MODIFIED RECORD OF DECISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARS SCIENCE LABORATORY MISSION

This modified Record of Decision (ROD) documents NASA's consideration of possible changes in the potential environmental impacts of the Mars Science Laboratory (MSL) mission with the launch postponed from the original 2009 launch opportunity to the next available launch opportunity in 2011.

This document modifies the ROD issued for the MSL mission on December 27, 2006. In 2006, NASA decided to complete preparations for launch of the MSL mission during a September to November 2009 launch period and to operate the mission using a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) as the primary power source for the rover. However, in December 2008, NASA made a determination that the MSL rover could not be ready in time for the original 2009 launch window because of unexpected spacecraft technical and testing challenges. Launch opportunities for Mars missions occur approximately every 26 months; consequently, the next launch opportunity is November to December 2011. NASA is continuing preparations for launch of the MSL mission during this next launch opportunity.

In considering the launch of the MSL mission during late 2011, NASA identified factors that might affect the environmental impact analysis presented in the existing Final Environmental Impact Statement (FEIS) for the MSL mission. The Department of Energy (DOE) helped NASA reassess potential radiological impacts by evaluating the nuclear risk described in the 2006 FEIS against up to date information regarding the MSL mission and use of the 2011 launch opportunity. Factors included in this evaluation included the launch vehicle selection, duration and time of the launch period, meteorology for the launch period, launch trajectories, and ground processing of the launch vehicle. NASA also reassessed the non-radiological environmental impacts discussed in the FEIS against up to date information regarding the MSL mission. Factors included in this evaluation included updated information concerning spacecraft trajectories and potential reentry accidents and environments.

Background (Purpose and Need for the Proposed Mission)

The purpose of the MSL mission is to both conduct comprehensive science on the surface of Mars and demonstrate technological advancements in the exploration of Mars. As described in the 2006 FEIS, the mission's overall scientific goals are: (1) assess the biological potential of at least one selected site on Mars; (2) characterize the geology and geochemistry of the landing region at all appropriate spatial scales; (3) investigate planetary processes of relevance to past habitability; and (4) characterize the broad spectrum of the Martian surface radiation environment. The objectives planned for the mission are described in the December 27, 2006, NASA Record of Decision for the MSL mission.

History of MSL NEPA Compliance Activities

NASA prepared an environmental impact statement (EIS) to analyze the potential environmental impacts of the planned MSL mission. The DOE was a cooperating agency in the EIS because the Proposed Action would use a DOE-developed and owned radioisotope power system (RPS), specifically the MMRTG, to provide electrical power for the MSL rover.

On March 10, 2006, NASA published a Notice of Intent in the *Federal Register* (71 FR 12402) to prepare an EIS and conduct scoping for the MSL mission. Public input and comments on alternatives, potential environmental impacts and concerns associated with the proposed MSL mission were requested. The scoping period ended on April 24, 2006. One scoping comment was received during this period from a Federal agency expressing concerns regarding habitat management of threatened and endangered species near the MSL launch site at Cape Canaveral Air Force Station (CCAFS), Florida. These concerns were addressed in the Draft EIS (DEIS).

NASA published a Notice of Availability (NOA) of the DEIS for the MSL mission in the *Federal Register* on September 5, 2006 (71 FR 52347). The DEIS was mailed by NASA to 59 potentially interested Federal, State and local agencies, organizations and individuals. In addition, the DEIS was publicly available in electronic format on NASA's web site. The U.S. Environmental Protection Agency (EPA) published its NOA for the DEIS in the *Federal Register* on September 8, 2006 (71 FR 53093), initiating the 45-day review and comment period.

The public review and comment period closed on October 23, 2006. NASA received ten comment submissions (letters and other written comments) from three Federal agencies, one State agency, one private organization, and five individuals. The comments received included "no comment", requests for clarification of specific sections of text, and objections to the use of nuclear material for space missions. In addition, NASA received a total of 34 comment submissions via electronic mail (e-mail) from 32 individuals. These comment submissions include objections to the use of nuclear material for space missions, and general support for the proposed MSL mission. These comments were considered in developing the FEIS, and responses to these comments were prepared and included in the FEIS as Appendix D.

In addition to soliciting comments for submittal by letter and e-mail, NASA held three meetings during which the public was invited to provide both oral and written comments on the MSL DEIS. Two meetings were held on September 27, 2006, at the Florida Solar Energy Center in Cocoa, Florida, and one meeting was held on October 10, 2006, at the Hyatt Regency Hotel in Washington, DC. NASA placed paid advertisements announcing the dates, times, and purpose of the public meetings in local and regional newspapers together with the full text of NASA's NOA in the legal notices section of each newspaper. Members of the public attending each meeting were asked to register their attendance at the meeting. However, registration was not a requirement for anyone wishing to present either oral or written comments. Eleven members of the public registered for the 1 p.m. meeting and seven registered for the 6 p.m. meeting on September 27 in Cocoa, Florida. Eleven members of the public registered for the meeting on October 10 in Washington, D.C. Excerpts of the official transcripts taken by a court reporter during the September 27 meetings, during which three members of the public presented oral comments, were included in the FEIS as Appendix E; no oral comments were presented during the October 10 meeting.

The EPA published a finding of no objection (*i.e.*, LO – Lack of Objection) to the Proposed Action regarding NASA's DEIS in the *Federal Register* on November 3, 2006 (71 FR 64701).

NASA published its NOA for the FEIS in the *Federal Register* on November 21, 2006 (71 FR 67389), and mailed copies to 119 Federal, State and local agencies, organizations, and individuals. In addition, NASA made the FEIS available in electronic format on its web site and mailed the FEIS to commentors on the DEIS. NASA sent e-mail notifications to 23 individuals who had submitted comments on the DEIS via e-mail or had previously expressed interest in the MSL mission. The EPA published its NOA in the *Federal Register* on November 24, 2006 (71 FR 67863), initiating the 30-day waiting period, which ended on December 26, 2006. The EPA issued a finding of no objection to the Proposed Action in the FEIS on December 21, 2006. No additional comments were received by NASA during this period.

On December 27, 2006, NASA issued a ROD to complete preparations for launch of the proposed MSL mission during September through November 2009 and to operate the mission using an MMRTG as the primary power source for the rover.

Key Environmental Issues Addressed in the MSL EIS

Two key environmental issues addressed in the MSL EIS were the air emissions that would accompany normal launch of the MSL spacecraft, and the environmental consequences associated with potential launch accidents.

Environmental Consequences of a Normal Launch

The primary environmental impacts of a normal mission launch would be associated with airborne emissions from the strap-on solid rocket boosters that would be used on the Atlas V launch vehicle. Air emissions from the liquid propellant engines on the Atlas V core vehicle, although large in magnitude, would be relatively inconsequential in terms of environmental effects. The effects of a normal launch would include short-term adverse impacts on air quality within the exhaust cloud at and near the launch pad, and the potential for acidic deposition from the solid booster exhaust on the vegetation and surface water bodies at and near the launch complex. Shortly after lift-off, the exhaust cloud would be transported downwind and upward, eventually dissipating to background concentrations. Because launches from Cape Canaveral Air Force Station (CCAFS) are relatively infrequent events and winds rapidly disperse and dilute the launch emissions to background concentrations, no long-term adverse impacts to air quality in offsite areas would be anticipated. Surface waters in the immediate area of the exhaust cloud would temporarily acidify from deposition of hydrogen chloride, but no prolonged acidification or other long-term adverse effects would be anticipated. Biota in the immediate vicinity of the launch pad could be damaged or killed by intense heat following ignition and hydrogen chloride deposition from the exhaust cloud, but no long-term adverse effects to biota would be anticipated. Neither short-term nor long-term adverse impacts to threatened or endangered species would be expected. No significant socioeconomic impacts would be expected on nearby communities, and no impacts would be expected to cultural, historical, or archeological resources as a result of the MSL mission launch.

Some short-term ozone degradation would occur along the flight path as the Atlas V launch vehicle passes through the stratosphere and deposits ozone-depleting chemicals from the exhaust products of the solid rocket boosters. However, the depletion trail from a launch

vehicle has been estimated to be largely temporary, and is self-healing within a few hours of the vehicle's passage. The total contribution to the average annual depletion of ozone from the launch of large expendable launch vehicles with solid rocket boosters in a given year has been estimated to be small (approximately 0.014 percent per year). 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 cannot occur.

Launch of the Atlas V for the MSL mission would produce a very small fraction (less than 0.00001 percent) of the annual net greenhouse gases emitted by the United States. Therefore, launch of the mission would not be anticipated to substantially contribute to the accumulation of greenhouse gases.

Environmental Consequences of Potential Accidents

Radiological Considerations

Consideration of launch accidents involving radiological consequences was a principal focus of the MSL EIS. As described in the MSL EIS, depending upon the sequence of events, some launch accidents could result in release of some of the plutonium dioxide (PuO_2) contained in the MMRTG, which could have adverse impacts on human health and the environment.

Results of the DOE risk assessment for the EIS showed that the most likely outcome of implementing the MSL mission would be a successful launch with no release of radioactive materials. For most launch-related problems that could occur prior to launch, the most likely result would be a safe hold or termination of the launch countdown.

The EIS risk assessment did, however, identify potential launch accidents that, although unlikely, could result in a release of PuO_2 in the launch area, southern Africa following suborbital reentry and other global locations following orbital reentry.

For those postulated accidents with a release which could occur in and near the launch area, the predicted mean radiological dose to the maximally exposed individual was about 0.14 rem, which is the equivalent of about 40 percent of the normal annual background dose received by each member of the U.S. population during a year. No short-term radiological effects would be expected from any of these exposures. Each exposure would, however, increase the statistical likelihood of a cancer fatality over the long term. For such unlikely accidents with a release, additional latent cancer fatalities are predicted to be small. (*i.e.*, a mean of 0.4 additional latent cancer fatalities among the potentially exposed members of the local population near the launch area, and a mean of 0.2 additional latent cancer fatalities among potentially exposed members of the global population). These estimates of health consequences assumed no mitigation actions, such as sheltering and exclusion of people from contaminated land areas.

Potential environmental contamination was evaluated in terms of land area exceeding various screening levels and dose-rate related criteria. Results of the MSL EIS risk assessment indicated that a potential, but unlikely launch area accident, involving the intentional destruction of all launch vehicle stages freeing the MMRTG to fall to the ground, could result in about six square kilometers (about two square miles) potentially contaminated above the 0.2 $\mu Ci/m^2$ screening level.

Less likely launch accidents were also assessed. These events were postulated for cases in which an accident occurs in the launch area and the safety systems fail to destroy the launch vehicle. The mean probabilities of these events were estimated to range from 1 in 8,000 to 1 in 800,000. These less likely accidents could, however, expose the MMRTG to severe accident environments, including mechanical damage, fragments, and solid propellant fires, and could result in higher releases of PuO_2 (up to 2 percent of the MMRTG inventory) with the corresponding potential for higher consequences. The maximally exposed individual could receive a mean dose ranging from a fraction of one rem up to about 30 rem following the more severe types of less likely accidents, such as ground impact of the entire launch vehicle, which are considered to be very unlikely (*i.e.*, probabilities ranging from 1 in 10,000 to 1 in 1 million). Assuming no mitigation actions, such as sheltering and exclusion of people from contaminated land areas, radiation doses to the potentially exposed members of the population from a very unlikely launch accident could result in up to 60 mean additional cancer fatalities over the long term.

For the very unlikely accident that involved ground impact of the entire launch vehicle, roughly 90 square kilometers (about 35 square miles) of land area could be contaminated above the 0.2 $\mu Ci/m^2$ screening level. Contamination at this level could necessitate radiological surveys and potential mitigation and cleanup actions.

Non-Radiological Considerations

The two non-radiological accidents of greatest concern would be a liquid propellant spill during fueling operations and a launch vehicle failure. A liquid propellant spill during fueling operations would not be expected to result in any public health impacts or any long-term environmental consequences. Fueling operations for the Atlas V involve rocket propellant-1 (a form of kerosene), liquid hydrogen, liquid oxygen, and hydrazine. Launch preparation activities at CCAFS are subject to environmental regulations, including spill prevention and response requirements, and U.S. Air Force (USAF) and launch service contractor safety requirements specify detailed policies and procedures to be followed to ensure worker and public safety during all liquid propellant fueling operations. Spill containment would be in place prior to any propellant transfer to capture any potential release.

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 Atlas V and the spacecraft. The resulting emissions would resemble those from a normal launch, consisting principally of carbon monoxide, carbon dioxide, hydrogen chloride, oxides of nitrogen, and aluminum oxide from the combusted propellants. A launch vehicle failure would result in the prompt combustion of a portion of the released 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 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 rapidly dispersed and buffered, resulting in little long-term adverse impact on water quality and resident biota.

Reconsideration of Environmental Issues in Light of Up to Date Mission Information and the Proposed 2011 Launch of MSL

Radiological Considerations

DOE's risk assessment for the MSL EIS was developed during the time when the candidate launch vehicles being considered by NASA for the MSL mission were the Atlas V 541 and the Delta IV Heavy, prior to NASA's selection of the Atlas V 541. A composite approach was taken in the risk assessment in which results for representative configurations of the Atlas V 541 and Delta IV Heavy launch vehicles were combined in a probability-weighted manner to derive accident probabilities, potential releases of PuO_2 in case of an accident, radiological consequences, and mission risks. Differences in the two launch vehicles in terms of design, accident probabilities and accident environments were taken into account in developing composite results.

For the MSL EIS, radiological impacts or consequences 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 exposed portion of 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 would 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.

In considering the launch of the MSL mission during late 2011, NASA identified factors that might have an impact on the environmental consequences described in the existing EIS. DOE in cooperation with NASA evaluated their risk assessment supporting the EIS against up to date information regarding the MSL mission and use of the 2011 launch opportunity . Factors in that evaluation included the launch vehicle selection, duration and time of the launch period, meteorology for the launch period, launch trajectories, and ground processing of the launch vehicle.

DOE evaluated the changes associated with the 2011 launch in terms of potential changes in (1) impacts to individuals in terms of the maximum individual dose; (2) impacts to the exposed portion of the population in terms of the potential for additional latent cancer fatalities due to a radioactive release; and (3) impacts to the environment in terms of land area contaminated at or above specified levels. DOE documented the results of this evaluation and provided the results to NASA. DOE's conclusion is that the updated results are consistent with results reported in the MSL FEIS and summarized in the 2006 MSL ROD and the preceding section of this ROD.

Non-Radiological Considerations

The non-radiological environmental impacts from a normal launch in 2011 also remain unchanged from those expected for the 2009 launch opportunity.

Similarly, expected non-radiological impacts associated with potential launch accidents are also unchanged from those for the 2009 launch opportunity. However, because there has been some recent heightened general interest in the non-radiological hazards associated with reentering space objects, the following additional information is provided.

Consistent with the FEIS, after the launch vehicle clears land, debris from an accident including the MSL spacecraft, would be expected to fall over the Atlantic Ocean. Under certain launch accident conditions, there is 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 is on the order of 1 in 20,000. As indicated in the FEIS, the MSL spacecraft's propellant is hydrazine. The overall risk of an individual injury resulting from the land impact of a spacecraft and exposure to hydrazine is less than one in 100,000.

In other potential accident scenarios (i.e., those occurring after achievement of the park orbit), the spacecraft could reenter from orbit, potentially impacting land anywhere between 36° north or 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 is less than 1 in 200. In this type of accident it is extremely unlikely that there would be any hydrazine residual remaining inside the propellant tanks at the point of ground impact.

Incomplete and Unavailable Information

As is typical for complex, long lead time NASA missions such as MSL, several technical issues that could affect the results summarized in this modified ROD will undergo continuing evaluation as a part of a more detailed safety analysis and as part of other non-mission specific test and analysis work by NASA and DOE. Issues that continue to be evaluated include:

- the solid propellant fire environment and its potential effect on the release of PuO2 from an MMRTG,
- the behavior of solid PuO2 and PuO2 vapor in the fire environment and the potential for PuO2 vapor to permeate the graphite components in an MMRTG,
- the mechanical response of the MMRTG for the mission-specific configuration of the MSL mission, and
- the risks (i.e., probabilities and effects) from release of spacecraft and launch vehicle propellants in various launch accident scenarios.

Results from these ongoing analyses and tests are not anticipated to substantively affect the environmental evaluations summarized in this modified ROD. However, NASA will review such results as they become available and will consider their potential effects on the MSL environmental impact analyses and, as appropriate, the need for additional MSL environmental documentation.

Conclusion

Based on CEQ regulations, specifically 40 CFR 1502.9(c)(1), the two situations in which an agency must issue a supplemental EIS are: (i) substantial changes in the proposed action that are relevant to environmental concerns or (ii) significant new circumstances or information relevant to environmental concerns associated with the proposed action. Using these criteria, NASA has evaluated its updated MSL mission information, including the changes to the mission associated with a 2011 launch opportunity and further considered DOE's evaluation of the existing EIS risk assessment. Based upon these evaluations, NASA has concluded there are no substantial changes relevant to environmental concerns associated with the updated mission information and change in launch opportunity from 2009 to 2011. NASA has further concluded there are no significant new circumstances or information relevant to environmental concerns associated with the updated mission information and change in launch opportunity from 2009 to 2011.

Decision

Based upon all of the forgoing, including consideration of the 2006 Record of Decision, it is my decision to complete development and preparations for launch of the proposed MSL mission during November – December 2011, and to operate the mission using an MMRTG as the primary power source for the rover.

Edward J. Weiler
Associate Administrator
Science Mission Directorate

8-23-10
Date