis would be limited only to the heavy elements, and thus cannot provide the scientific insights most directly relevant to the understanding of processes involving water on Mars. In addition, such an instrument would also require the use of radioactive material (*e.g.*, iron-55 and cadmium-109) to provide a source of X-rays to carry out the measurements. Considering the project science objectives and mass and volume constraints imposed by the rovers, the APXS is the best-suited instrument for satisfying the mission objectives.

2.1.2 Radioisotope Heater Units

The MER–2003 rovers would use a combination of lightweight RHUs and electric heaters to maintain internal temperature during the Martian night. Each RHU (see Figure 2-4) would provide about 1 watt of heat derived from the radioactive decay of 2.7 grams (g) (0.095 ounce (oz)) of plutonium (mostly Pu-238) dioxide in ceramic form. Each RHU would contribute approximately 33.2 curies (Ci) for a total plutonium dioxide inventory of up to 365 Ci on each rover (based on the use of up to 11 RHUs). Table 2-2 provides the typical radionuclide composition of a RHU's fuel. The exterior dimensions of a RHU are 2.6 cm (1.03 in) in diameter by 3.2 cm (1.26 in) in length. Each RHU has a mass of about 40 g (1.4 oz).

RHUs are designed to contain the plutonium dioxide during normal operations and under a wide range of accident environments. The integrity and durability of RHUs have been well documented by the U.S. Department of Energy (DOE 2002). The plutonium dioxide ceramic is encapsulated in a 70% platinum and 30% rhodium alloy clad. Protection against high temperature accident environments is provided by a fine weave pierced fabric of carbon graphite used as a heatshield, and a series of concentric pyrolytic graphite sleeves and end plugs to thermally insulate the encapsulated radioactive material. The RHU's plutonium dioxide is principally protected from ground or debris impact by the alloy clad. The heatshield and inner pyrolytic graphite insulators provide additional protection.



Source: Adapted from DOE 2002

Figure 2-4. The Principle Features of a Radioisotope Heater Unit (RHU)

2.1.3 Space Launch Complex 17

Space Launch Complex 17 (SLC–17) is located in the southeastern section of CCAFS. SLC–17 consists of two launch pads (17A and 17B), a blockhouse, ready room, shops, mobile service towers, fixed umbilical towers, launch decks, exhaust flumes, fuel storage tanks, and other facilities that are needed to prepare, service, and launch Delta II vehicles. A Delta II 7925 could be launched from either Pad 17A or Pad 17B, whereas a Delta II 7925H can only be launched from Pad 17B.

Security at SLC–17 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 also be restricted as part of the overall security measures that will be in place for the launch.

Table 2-2. Typical Radionuclide Composition of a RHU's Fuel

Fuel Component	Weight Percent	Half-Life (Years)	Specific Activity (Ci/g Of Fuel Component) [a]	Total Activity (Ci)
Plutonium	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 [b]	NA	NA
Oxygen	11.852	NA	NA	NA
Total	**100.00**	**NA**	**NA**	**33.231**

Source: DOE 2002

a. Ci/g = curies per gram
b. NA = Not Applicable

2.1.4 Payload Processing

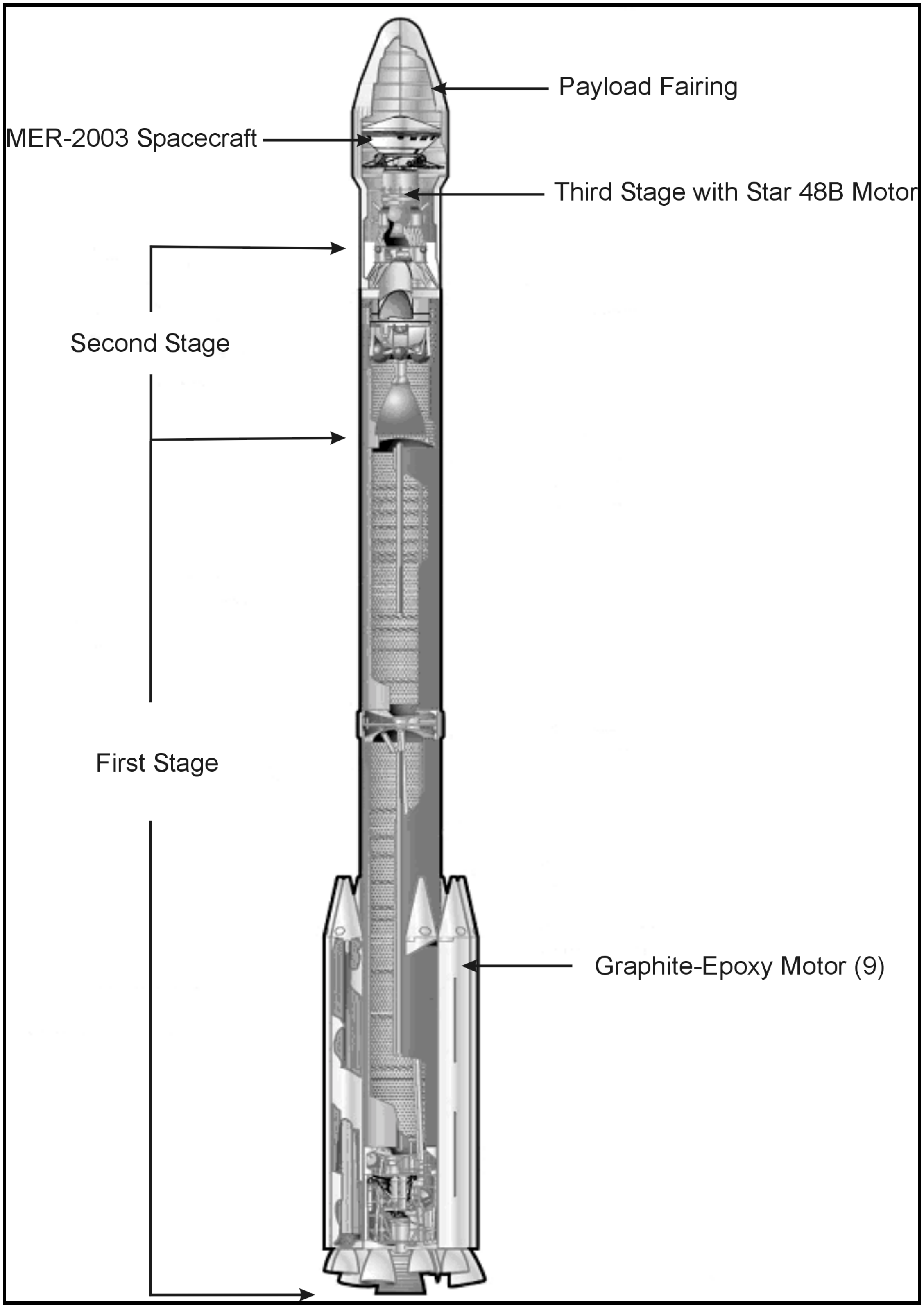
Industrial activities associated with integrating the MER–2003 spacecraft to the Delta II 7925 and the Delta II 7925H would involve receipt of components, inspection, storage, assembly, and testing at KSC, and transport to SLC–17 at CCAFS where the spacecraft would be mated to the Delta II vehicles. Spacecraft safety, security, and contamination control would be ensured by payload encapsulation within a special container prior to its transport to the launch pad. Transportation of the spacecraft within its container from KSC to the launch pad at CCAFS would be by truck, limited to a speed of 8 kilometers per hour (5 miles per hour). All effluents and wastes generated would be subject to Federal and State laws, regulations, and permits; CCAFS has permits and waste management programs in place. In addition, at KSC and CCAFS, all radiological safety controls and precautions relating to receipt, storage, handling, and installation of the RHUs and the small-quantity radioactive sources would be strictly followed.

2.1.5 The Delta II 7925 Launch Vehicle

The Delta II 7925 expendable launch vehicle main elements include a liquid-propellant first stage with nine graphite-epoxy solid rocket motors (called GEMs), a liquid-propellant second stage, a solid-propellant third stage, and a payload fairing (PLF) (see Figure 2-5). The Delta II 7925 stands more than 38 m (125 ft) in height at launch (NASA 2001).

2.1.5.1 First Stage and Solid Rocket Motors

The Delta II 7925 first stage is powered by a liquid-propellant RS-27A main engine. The first stage contains about 94,123 kg (207,504 lb) of propellant (NASA 2001). The fuel is rocket propellant-1 (RP-1), a thermally stable kerosene, and the oxidizer is liquid oxygen (LOX).



Source: Adapted from NASA 2001

Figure 2-5. Delta II 7925 Launch Vehicle with the MER–2003 Spacecraft

The nine externally attached GEMs provide thrust augmentation during the initial boost of the Delta II. The propellant case of each GEM is approximately 1 m (40 in) in diameter and 10 m (33 ft) long, and contains 11,740 kg (25,882 lb) of solid propellant (NASA 2001), consisting mostly of ammonium perchlorate with powdered aluminum additive and hydroxyl-terminated polybutadiene (HTPB) binder (Giles 2001). The total propellant load for the nine GEMs would be 105,660 kg (232,938 lb).

2.1.5.2 Second Stage

The Delta II 7925 second stage is powered by a liquid-propellant AJ10-118K engine. The propellant consists of Aerozine–50 (a 50:50 mix of N_2H_4 and unsymmetrical dimethylhydrazine (UDMH)) as fuel and nitrogen tetroxide (N_2O_4) as oxidizer. Approximately 6,052 kg (13,342 lb) of propellant is carried in the second stage (NASA 2001).

2.1.5.3 Third Stage

The Delta II 7925 third stage for the MER–A mission consists of a spin table assembly, a Star 48B solid rocket motor, and a payload attach fitting. The Star 48B is about 2 m (6.7 ft) in length and carries 2,009 kg (4,430 lb) of solid propellant, consisting mostly of ammonium perchlorate with powdered aluminum additive and HTPB binder (NASA 2001).

2.1.5.4 Payload Fairing

The Delta II 7925 PLF consists of two aluminum sections and is about 8.5 m (28 ft) tall and 2.9 m (9.5 ft) in diameter. The PLF protects the spacecraft from environmental, acoustic and aerodynamic forces during launch and ascent (NASA 2001).

2.1.5.5 Flight Termination System

Range Safety requires launch vehicles to be equipped with a Flight Termination System (FTS) capable of causing destruction of the launch vehicle in the event of a major vehicle malfunction. The FTS consists of both an Automatic Destruct System (ADS) and a Command Destruct System (CDS). As configured for this mission, the ADS and CDS would initiate destruct ordnance components that split open all first and second stage propellant tanks to disperse the liquid propellants and split all GEM cases to terminate solid motor thrusting. The Star 48B motor in the third stage would also be rendered non-propulsive. A Star 48B Breakup System (BUS) would be added for the MER-2003 missions. The BUS would add two conical shaped charges mounted above the motor and directed into its dome. The purpose of the BUS would be to break up the large propellant dome into fragments to preclude an intact dome and attached spacecraft falling to the ground, with potential for significant mechanical damage to the RHUs. The resulting fragments would be small enough to minimize the thermal threat to an intact RHU should it be exposed to a burning Star 48B propellant fragment. The BUS ordnance would be activated from either the CDS or the ADS and would not otherwise affect any of the normal CDS or ADS design functions (NASA 2001).

2.1.5.6 Launch Vehicle Processing

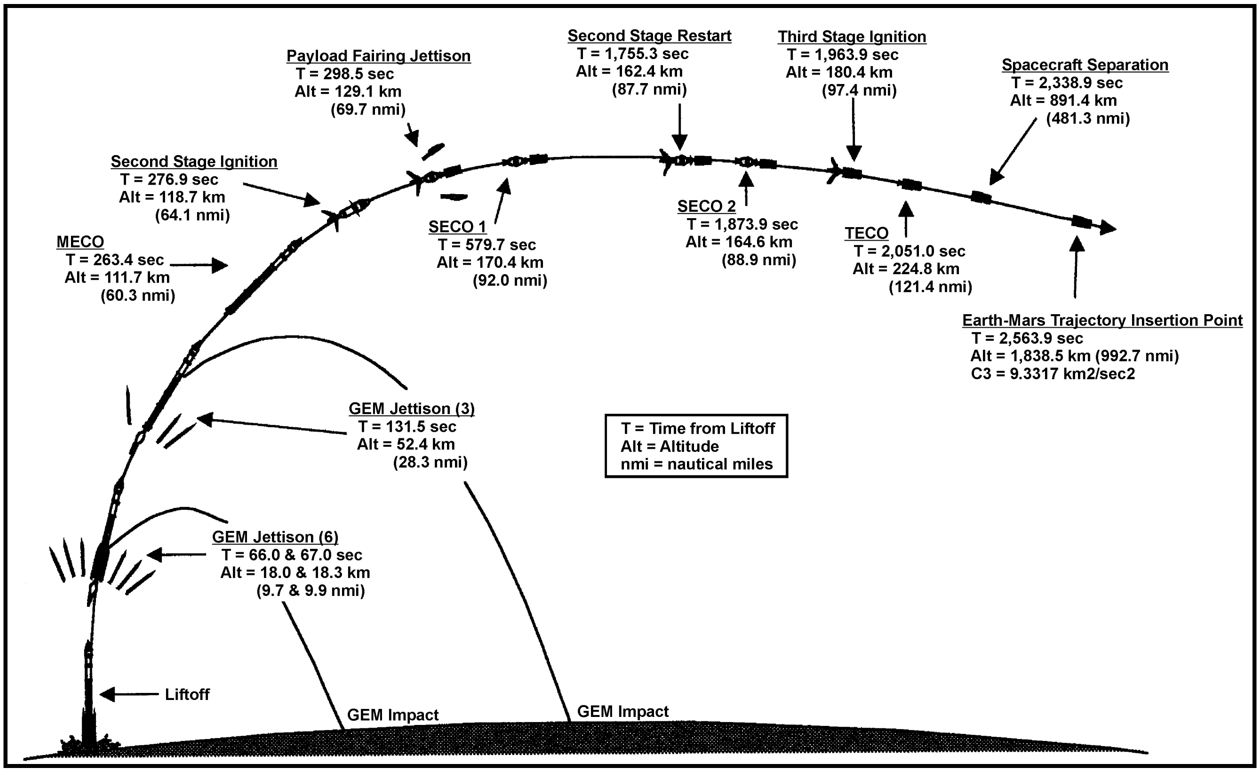
Delta launch vehicle preparation activities and procedures during and after launch have been well documented and standardized since Delta rockets began being launched from CCAFS over 30 years ago. These procedures and protocols are continuously being reviewed, and all NASA launches follow these standard operating procedures.

The Delta II 7925 launch vehicle components for the MER–A mission would be received, inspected, stored, and processed at appropriate facilities at CCAFS. Final integration, testing, and fueling would occur at SLC–17. The GEMs would be received and processed at the solid rocket motor facility before being transported to the launch pad and attached to the first stage (NASA 2001).

Because the Delta II 7925 for the MER–A mission would use processes and components similar to other Delta II vehicles, processing activities would be similar to those routinely practiced for other Delta II 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. CCAFS has the necessary permits and procedures in place to accomplish launch vehicle processing activities in an environmentally responsible manner (see Section 4.8 for details).

2.1.5.7 Launch Events for the MER–A Mission

A typical sequence of events for the Delta II 7925 launch of the MER–A mission is illustrated in Figure 2-6 for a launch on May 30, 2003, the opening of the mission's 18-day launch period (NASA 2001). The Delta II 7925 with the MER–A spacecraft would be launched from SLC–17 Pad A. The first stage main engine and six of the GEMs would be ignited at liftoff. After the six ground-lit GEMs burn out, the three remaining GEMs would be ignited in the air. The spent GEM casings would be jettisoned after burnout; the six ground-lit GEMs would be jettisoned first followed by the three air-lit GEMs after they completely burn out. Separation of the first and second stages would follow main engine cutoff (MECO). After separation, the second stage would be ignited and the PLF would be jettisoned. The jettisoned GEM casings, the first stage, and the PLF components would fall into the ocean. The second stage engine would be cut off (SECO 1) for a brief coast period and then restarted. The second and third stages would separate following SECO 2. The second stage would remain in orbit and would reenter the atmosphere within about two to three months (USAF 1996); the depleted second stage would typically burn up upon reentry. The third stage Star 48B motor would provide the final acceleration needed to inject the spacecraft onto the proper interplanetary trajectory. After third stage engine cutoff (TECO) the MER–A spacecraft would be separated and proceed toward Mars. The third stage would continue separately into interplanetary space.



Source: Adapted from NASA 2001

Figure 2-6. Delta II 7925 MER–A Mission Typical Launch Events Profile

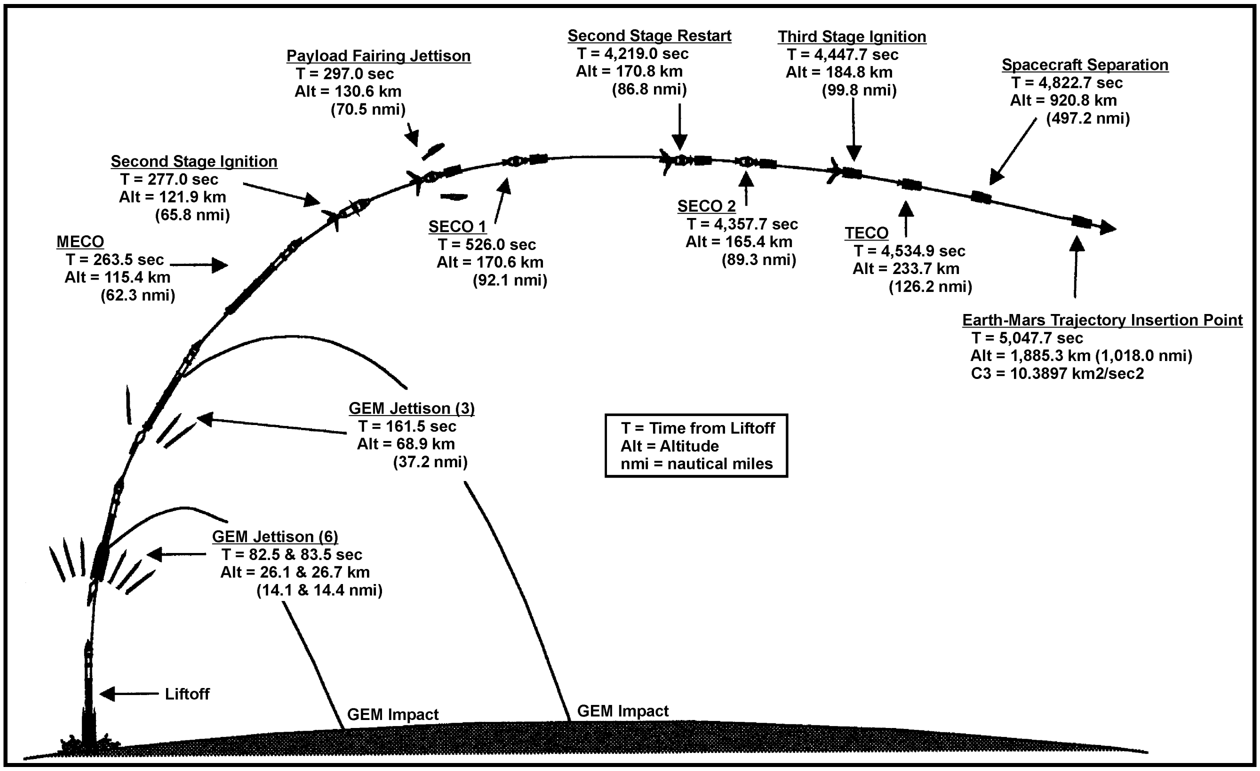
2.1.6 The Delta II 7925 Heavy Launch Vehicle

The Delta II 7925H expendable launch vehicle for the MER–B mission is essentially the same as the Delta II 7925 except that the nine standard GEMs are replaced with nine Large Diameter Extra Long (LDXL) GEMs for more thrust at liftoff and early ascent. Some structural and avionics modifications have been made to the Delta II core vehicle to accommodate these heavier, more powerful solid motors (NASA 2001).

Each LDXL GEM propellant case is approximately 0.2 m (6 in) larger in diameter and 1.2 m (4 ft) longer than the standard GEM. Each LDXL GEM contains 16,865 kg (37,180 lb) of the same solid propellant used in a standard GEM (NASA 2001). The total propellant load for the nine LDXL GEMs would be 151,785 kg (334,620 lb).

The first, second and third stages, the payload fairing, and processing of the Delta II 7925H launch vehicle for the MER–B mission would be essentially the same as those elements described in Section 2.1.5 for the Delta II 7925 launch vehicle for the MER–A mission. To meet Eastern Range safety requirements, the FTS for the Delta II 7925H includes an Inadvertent Separation Destruct System (ISDS). If a LDXL GEM inadvertently separates from the core vehicle due to mechanical failure, the ISDS would render the solid motor non-propulsive by activating ordnance charges that would split open the motor case.

A typical sequence of events for the Delta II 7925H launch of the MER–B mission is illustrated in Figure 2-7 for a launch on June 25, 2003, the opening of the mission's 18-day launch period (NASA 2001). The Delta II 7925H with the MER–B spacecraft would be launched from SLC–17 Pad B. The launch sequence for the Delta II 7925H would be similar to that described previously for the Delta II 7925.



Source: Adapted from NASA 2001

Figure 2-7. Delta II 7925H MER–B Mission Typical Launch Events Profile

2.1.7 Range Safety Considerations

CCAFS has implemented range safety programs, described in USAF 1997. For the MER–2003 missions, pre-determined flight safety limits would be established for the flight azimuth of each launch. Wind criteria, impacts from fragments that could be produced in a launch accident, dispersion and reaction (*e.g.*, toxic plumes, fire, etc.) of liquid and solid propellants, human reaction time, data delay time, and other pertinent data are considered when determining flight safety limits. The Mission Flight Control Officer (MFCO) would take any necessary actions, including vehicle destruction, if the vehicle trajectory indicates flight anomalies (*e.g.*, exceeding flight safety limits) (USAF 1997).

2.1.8 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 (explosives and explosive detonators/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 (NASA 1995).

2.2 DESCRIPTION OF THE NO ACTION ALTERNATIVE

Under the No Action Alternative, planning and preparations for the MER–2003 project would stop and neither the MER–A nor the MER–B spacecraft would be launched to Mars during the 2003 opportunity. None of the physical, geological, and chemical scientific investigations planned for the project (Table 2-1) would be achieved, and the objectives of NASA's planned follow-on missions to Mars would be adversely affected without the data to be obtained by the MER–2003 missions. Lessons expected to be learned during all phases of each mission (atmospheric entry, descent, and landing; initial deployment on the surface; real-time site traverse planning, execution and navigation; simultaneous operation of two rovers; and science data collection) would not be gained. NASA has no other Mars missions at a stage of development that could be substituted for the Proposed Action, and the efficient launch opportunity in 2003 would be lost to NASA’s overall Mars exploration effort.

2.3 ALTERNATIVES CONSIDERED BUT NOT EVALUATED FURTHER

This section discusses alternatives that were considered but were not evaluated further. These alternatives include a single mission and concepts studied for reducing or eliminating the plutonium heat sources onboard the MER–2003 rovers.

2.3.1 Single-Mission Alternative

As opposed to the Proposed Action, a single mission would not allow NASA to complete all mission objectives. Specifically, a single mission would not allow for:

- demonstrating complex science operations through the simultaneous use of multiple science-focused mobile laboratories (rovers), and
- exploration of two diverse landing sites.

In addition, a single mission would not allow for:

- taking full advantage of the uniquely efficient 2003 launch opportunity, and
- maximizing NASA's chances for successfully landing mobile laboratories on the surface of Mars.

For the above reasons, the single mission alternative was not evaluated further.

2.3.2 Reduction or Elimination of Plutonium Heat Sources

The MER–2003 rover batteries were qualified for survival and operation at temperatures as low as -30° C (-22° F) and the electronics were qualified for survival and operation down to -55° C (-67° F). Thermal data and modeling indicates that, over the potential range of landing sites (between 15° South and 10° North) for two rovers, the expected coldest night time Martian atmospheric temperature is approximately -105° C (-157° F). The baseline mission plan involves night-time operation of the APXS and Mössbauer Spectrometer to acquire measurements. Without the RHUs, the rover battery would then be required to provide power to these instruments and maintain the required rover thermal conditions throughout the Martian night.

Thermal analyses of expected landing site temperature conditions were conducted using landed thermal environment models based upon actual data obtained by the Viking and Mars Pathfinder missions for a 9° South latitude landing site. The thermal analyses indicated that, accounting for the combination of RHUs, waste heat from the electronics, insulation, and a battery energy of approximately 95 watt-hours, the rover battery temperatures inside the Warm Electronics Box (WEB) thermal enclosure would be expected to be between -15° C and +8° C (+5° F and +46° F). These analyses were performed assuming rover conditions at the end of the primary mission (*i.e.*, 90 sols). Also, the battery, electronics module, and mini-TES instrument have distinct electrical survival heaters that maintain this equipment to conditions no colder than -17° C (+1.4° F) for the battery, and -38° C (-36.4° F) for the electronics module and mini-TES. Therefore, internal rover temperature would always be maintained at the expense of rover battery energy. For this scenario, the total rover battery energy consumption for the survival heaters would be 542 watt-hours without RHUs, well over the current battery capacity of 392 watt-hours.

<u>Reduction of Heat Loss in the WEB</u>. The MER–2003 rover would be subject to stringent mass and volume limitations. The WEB design would include highly efficient Aerogel insulation. Heat loss from the wiring between external rover elements and the WEB electronics would be minimized by using flex print wiring. The WEB would be heated by waste heat from operation of the electronics and by heaters operated from the solar panels. Due to WEB volume limitations, there would not be room for additional insulation. There have been no additional options identified to further reduce heat loss from the WEB.

<u>Operating Electric Heaters with the Rover Batteries</u>. Plans call for electrical survival heaters to be used and powered by the rover batteries. If the electrical survival heaters were not supplemented by the RHUs, then the situation where all the RHUs were eliminated, discussed above, would apply. Even with a battery sized to accommodate electrical survival heaters, the battery itself would eventually fail due to extreme thermal cycling. It is estimated that the mission duration for a MER–2003 rover using only electrical heaters would last a maximum of 16 sols, considerably less than the 90-sol duration requirement for the MER–2003 project.

<u>Operating Electric Heaters via a Lander Power Umbilical</u>. A primary requirement for the MER–2003 project is that the rover explore to a distance of at least of 600 m (1,968 ft), with a goal of 1 km (0.62 mi). The use of an umbilical from the lander to provide supplemental power for electrical heaters would require additional mass to accommodate more than 1,000 m (3,281 ft) of power cable, the accompanying hardware to manage the cable mass, and the equipment necessary to convert and

transmit power over that length of cable. Use of an umbilical would also significantly complicate rover navigation in order to avoid cable snags in the rock fields. These considerations cause this alternative to be precluded from further consideration.

2.4 COMPARISON OF PROJECT ALTERNATIVES INCLUDING THE PROPOSED ACTION

This section summarizes and compares the potential environmental impacts of the MER–2003 Project Proposed Action and the No Action Alternative. The anticipated impacts associated with nominal or normal implementation of the Proposed Action are considered first, followed by a summary and comparison of the potential radiological consequences and risks from an accident associated with the Proposed Action. Details summarized in this section can be found in Chapter 4 and in DOE 2002.

2.4.1 Environmental Impacts of Normal Implementation of the MER–2003 Project Proposed Action and No Action Alternative

Table 2-3 provides a summary comparison of the anticipated environmental impacts associated with normal implementation of the MER–2003 project Proposed Action and the No Action Alternative.

Proposed Action

The environmental impacts associated with implementing the Proposed Action would center largely on the exhaust products emitted from the Delta II launch vehicles' GEMs and the short-term impacts of those emissions. 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 CO_2 and 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. The exhaust from a Delta II is relatively dry, thus high concentrations of HCl would not be expected, and damage to vegetation and prolonged acidification of nearby water bodies should not occur. No adverse impacts to air quality in offsite areas 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 CCAFS. As the launch vehicles gain 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 each vehicle's flight path. Recovery, however, would be rapid.

Table 2-3. Summary Comparison of the MER–2003 Project Alternatives

Impact Category	Normal Implementation of the Proposed Action	No Action
Land Use	No adverse impact on non-launch-related land uses at CCAFS for either launch vehicle.	No change in baseline condition.
Air Quality	High levels of GEM combustion products within the exhaust cloud as it leaves the launch pad's flame trench; cloud would rise and begin to disperse near the launch complex. Exhaust product concentrations expected to drop rapidly with buoyant rise and mixing/dispersal of exhaust cloud. No adverse air quality impacts expected in offsite areas.	No change in baseline condition.
Noise and Sonic Boom	Short-term (5 sec) worker and public exposure to sound levels > 90 dBA; exposure levels within OSHA and EPA guidelines for affected workers and public.	No change in baseline condition.
Geology and Soils	Some particulate and HCl deposition near launch complexes. No impacts to underlying geology.	No change in baseline condition.
Hydrology and Water Quality	No substantial adverse long-term impacts to groundwater or surface water; potential short-term increase in the acidity of nearby surface waters.	No change in baseline condition.
Biological Resources	Biota in launch complex area could be damaged or killed during launch; possible acidification of nearby surface waters could cause some mortality of aquatic biota. No long-term adverse effects expected. No substantial short-term or long-term impact to threatened or endangered species.	No change in baseline condition.
Socioeconomics	No impact expected.	No change in baseline condition.
Cultural/Historical/ Archaeological Resources	No impact expected.	No change in baseline condition.
Global Environment	Not anticipated to adversely affect global climate. Temporary localized decrease in ozone along the flight paths with rapid recovery.	No change in baseline condition.

Noise and sonic booms would be associated with each launch. However, neither launch site workers nor the public would be adversely affected. No impacts to cultural, historical or archaeological resources would be expected from either launch. Neither MER–2003 mission launch would be expected to disproportionately impact either minority or low-income populations.

<u>No Action Alternative</u>

The No Action Alternative would not implement either launch associated with the Proposed Action. Thus, none of the anticipated impacts associated with either of the normal launches would occur.

2.4.2 Environmental Impacts of Nonradiological Accidents for the MER–2003 Project Proposed Action

A variety of nonradiological accidents could occur during preparation for and launch of the MER–2003 spacecraft at CCAFS. The potential nonradiological impacts from an accidental liquid fuel spill or a launch vehicle failure would be similar for the two launches of the Proposed Action. The No Action Alternative would not implement either launch associated with the Proposed Action. Thus, there would be no potential for such accidents to occur.

The potential for off-site consequences would be limited primarily to a liquid propellant (N_2O_4) spill during fueling operations of the Delta II second stage and a launch failure at or near the launch pad. USAF safety requirements (USAF 1997) specify detailed policies and procedures to be followed to ensure worker and public safety during liquid propellant (*e.g.*, RP-1, N_2H_4) fueling operations. If a spill were to occur, rapid oxidation of the N_2O_4 combined with activation of the deluge water system would limit the potential toxic effects of the propellant to the immediate vicinity of the launch pad. Workers performing propellant loading 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 failure 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 Delta II and the spacecraft. The resulting emissions would resemble those from a normal launch, consisting principally of CO, HCl, NO_X, and aluminum oxide particulates from the burning solid propellant. A launch vehicle failure 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. 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 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 uncombusted solid and liquid propellants could enter surface water bodies and the ocean. Uncombusted solid and liquid propellants entering surface water bodies could result in short-term, localized degradation of water quality and toxic conditions to aquatic life. Such chemicals entering the ocean would be rapidly dispersed and buffered, resulting in little long-term impact on water quality and resident biota.

2.4.3 Overview of the Nuclear Risk Assessment Process

This section presents a summary of the nuclear risk assessment performed for this FEIS. A more detailed presentation can be found in Sections 4.1.4 and 4.1.5. NASA, and DOE and its contractors have conducted safety assessments of launching and operating spacecraft using RHUs (*e.g.*, the Galileo mission in 1989, the Mars Pathfinder mission in 1996, the Cassini mission in 1997, and the proposed Mars Surveyor 2001 mission[2] in 1999). NASA and DOE, therefore, have built upon an extensive experience base that involves:

- testing and analysis of the RHUs under simulated launch accident environments;
- evaluating the probability of launch-related accidents based on evaluation of launch histories, including extensive studies of the January 1997 Delta II accident at CCAFS, and system designs; and
- estimating the outcomes of the RHU and small-quantity radioactive source responses to the launch accident environments.

The risk assessment for the MER–2003 missions began with NASA's identification of initial launch vehicle system failures and the subsequent chain of accident events that could ultimately lead to the accident conditions (*e.g.*, fire, fragments, explosive overpressures) that could threaten the RHUs and small-quantity radioactive sources onboard the MER–A and MER–B spacecraft. Based on Delta II system reliabilities and failure probabilities, accident initial conditions that could lead to failure of the launch vehicle were identified across all major mission phases[3].

NASA then identified the specific accident outcomes that threaten the RHUs and/or small-quantity radioactive sources and which could potentially lead to a release of radioactive material. DOE then determined the response of the RHUs and small-quantity radioactive sources to the accident conditions (DOE 2002). DOE utilized the results of modeling and data from its RHU tests conducted during the early 1980s in support of the Galileo mission and the mid 1990s in support of the Cassini mission to determine if a release of radioactive material from a RHU could potentially occur.

For the purpose of the analysis performed for this FEIS, the following inventory of radioactive materials was assumed to be onboard each rover.

- Pu-238: 33.2 Ci in each of up to 11 RHUs (an alpha emitter with a half-life of 87.7 years. The activity includes minor contributions from other related plutonium and actinide radionuclides);
- Cm-244: up to 0.05 Ci (an alpha emitter with an 18.1 year half-life); and
- Co-57: up to 0.35 Ci (a gamma emitter with a 271 day half-life).

Taking into consideration the characteristics of the release (release location, particle size, and weather conditions), modeling is used to predict how the released material would be dispersed in the environment. The amount potentially released for each accident scenario can then be used to determine the potential consequences of the release to the environment and to people. The approach used was similar to that used in the Galileo, Mars Pathfinder, Cassini, and Mars Surveyor 2001 risk assessments.

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[2] A risk assessment was being prepared for the Mars Surveyor 2001 lander-rover mission when that mission was cancelled.

[3] For the purpose of the risk assessment, the sequence of launch events for each mission was divided into five mission phases on the basis of the mission elapsed time (the time (T) in seconds (s) after liftoff).

The analysis conducted by DOE is described in Chapter 4, with results presented using mean and 99th percentile values. Chapter 2 presents the analysis in terms of the mean. The 99th percentile values are indicative of more severe accidents included in the mean values. However, none of the 99th percentile values for the MER–2003 missions result in any different conclusions about the safety of the missions.

2.4.3.1 Accident Scenarios and Probabilities

A range of potential Delta II launch vehicle accident scenarios that could occur during launch of the MER–2003 spacecraft were evaluated. These scenarios were developed based on launch vehicle reliability data updated to reflect actual flight history (NASA 2001). System-level failures that might lead to accidents include trajectory control malfunction, attitude control malfunction, propellant tank failure, catastrophic engine/motor failure, structural failure, inadvertent FTS activation or PLF separation, and staging failure. These failures were found to lead to several basic types of accident outcomes, including ground impact of the spacecraft still attached to all or portions of the rest of the launch vehicle (called intact impact), low altitude CDS or ADS activation, sub-orbital reentry, and orbital reentry. Details of the development of the accident scenarios, probabilities, and accident environments are presented in the EIS Databook (NASA 2001).

Using methodologies that combine both actual flight history with analytical failure rate predictions, the total probability of an accident occurring during the MER–A mission was estimated to be 1 in 31 and 1 in 34 during the MER–B mission. The probabilities that a launch accident would result in a release of radioactive material from either the MER–A or MER–B spacecraft are much lower, however.

2.4.3.2 Accident Environments

Each accident scenario was evaluated to determine the potential accident environments that could threaten the integrity of the RHUs and the small-quantity radioactive sources onboard the MER–A and MER–B spacecraft. These accident environments are summarized in the DOE risk assessment (DOE 2002), which is based on detailed analyses by NASA presented in the EIS Databook (NASA 2001). The launch area accident environments include: blast (explosion overpressure), fragments, fire (burning liquid propellant and/or solid propellant), and surface impacts of the launch vehicle and/or the Star 48B upper stage and the MER–2003 spacecraft on the launch pad and structures or the area near the launch pad. While explosions and fragments are unlikely to lead to a release from the RHUs, these environments could damage the graphite components such that the RHUs become more susceptible to other environments produced by burning solid rocket propellant. The most severe accident environments are associated with accidents in which part or all of the launch vehicle comes down with the spacecraft and subjects the spacecraft to high impact forces. This accident scenario has the potential to damage the graphite components and subject the exposed RHUs to high-temperature solid propellant fires.

Accidents during later launch phases could involve second stage, third stage, and spacecraft propellant explosion and fragments. Reentry from orbit would subject the spacecraft and/or the upper stage to aerodynamic stress and reentry heating. The risk analysis assumed that during reentry the spacecraft would break apart, releasing the RHUs, which would then impact the Earth's surface.

2.4.3.3 Potential Accident Source Terms

The assessment of the responses of the RHUs and small-quantity radioactive sources to the accident environments resulted in estimates of the likelihood of a release and the fraction of the inventory of RHUs and small-quantity radioactive sources that might become airborne. These potential releases are referred to as source terms. In developing these estimates, DOE used data developed in its safety tests and response analyses of RHUs over the almost 20-year period that RHUs have been used. This database includes explosion overpressure tests, tests with fragments and projectiles, impact testing of RHUs and bare clads onto aluminum and steel plates, exposure of RHUs to burning solid rocket propellant, and immersion testing in seawater (DOE 2002).

Safety testing and response analyses of the RHU to accident environments show that the protection provided by graphite components and the platinum-rhodium clad encapsulating the PuO_2 makes releases unlikely due to purely mechanical damage, including overpressures and fragments. The primary release mechanism is exposure to the high temperature of burning solid propellant. Should the graphite components be damaged or stripped and the clad exposed to this fire environment, some PuO_2 could be vaporized and released. If the graphite components remain intact, any vaporized PuO_2 release would be limited to that which permeates through the graphite components. Such a release would be a very small fraction (about 1/1000) of the release associated with a RHU with damaged graphite components. A very small percentage of early launch accidents could lead to intact impact of various spacecraft/launch vehicle configurations. The resulting impact could lead to mechanical damage of the graphite components, depending on the orientation and velocity at impact, and subsequent exposure to burning Star 48B solid propellant. This in turn could potentially lead to PuO_2 releases.

In later phases of the mission, accidents could lead to reentry heating and ground impact environments. The RHU is designed to survive these reentry environments and subsequent surface impacts.

The Cm-244 and Co-57 small-quantity radioactive sources and their mounting fixtures used in spacecraft instrumentation have relatively low melting temperatures compared to PuO_2, and their release in the thermal environment of launch area accidents is assumed to be likely. Reentry conditions would also likely lead to the release of the small-quantity radioactive sources at high altitudes.

A summary of the accident and source term probabilities by mission phase are presented in Table 2-4. The mission is divided into phases corresponding to potential accident environments that could occur during specific time periods. These do not directly correspond to the mission events discussed in Sections 2.1.5.7 and 2.1.6. A summary of radionuclide contributions to the estimated mean source terms (Pu-238, Cm-244, and Co-57) is presented in Table 2-5.

Table 2-4. Summary of Accident and Source Term Probabilities

Mission Phase	Initiating Accident Probability	Probability of Release Given an Accident [a]		Total Probability of a Radioactive Release [b]
		Pu-238	Cm-244 Co-57	
MER–A Mission				
0 (Pre-Launch)	1 in 8,600	1 in 1.8	1 in 1.8	1 in 16,000
1 (Early Launch)	1 in 210	1 in 34	1 in 5.2	1 in 1,100
2 (Late Launch)	1 in 41	-	1 in 31	1 in 1,300
3 (Pre-Orbit/Orbit)	1 in 3,000	-	1 in 2.0	1 in 6,000
4 (Orbit/Escape)	1 in 350	-	1 in 1.1	1 in 400
Overall Mission	**1 in 31**	**1 in 160**	**1 in 7.2**	**1 in 230**
MER–B Mission				
0 (Pre-Launch)	1 in 8,600	1 in 1.8	1 in 1.8	1 in 16,000
1 (Early Launch)	1 in 300	1 in 30	1 in 5.3	1 in 1,600
2 (Late Launch)	1 in 44	-	1 in 32	1 in 1,400
3 (Pre-Orbit/Orbit)	1 in 3,600	-	1 in 2.0	1 in 7,200
4 (Orbit/Escape)	1 in 340	-	1 in 1.1	1 in 380
Overall Mission	**1 in 34**	**1 in 170**	**1 in 6.8**	**1 in 240**

Source: Adapted from DOE 2002

a. Conditional probability of release given that the initiating accident occurs.

b. Total probability of a release, calculated as the product of the initiating accident probability times the larger of the Pu-238 or Cm-244/Co-57 conditional release probabilities. The values shown are rounded to two significant digits.

The essential results, in terms of the estimated means, are as follows for the MER–A mission. Results for the MER–B mission would be similar.

- Phase 0 (Pre-Launch, T < 0 s): Prior to launch vehicle liftoff, the chance of on-pad accidents that could result in a release is about 1 in 16,000. The mean source terms are estimated to be 0.033% of the Pu-238 inventory, about 55% of the Cm-244, and about 29% of the Co-57.

- Phase 1 (Early Launch, 0 ≤ T < 23 s): During Phase 1 from liftoff to 23 s, the chance of an accident with a release of the small-quantity radioactive sources is about 1 in 1,100. The probability of a release of Pu-238 is about 1 in 7,200. The mean source terms are estimated to be 0.13% of the Pu-238 inventory, about 18% of the Cm-244, and about 9.7% of the Co-57.

- Phase 2 (Late Launch, 23 s ≤ T < 297 s): In Phase 2, after which land impacts in the launch area are unlikely, most accidents lead to impact of debris in the Atlantic Ocean, and the at-altitude accident environments are not severe enough to lead to releases. Some accidents during Phase 2 could lead to a sub-orbital reentry or a subsequent orbital reentry at later times after Phase 2. Prior to achieving Earth orbit, those accidents could lead to sub-orbital reentry within minutes. Following spacecraft breakup during reentry, about 2% of sub-orbital reentries could result in impacts of RHUs along portions of the vehicle flight path over southern Africa, Madagascar, and western Australia. Accidents which might occur after reaching orbit could result in orbital reentries from minutes to years after the accident. Orbital reentries would lead to surface impacts between 28º South and 28º North latitudes.

Table 2-5. Summary of Mean Source Terms

Mission	Percent of Inventory Airborne in Accidents that Result in a Release [a]		
	Pu-238 (365 Ci)	**Cm-244 (0.05 Ci)**	**Co-57 (0.35 Ci)**
MER–A Mission			
0 (Pre-Launch)	0.033	55	29
1 (Early Launch)	0.13	18	9.7
2 (Late Launch)	-	50	25
3 (Pre-Orbit/Orbit)	-	50	25
4 (Orbit/Escape)	-	50	25
Overall Mission	**0.098**	**44**	**22**
MER–B Mission			
0 (Pre-Launch)	0.033	55	29
1 (Early Launch)	0.16	19	10
2 (Late Launch)	-	50	25
3 (Pre-Orbit/Orbit)	-	50	25
4 (Orbit/Escape)	-	50	25
Overall Mission	**0.11**	**46**	**23**

Source: Adapted from DOE 2002

a. Source terms for each radionuclide given a release of that radionuclide at the corresponding probabilities in Table 2-4.

The RHUs are designed to survive reentry environments resulting from sub-orbital or orbital reentries without release. Due to the lesser degree of protection and lower melting temperatures associated with the small-quantity radioactive sources, an estimated 50% of the Cm-244 and 25% of the Co-57 would be vaporized on average if subjected to reentry heating. During the Late Launch Phase, the estimated chance of an accident with a release is 1 in 1,300.

- Phase 3 (Pre-Orbit/Orbit, 297 s ≤ T < 640 s): Accidents during Phase 3 could lead to sub-orbital or orbital reentry conditions at a total probability of release for the small-quantity radioactive sources of 1 in 6,000. The source terms would be identical to those estimated for Phase 2. The characteristics of sub-orbital reentries in Phase 3 would be similar to those described in Phase 2.
- Phase 4 (Orbit/Escape, 640 s ≤ T < 2237 s): Accidents during Phase 4 could lead to immediate reentry conditions at a total probability of release for the small-quantity radioactive sources of 1 in 400. The source terms would be identical to

those estimated for Phase 2. The characteristics of sub-orbital reentries in Phase 4 would be similar to those described in Phase 2.

The total probabilities of release, source term ranges, and release characteristics for the MER–B mission are very similar to those estimated for the MER–A mission, as is evident from Tables 2-4 and 2-5.

2.4.4 Potential Radiological Consequences and Risks of Accidents for the MER–2003 Project Proposed Action

The following paragraphs summarize the potential consequences of launch accidents that could result in release of radioactive material with implementation of the Proposed Action.

The radiological consequences for each accident scenario were calculated in terms of (1) maximum individual dose; (2) health effects; and (3) land area contaminated at or above specified levels. The maximum individual dose is used to estimate the potential impact on a representative individual within the exposed population. Health effect consequences were determined using methods described in Section 4.1.5. Health effects are an estimate of the potential radiological impacts on the regional or global population following an accident. The regional population, estimated to be approximately 2.4 million people, is considered to be all persons within 100 km (62 mi) of SLC–17 at the time of launch. The global population is the worldwide population at the time of launch. An estimate of the amount of land that could be contaminated above a level of concern is one measure of potential environmental impact.

Summaries of the mean radiological consequences by mission phase are provided in Table 2-6. The results, in terms of the estimated means, are as follows for the MER–A mission. The results for the MER–B mission would be similar.

- Phase 0 (Pre-Launch): The mean value of the maximum individual dose estimated for a Phase 0 accident is 11 millirem. This is the dose that would occur over a 50-year period following the release of radioactive material during a launch accident. For comparative purposes, this mean dose would be about 3% of the annual average dose to a person living in the U.S., from natural background radiation.

  The mean impacts on the potentially exposed population would be very small (see Table 2-6). No excess cancer fatalities would be expected as a result of a Phase 0 accident.

- Phase 1 (Early Launch): The mean maximum individual doses estimated for a Phase 1 accident would be 5.6 millirem (see Table 2-6). The doses to the potentially exposed regional population would be small and would not be expected to result in any excess cancer fatality over a 50-year period (see Table 2-6).

- Phases 2, 3, and 4 (Late-Launch, Pre-Orbit/Orbit and Orbit/Escape): Maximum individual doses would be a very small fraction of a millirem over a 50-year period. In all analyses, the dose to the potentially exposed global population would also be very small, and would not be expected to result in any excess cancer fatalities over the 50-year period following a release. The maximum individual doses in Phases 2 through 4 would be due to Co-57 and Cm-244 released as a vapor at high altitudes.

Table 2-6. Summary of Mean Radiological Consequences

Mission Phase	Maximum Individual Dose (millirem)	Population Health Effects [a]
MER–A Mission		
0 (Pre-Launch)	11	0.019
1 (Early Launch)	5.6	0.0098
2 (Late Launch)	0.0022	0.0013
3 (Pre-Orbit/Orbit)	0.0022	0.0013
4 (Orbit/Escape)	0.0022	0.0013
Overall Mission [b]	**1.3**	**0.0033**
MER–B Mission		
0 (Pre-Launch)	2.5	0.015
1 (Early Launch)	1.7	0.011
2 (Late Launch)	0.0022	0.0013
3 (Pre-Orbit/Orbit)	0.0022	0.0013
4 (Orbit/Escape)	0.0022	0.0013
Overall Mission [b]	**0.30**	**0.0030**

Source: Adapted from DOE 2002

a. Based on ICRP-60 health effects estimators of 4 x 10^{-4} health effects per person-rem for workers and 5 x 10^{-4} health effects per person-rem for the general population.

b. Overall mission values weighted by total probability of release for each mission phase.

2.4.4.1 Impacts on Individuals

If a launch-area accident occurs, spectators and people offsite in the downwind direction could inhale extremely small quantities of radionuclides, including Pu-238, Cm-244, and Co-57. The amount of additional radiation exposure would be a very small fraction of the annual radiation exposure from naturally occurring radiation in the Earth and from cosmic radiation. The person with the highest exposure would typically receive less than a few tens of millirem. In comparison, a person receives about 10 millirem from a single dental X-ray, and about 300 millirem/yr from natural sources.

2.4.4.2 Impacts on the Regional and Worldwide Populations

The total radiological exposures to the regional and worldwide populations from an accidental release were estimated. The amount of exposure to any individual is very small, as indicated above. In accordance with radiation health effects modeling accepted by the International Commission on Radiological Protection (ICRP 1990), any exposure is assumed to increase a person's chance of certain cancers. When this same model is applied to a large number of people, with each person getting a very, very small exposure, there is assumed to be a statistical increase in the incidence of cancer among the exposed population.

With either launch area or orbital/reentry accidents, the releases and resultant predicted average individual doses are so small that no additional cancers among the potentially exposed regional or global population would be expected.

2.4.4.3 Potential for Land Impacts

The airborne radioactive materials released in a launch area accident would be deposited downwind from the accident location. The results of the analysis indicated that the land area contaminated at levels exceeding 0.1 and 0.2 microcuries per square meter ($\mu Ci/m^2$) is expected to be less than 0.5 square kilometer (0.2 square mile) for any postulated pre-launch and launch phase accidents. In the past, the U.S. Environmental Protection Agency (EPA) used 0.2 $\mu Ci/m^2$ as a screening level to determine the need for further action, such as monitoring or cleanup.

The results indicated that under certain conditions dose-related land cleanup criteria, currently used by the EPA, could be exceeded during the first year following an accident, due primarily to resuspension. After the first year, these dose rates would fall well below these criteria levels. It is anticipated that no remedial action would be considered necessary on the basis of the dose rate criteria. Local remedial action at the accident site would be necessary to locate and recover the RHUs, small-quantity radioactive sources, and to clean up any residual radioactive materials and contamination (DOE 2002).

2.4.4.4 Mission Risks

To place the estimates of potential health effects (excess latent cancer fatalities) due to launch accidents for the proposed MER–2003 missions into a perspective that can be compared with other human undertakings and events, it is useful to use the concept of risk. Risk is defined by multiplying the total probability of a release by the health effects resulting from that release. The risks are estimated for the exposed population and individuals within the exposed population.

Phase 1 accidents represent 60% of the radiological risk for the MER–A mission and 55% of that for the MER–B mission. The relative contributions of Pu-238, Cm-244, and Co-57 to the total mission risks are estimated to be 57%, 43%, and 0.13%, respectively, for both missions combined.

<u>Population Risks</u>

For potential MER–2003 launch accidents resulting in a release of radioactive material, the total probability is obtained by multiplying the probability of the initiating accident by the conditional probability that a release will occur. For each mission phase, the risk to the potentially exposed population is then determined by multiplying this total probability of release by the associated health effects. Given the proposed MER–2003 missions, the risks calculated in this manner can be interpreted as the probability of one excess cancer fatality in the exposed population.

For the MER–A and MER–B missions, overall population health effects risks (*i.e.*, the probability of an excess latent cancer fatality as a result of the launches) are estimated to be 1 in 68,500 and 1 in 81,300, respectively. The combined risk for both missions is the sum of these two values, or 1 in 37,200. Considering both pre-launch and early launch accidents for both missions combined, the total probability of an excess latent cancer fatality within the regional population is about 1 in 106,000. Within the global population, the risk would be due to the potential for accidental release occurring from pre-launch through Mars trajectory insertion and was estimated by DOE to be about 1 in 57,500 (see Table 4-10).

Individual Risks

The risks of health effects to individuals within the potentially exposed regional and global populations due to the MER–A and MER–B missions were also estimated. The average individual risk, defined in this FEIS as the risk to the population divided by the number of persons exposed is estimated to be about 1 in 10 billion in the regional area and 1 in 170 trillion globally for both missions combined. This means, for example, that an individual within the launch area has about a 1 in 10 billion chance of incurring a fatal cancer associated with these missions.

While some individuals within the population, such as those very close to the launch area, would face higher risks, those risks are predicted to be very small. The risk to the maximum exposed individual within the regional population would be about 1 in 350 million for MER–A and about 1 in 1.6 billion for MER–B.

These risk estimates are very small relative to the other risks. For example, Table 2-7 presents information on annual individual fatality risks to U.S. residents due to various types of hazards. This data indicates that the average individual risk of accidental death in the U.S. is about 1 in 2,900 per year.

2.4.4.5 Radiological Emergency Response Planning

Prior to the launch of the MER–2003 missions with the RHUs and small-quantity radioactive sources onboard each rover, NASA, as the Lead Federal Agency, would develop a comprehensive plan in accordance with the Federal Radiological Emergency Response Plan. This plan would ensure that any accident could be met with a well-developed and tested response. The plan would be developed through the combined efforts of Federal agencies (*e.g.*, NASA, DOE, the U.S. Department of Defense (DoD), EPA, the Federal Emergency Management Agency, and others as appropriate), the State of Florida, and local organizations involved in local emergency response.

A Radiological Control Center would coordinate any emergency actions required during the pre-launch countdown or the early phases of the mission. In the event of an accident, a nearby offsite location would be established to conduct monitoring and surveillance in areas outside the launch site, assess the accumulated data, and coordinate further actions through the Radiological Control Center.

Table 2-7. Calculated Individual Risk of Fatality by Various Causes in the United States

Accident Type	Number of Fatalities [a]	Approximate Individual Risk Per Year [a]
Motor Vehicle	43,363	1 in 6,060
Suicide	31,300	1 in 8,400
Homicide and Legal Intervention (Executions)	22,900	1 in 11,500
Falls	13,986	1 in 18,800
Accidental Poisoning [b]	9,072	1 in 29,000
Drowning	3,790	1 in 69,400
Fires and Flames	3,761	1 in 69,900
Suffocation	2,095	1 in 129,000
Guns, Firearms, and Explosives	1,225	1 in 215,000
Air Travel	851	1 in 309,000
Water Transport	762	1 in 345,000
Manufacturing [c]	743	1 in 361,000
Railway	569	1 in 463,000
Electrocution	559	1 in 469,000
Lightning	85	1 in 3,100,000
Floods and Flash Floods	80	1 in 3,290,000
Tornadoes	30	1 in 8,770,000
Hurricanes	17	1 in 15,500,000
All Accidents	92,429	1 in 2,850
Diseases	2,164,600	1 in 122
All Causes	**2,392,217**	**1 in 110**

Sources: BLS 1998; NOAA 1995; USBC 1998

a. Based on 1995 statistics and a population of 263,039,000, except where noted.
b. Includes drugs, medicines, other solid and liquid substances, gases, and vapors.
c. Based on 1997 statistics and a population of 267,901,000.

The response to launch accidents would also depend on the geographical locations involved. Accident sites within the United States and U.S. Territories may be supported initially by the nearest Federal installation possessing a radiological contingency response capability. Personnel from all supporting installations would be alerted to this potential requirement prior to launch. Additional support would be dispatched from the launch site support personnel or from other support agencies, as needed. For accidents occurring outside the United States or its territorial jurisdictions, the U.S. Department of State and diplomatic channels would be employed in accordance with pre-arranged procedures and support elements would be dispatched as appropriate.

If an ocean or water impact occurs, the Federal agencies would undertake security measures, as appropriate, and search and retrieval operations. The recovery of the plutonium dioxide would be based on the technological feasibility, the health hazard presented to recovery personnel, the environmental impacts, and other pertinent factors.

2.4.5 Comparison of the Science Returns for the Project Alternatives

Proposed Action

The Proposed Action would have a substantial positive impact on NASA's program for the exploration of Mars. The payload of instruments on each rover has been carefully selected to maximize collection of scientific data to meet MER–2003 project objectives. Scientists would be able to closely examine the physical, geological and chemical characteristics of the landing sites and determine their aqueous, climatic, and geologic histories. By reading the geologic record at each site, scientists would investigate the role water played there and determine how suitable the conditions would have been for life.

Operation of the rovers and their science instruments would also benefit the planning and design of future missions. Lessons learned during all phases of each MER–2003 mission (atmospheric entry, descent, and landing; initial deployment on the surface; real-time site traverse planning, execution and navigation; and science data collection) would provide valuable information for refining future mission designs and procedures.

If programmatic issues (*e.g.*, changes in NASA priorities or unforeseen circumstances) were to necessitate modification of the mission objectives and timing, such issues could result in the need to launch one mission in 2003, and a second mission at a later launch opportunity or not at all. If such an event was to occur, the resulting mission would not allow NASA to complete all project objectives. Specifically, it would not allow NASA to achieve complex science operations through the simultaneous use of multiple science-focused mobile laboratories, and simultaneous exploration of two diverse landing sites. In addition, NASA would not be able to take full advantage of the uniquely efficient 2003 launch opportunity.

No Action Alternative

Under the No Action Alternative, planning and preparations for the MER–2003 project would cease and neither spacecraft would be launched during the 2003 launch opportunity to Mars. None of the science planned for the Proposed Action would be obtained and the objectives of NASA's planned follow-on missions to Mars would be adversely affected without the data to be obtained by the MER–2003 missions. NASA has no other missions at a stage of development that could be substituted for the Proposed Action and the launch opportunity for 2003 would be lost to NASA's overall Mars exploration effort.

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