NASA Mars Exploration Program

Mars 2007 Smart Lander Mission

Science Definition Team Report

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1.0 Introduction

The 2007 Mars Smart Lander Mission Science Definition Team (SDT), chartered by NASA Headquarters in April 2001, was given the task of defining and prioritizing the science goals, objectives, investigations, and measurements associated with this landed opportunity. In addition, the SDT was asked to consider: (a) the extent to which meeting science objectives associated with the 2007 mission should depend on precursor measurements such as those expected from the planned Mars Reconnaissance Orbiter (MRO), (b) whether or not direct life detection experiments should be attempted, (c) the extent to which the mission should be used for technology development and testing to help prepare for Mars Sample Return, and (d) the importance of radioisotope power sources (RPS) for meeting mission objectives. For reference, Appendix 1 provides the detailed SDT Charter, Appendix 2 lists SDT Membership, and Appendix 3 is a summary of the tasks that led to generation of this report.

The report is structured in the following way: An overview of the main aspects of the Mars Smart Lander Mission is first presented to set the stage for consideration of science opportunities. Next, specific science objectives are defined that are of highest priority and well matched to the mission objectives. Two options for surface science are then delineated, followed by detailed scenario analyses that demonstrate that the options are credible. The report closes with specific recommendations associated with programmatic issues and a concluding statement.

2.0 Overview of Smart Lander Mission

The Mars 2007 Smart Lander Mission will feature a precision landing capability to get to within approximately 5 km of a given target site. This capability will allow landing in any of a large number of relatively safe places that are in close proximity to rougher areas of very high scientific interest. In addition, a terminal hazard detection and avoidance system will be used to select safe areas within the landing ellipse, thereby allowing a landing to occur in more hazardous terrain than possible before the 2007 opportunity. Touchdown robustness will also be enhanced by judicious hardening of landed systems using appropriate technologies. Landing site altitudes will need to be less than +2.5 km above the MOLA-derived zero elevation of Mars. These capabilities in total will allow delivery of approximately 1620 kg (820 kg for landing systems; 800 kg for surface systems, including approximately 70 to 100 kg of science payload) of landed assets in 2007 with a much wider selection of locations than possible, for example, with the 2003 Mars Exploration Rover (MER) landing system.

Launch, transfer, and arrival constraints associated with the 2007 opportunity, combined with the payload mass, dictate use of a Delta IV or Atlas V launch vehicle and an arrival subsolar longitude of approximately 130 degrees (northern summer). Direct entry will be used to place assets on the surface. For solar-powered systems the range of latitudes for surface operations will be limited to approximately 30 degrees about the equator. The mission lifetime and operational activities will also be highly modulated by seasonal controls on amount of sunlight. On the other hand, use of RPS power systems would allow access to all locations on the planet below the altitude cutoff, with an extended period of operations. A primary mission duration of 180 sols is assumed for solar-powered missions and 360 sols for RPS-powered systems. It is noted that RPS systems could easily provide steady power for up to 720 sols, but that the total cost of the mission would need to increase significantly to accommodate flight systems designed to operate over such a long period of time.

These main characteristics of the Smart Lander Mission were the background for the SDT deliberations. The job of the SDT was to make recommendations focused on science to be accomplished during this landed opportunity and the payloads needed to accomplish the science, and to comment on topics specifically requested in the SDT Charter (Appendix 1). The Smart Lander precision landing, coupled with delivery of a large payload to the surface, offers an opportunity to conduct science on an unprecedented scale on Mars. The SDT looked at this opportunity to define the Smart Lander Mission as the capstone mission for this decade by making groundbreaking scientific discoveries and paving the way for the sample return mission.

3.0 Science Objectives and Measurements Matched to Mission Capabilities

The Mars Exploration Payload Analysis Group (MEPAG) has developed a comprehensive strategic plan for exploration of Mars that is focused on the overarching goals of understanding whether or not life got started and evolved, the causes and timing of current and past climates, and the nature and extent of resources available at and beneath the surface [Greeley, 2000]. The role and availability of water is a central theme. Further, a full understanding of life, climate, and resources requires detailed study of the evolution of the interior, surface, and atmosphere, along with the interplay of various cycles (e.g., climatic and tectonic) that may have dominated Mars during past epochs. All of these results impact our understanding of the extent to which surface and near-surface materials can be used to support human expeditions and the extent to which humans need to cope with hazards during their missions.

The MEPAG document was the starting point for SDT deliberations. That is, the goals, objectives, investigations, and measurements defined by MEPAG were scrutinized for applicability to the Smart Lander Mission, refined and updated as needed, and used to form the backbone of the science to be accomplished during the 2007 landed opportunity. What follows in this section is a discussion of the science objectives that can be addressed for each of the Mars Exploration Program's main themes, which are: development and evolution of life, current and past climates, evolution of the surface and interior, and preparation for human expeditions.

3.1 Development and Evolution of Life

The possibility that life may have started and evolved on Mars has fascinated mankind for more than a century. The Viking Landers in 1976 conducted pioneering measurements focusing on the detection of organic compounds and the presence of life in surface soils [Klein, 1979]. (Soils in the case of Mars are defined as particulate material produced by such processes as impact, water, and wind action, with some degree of *in-situ* alteration and/or induration [Moore *et al.*, 1987].) Life detection experiments were conducted, including measurements focused on detecting photosynthesis, metabolism, and a combination of processes. With few exceptions, the scientific community concluded from the Viking results that life was not detected, a result compatible with the lack of volatile organic compounds at the parts per billion level (or in some cases such as amines derived from amino acids at the parts per million level). During the more than 20 years since the Viking measurements there has been a growing realization that life may have, in fact, started and evolved on Mars, but would not be present in the well-mixed and highly oxidized aeolian soils sampled during the Viking mission [Farmer and Des Marais, 1999]. A new strategy is thus needed to guide the search for life.

The strategy takes advantage of the fact that evidence of life could be preserved in the rock record under the right conditions. On Earth life has become global, inhabiting nearly every niche available. If the same processes occurred on Mars, then nearly any sample might be expected to yield evidence for past life. Yet, the surface and soil of Mars are hostile and highly oxidizing, a harsh environment for life and preservation of the evidence. When the surface environment became hostile on Mars, life could have moved into rocks and deeper below the surface, and/or the biomes that evolved beneath the surface may have been the only systems to survive and thrive. The most promising place to explore for evidence of life on Mars is in lacustrine or marine sedimentary rocks that accumulated rapidly under reducing conditions and where subsequent diagenesis did not obliterate the original textural and compositional (isotopic, organic, and mineralogic) evidence for the environment of deposition and associated biomes. Many candidate sites exist on the planet, as evident from analysis of MOC images [Malin and Edgett, 2001], although the presence of aqueous minerals produced under reducing conditions has thus far eluded discovery [Christensen *et al.*, 2000].

Thus, a key part of the exploration strategy for the search for life for the Smart Lander Mission is to maximize the chance of landing on layered sedimentary rocks that preserve original depositional signatures and conditions. Precursor measurements from the Mars Global Surveyor, Odyssey, Mars Express (High Resolution Stereo Camera [HRSC] and Omega imaging spectrometer), and in particular the Mars Reconnaissance Orbiter (MRO) high spatial resolution imaging system and hyperspectral mapper will be of great importance for identifying these sites [Zurek *et al.*, 2001]. MRO high-resolution images will be used to confirm the presence of layered deposits and to infer the environments of deposition. Further, the hyperspectral mapper data from MRO will provide the detailed maps of aqueous mineral occurrences, deposits that are too small to be resolved in Mars Global Surveyor TES or Mars Express Omega data and/or that might be of a grain size that does not produce a discernable thermal infrared signature. Acquisition of imaging data during descent would also greatly enhance terrain knowledge and rover traverse planning.

After landing, a rover would be needed to explore (using autonomous "go to" capability to get to distant targets) and make measurements to discern the environments of deposition, i.e., the sedimentary geology of the targeted units. The instrumentation would include remote sensing and contact *in-situ* systems patterned after the Athena Payload on the 2003 Mars Exploration Rover Mission, but incorporating new technologies and measurement approaches. Measurements would be employed to determine the site geologic setting, rock and soil textures, mineralogy and chemistry. Fundamental to the search for evidence of ancient climates and life would be drilling to access, retrieve, and analyze samples acquired from beneath any outer oxidation zones that would have been produced over time due to the current chemical weathering regime and during any ancient regimes. Viking Lander observations suggest that super-oxides exist in soils at both landing sites, with multiple compounds suggested because soil reactivities in the Viking experiments showed differing levels of thermal lability [Klein, 1979]. For hard crystalline rocks it is likely that drilling a few centimeters would penetrate these oxidized layers whereas for soils or partially consolidated sedimentary rock a depth of at least a meter would be needed. The key is to characterize the oxidation gradient and recover samples from below the oxidation layer within sedimentary deposits. Although MEPAG gave low priority to characterizing the surface oxidation gradient (level 6), the SDT believes that the investigation should be of high priority. This experiment will not be part of the 2003 MER Mission and was not attempted during either the Viking or Pathfinder Missions.

The next key step is to realize that life consists of complex structural and functional molecules that can be detected and characterized with use of the sensitive *in-situ* instrumentation. Early life on Earth was unicellular, i.e., archaea and bacteria. Most likely any early and perhaps even recent life on Mars was also unicellular. Sensitive *in-situ* measurements of samples collected from beneath the oxidized zones in rocks and soils would both allow determination of the biosignatures (isotopic composition, presence and nature of organic compounds [with chirality], elemental and mineralogical determinations) associated with former or extant life and provide direct indications of the structures and compositions of these life forms. Preliminary direct detection of biosignature textures could also be possible by a microscope using UV (220-249 nm) light for excitation and the detection of the fluorescence emission associated with organic molecules with conjugated double bonds.

In summary, the strategy for searching for evidence of life on Mars is to maximize the probability of landing on sedimentary deposits in which reducing conditions have been preserved, to use mobility to explore and characterize the deposits, and to obtain fresh samples for detailed analysis by drilling beneath the oxidized surface layers in rocks and soils. Sensitive *in-situ* measurements on retrieved samples would be used to search for and characterize biosignatures, focusing on those compositional and textural records that would provide clear indications that life developed and left unique signatures. The measurements to be conducted would be unprecedented in scope and would provide groundbreaking discoveries about Mars. Note that direct life detection experiments are not needed to implement this strategy for the Smart Lander Mission. Rather, positive signs of biosignatures would be used to help focus locations for sample return missions and / or follow-on missions with direct life detection experiments.

3.2 Current and Past Climates

Discussion of climatic studies for Mars naturally falls into two complementary areas: current atmospheric and climate dynamics, and reconstruction of past climatic conditions. With regard to current dynamics it is important to note that the Smart Lander Mission offers an opportunity to measure the atmospheric profile during entry, descent and landing (EDL). These measurements have only been accomplished three times in the past, during the two Viking Lander Missions and during the Pathfinder Mission. EDL atmospheric measurements would provide an additional important measurement set for this complex planet.

The Viking Landers and Pathfinder made measurements of the lower atmosphere during the landed phase of these missions. When coupled with orbital observations, these measurements make it clear that the current boundary layer dynamics involve the gaseous and aerosol components of the atmosphere and that these components interact strongly with the surface. The Smart Lander Mission provides an opportunity for characterizing these boundary layer dynamics by use of a surface climatology instrument package. Measurements would pertain to aspects of global circulation and passage of disturbances such as frontal systems, together with the interactions of the atmosphere-dust-surface system and possible electrical connections associated with dust storms and local perturbations such as dust devils. A climatology package making sustained measurements to characterize the atmospheric dynamics and surface-atmosphere interactions over the course of the 180 sol solar-powered mission or, better yet, over the course of a 360 sol RPS mission would dramatically add to our knowledge of Mars. It would also be of major importance for characterizing what may be a key hazard for human expeditions to the surface of the planet. Such a package would acquire the best data if placed away from the lander or rover so that it would be free from the perturbing effects of either system (i.e., turbulence). Further, better measurements would be acquired from a stationary package as opposed to moving with a rover. In fact, deployment of several “drop packages” separated by 1 km would be ideal. The SDT noted that an investigation focused on atmosphere-dust-surface dynamics was given a low priority (level 5) by MEPAG [Greeley, 2000]. The SDT believes that the investigation should be of a higher priority than that defined by MEPAG.

Determination of ancient climatic conditions on Mars has enormous synergy with the search for ancient life and the understanding of the sedimentary geology of the planet, as detailed in the previous subsection of this report. Certainly refined measurements should be made of the isotopic composition of the atmosphere, beyond the measurements acquired during entry and landed operations of the Viking Landers. Exploration of layered sediments to test the hypothesis that the deposits accumulated in lacustrine or marine environments is of major importance, using the exploration strategy detailed in the previous section of this report. If a landing at mid to high latitudes can be accomplished then there is also the exciting possibility of searching for ice that may have frozen close to the surface and been preserved in the sediments because of the low surface temperatures and reduced diffusive losses to the atmosphere [Carr, 1996]. Drilling to 5 to 10 m in such a site might not only get to non-oxidized samples but also encounter ice deposits with trapped gases and possible fluid inclusions.

The search for water and the understanding of its role in life and climate is of paramount importance to the exploration of Mars. Simple thermal calculations demonstrate that the likely interface between ice and liquid water will be hundreds of meters to kilometers beneath the surface [Carr, 1996]. The interface may be closer to the surface in some areas if it is maintained by enhanced heat flow or hydrothermal activity. Inclusion of an electromagnetic sounding capability on the Smart Lander Mission would allow detailed probing to the ice-water interface and would allow comparison with the orbital sounding expected with the Mars Express Orbiter (MARSIS) and Mars Reconnaissance Orbiter.

3.3 Structure and Dynamics of the Interior

Characterizing the structure and dynamics of the interior of Mars is a task of fundamental importance for understanding the thermal and geological evolution of the planet, with ramifications for climate and life. The Mars Global Surveyor gravity, laser altimetry, and magnetometer/electron reflectometer experiments have provided new views on the evolution of the planet, including the timing and climatic consequences of formation of the Tharsis uplift and the timing and demise of the dipole magnetic dynamo [e.g., Jakosky and Phillips, 2001]. The NetLander Mission will consist of an array of four stations to be placed on the surface in 2008 as part of the French Space Program. The NetLander payload will include short and long period seismometers to monitor Mars quakes, and the data will be used to map interior structure. The Smart Lander Mission could augment this array with both short and long period seismometers on the surface, nearly doubling the event-detection efficiency while halving the mission risk for NetLander. The short period seismometer would provide data on shallow crustal structure whereas the long period seismometer would produce data of relevance to characterizing global-scale interior structures. The seismometer would best be deployed as a stand-alone package operating for 180, and better yet, 360 sols. If needed, the package could also be placed on a live lander since this platform, in contrast to the rover, would be a static asset.

Determination of heat flow is a fundamental geophysical measurement that has been performed for many areas on Earth and by astronauts on the Moon. Heat flow measurements require instrumenting a drill hole with temperature sensors. The hole would need to be at least 3 to 5 m deep to be able to infer reliable heat flow values. There is a trade-off between shallow and deep holes, since shallow holes require longer integration times to remove seasonal temperature effects.

As noted in previous subsections of this report, electromagnetic sounding would be a very valuable way to search for the ice-water interface. These measurements would also provide fundamental data about lithospheric structure. Electromagnetic measurements need to be done from a stationary system to integrate the signal over time. This could be done from a lander. The measurements could also be done from a drop package delivered by a rover. A related capability to probe the shallow subsurface, and one that would be complementary to electromagnetic sounding, is the use of ground penetrating radar. This measurement technique requires a rover to move across the surface and thus provide the profiling baseline.

3.4 Preparation for Human Exploration and Development of Space

Investigations and measurements that prepare for human expeditions to the planet (HEDS) were discussed within the SDT. The decision was made to keep in mind key HEDS requirements while considering science. The optimum solution would be one in which the requirements are met as part of the high priority science investigations and measurements to be made as part of the Smart Lander Mission. For example, a high priority requirement is to demonstrate robust, precision landing. This requirement is core to the Smart Lander Mission. Likewise, acquisition of atmospheric data during EDL is a HEDS objective. Acquisition of these atmospheric profile data is recommended in a preceding subsection of this report.

Another high priority objective for HEDS is the measurement of high energy radiation that is dangerous to humans, both in orbit and on the surface. MARIE is a radiation dosimeter that was part of the now canceled 2001 lander mission. MARIE, or an instrument similar to or more capable than MARIE, should be flown as part of the Smart Lander Mission, acquiring radiation flux measurements over the lifetime of the mission.

Determination of the near-surface atmospheric dynamics, including electrostatic charging effects, is a HEDS objective that is met by the recommended meteorology package described in a preceding subsection of this report.

Determination of the oxidation dynamics at the surface and subsurface has importance for understanding possible toxic effects on humans. For example, the super-oxides in the soils may prove to be irritants. As noted in previous subsections of this report, measurements as a function of depth in rocks and soils will provide the data needed to understand the current oxidation properties, in addition to providing basic chemical data needed to determine the possible irritating and toxic substances. In addition, to provide a better understanding of the current oxidation dynamics, a long duration exposure facility is recommended for a portion of the surface of the rover, lander, or drop package. This facility would contain surfaces that would react in response to radiation and in response to interactions with accumulated aerosols or with soils dropped onto the surfaces.

Water is a resource that will be needed during human expeditions to Mars. Hence an important HEDS objective is to determine the nature and locations of water reservoirs and the extent to which they are accessible for use during missions. The Smart Lander Mission offers several ways of meeting this objective, including drilling to ice in the mid to high latitudes, use of ground penetrating radar, use of electromagnetic sounding to probe the subsurface to determine the presence of ice and the depth to the ice-water interface, and direct measurements of the water content of rocks and soils.

Finally, HEDS requirements include determination of the topography, rock abundances, soil types, and physical properties of various surfaces on Mars. These requirements would be met by use of stereo imaging from a lander or rover and acquisition of physical properties information during traverses, drilling, and special physical properties experiments, such as using rover wheels to excavate trenches and to expose subsurface soil horizons.

4.0 Mission Options

4.1 Overview

Below is a summary of the science objectives developed in the last section of this report that are well matched to the Smart Lander opportunity:

a. Acquisition of atmospheric profile data during entry, descent, and landing.

b. Acquisition of descent imaging data.

c. Landing on and exploring deposits thought to have formed in a lacustrine or marine environment, focusing on making measurements designed to understand the sedimentary geology, and searching for paleoclimatic indicators and biosignatures. These activities would require access to rock and soil samples at various depths to understand the weathering/oxidation gradient and to ensure that “fresh” samples are acquired for an unprecedented range of *in-situ* analyses focused on mineralogy, elemental and isotopic composition, the presence and nature of organic compounds, and textural evidence for former or extant microbial life.

d. High fidelity measurements of the isotopic composition of the atmosphere.

e. Characterization of atmospheric boundary layer dynamics, including atmosphere-dust-surface dynamics, using a meteorology package on the lander or a drop station.

f. Augmentation of the NetLander seismic array with short and long period seismometers on the lander or on a drop package.

g. Determination of heat flow by instrumenting a drill hole that is preferably at least 3 to 5 meters deep.

h. Deployment of a long duration exposure facility operating in a radiation energy range of relevance to tissue doses.

i. Determination of the oxidation potential of surface materials.

j. Searching for ice left in sedimentary deposits by drilling 5 to 10 m in mid to high latitudes.

k. Mapping the interface between ice and water using electromagnetic sounding from a lander or drop station.

After extensive discussion and feedback from the Smart Lander Project personnel it became apparent that conducting all of the investigations and measurements listed above could not be accomplished within the payload mass, volume, and cost envelopes associated with the Project. Thus the SDT considered two mission options, each of which would be a major new thrust that would serve as a capstone mission for this decade of Mars exploration. The first concept places emphasis on the Mobile Geobiology Explorer (i.e., Explorer), a rover capable of traversing beyond the landing error ellipse and making measurements related to the sedimentary geology of the site, focused on paleoclimate and biosignatures. The second concept places more emphasis on a Multidisciplinary Platform (i.e., Platform) that includes a live lander with a drill and associated *in-situ* instrumentation, meteorology, and geophysics packages. It also includes a rover capable of traversing in the vicinity of the lander, acquiring samples, and delivering the material to the lander-based instruments, followed by longer traverses to explore surrounding terrains.

EDL atmospheric measurements would be acquired with implementation of both mission concepts. Descent imaging would be acquired to place rover-based images into orbital perspectives and to help plan the rover traverses. Descent image resolution should span the resolution from orbital images to a resolution comparable to image data to be acquired from the rover. The SDT notes that the Smart Lander Mission will include the use of hazard avoidance techniques to land in a “safe area” within the error ellipse. The current technology under consideration would include use of radar and/or LIDAR to search for smooth terrain. These data should be saved and transmitted to Earth for use in understanding the landing site and for rover traverse planning.

What follows in this section of the report is a detailed description of each mission concept, including a list of instrumentation associated with each of the payloads. The

SDT did not have enough information to quantify completely each cost, mass, and volume element of each payload. The intent is to define the mission concepts and measurements in clear terms so that subsequent trade studies can use this information to define the final mission in ways that maximize scientific benefits while looking forward to sample return and needed technology developments. For reference, Table 1 summarizes the Explorer Payload and how the investigations map to MEPAG priorities. Table 2 contains the same information for the Platform Payload. Table 3 lists measurement requirements for each investigation. Appendix 4 provides detailed payload information for each mission concept. Specific instruments are included in Appendix 4 as examples only to demonstrate that the payload is credible. The instruments in Appendix 4 should not be construed to be specific recommendations made by the SDT.

4.2 Mobile Geobiology Explorer

The Explorer would be a rover capable of carrying a payload of approximately 100 kg and traversing >5 km to get to the specific scientific targets (e.g., layered deposits) that define the landing site. This corresponds to a “go-to” capability with enough reserves to explore the specific target, terrain, and materials that the rover “goes to”. The strength of the Explorer mission concept is that the Explorer can rove to and explore the sedimentary units that are relevant to the overarching program themes of life and climate. To confirm this assertion the SDT evaluated traverse scenarios for a number of possible landing sites, assuming the 5 km landing site error ellipse associated with the Smart Lander Mission. The sites included the hematite deposits that cover Noachian cratered terrain in Terra Meridiani, interior layered deposits within Gale Crater, and units within Gusev Crater. In each case it was demonstrated that a 6 to 9 km traverse (preferably 9 km), combined with detailed sampling and analysis in 3 locations, would provide data from multiple geologic units, including locations with postulated sedimentary deposits.

The combination of long distance traversing, remote sensing and contact *in-situ* science, access to subsurface samples (and associated paleoclimatic and biosignature evidence), and the wide array of *in-situ* measurements to be applied to the samples will make the Explorer a mission that builds on and goes far beyond the capabilities associated with the MER 2003 Mission.

The payload would consist of:

a. Descent imaging system.

b. Mast-based remote sensing system with multi-spectral stereo imaging, hyperspectral mapper operating in reflected and/or thermal emission wavelengths, and a laser-induced breakdown spectrometer or other instrument capable of remote elemental abundance mapping.

c. Ground penetrating radar operating at high frequency to characterize the structure of the shallow subsurface.

d. Arm-based contact *in-situ* package with rock abrasion tool, elemental and mineralogical analyzers, and microscope.

e. Long duration radiation experiments including energies of relevance to human tissue damage and surface oxidation potential.

f. Drill and sample acquisition system(s) capable of acquiring cores from hard crystalline rocks to depths of approximately 5 cm and soil/sedimentary rock samples to depths of approximately 1 m.

g. Sample preparation and delivery system capable of partitioning (as a function of depth of acquisition), grinding, and sending samples to an *in-situ* analysis laboratory.

h. *In-situ* laboratory that includes instrumentation designed to determine sample inorganic, organic, and isotopic chemistries (including atmosphere), oxidation state, and mineralogy, and to acquire high resolution imaging data.

If feasible the payload should also include:

a. Deployed electromagnetic sounding/seismology package.

b. Deployed climatology package or elements of the package on the rover.

Note that the key to the success of the Explorer Mission would be: (a) landing near and traversing to key targets (layered sedimentary rocks), (b) characterizing the geologic setting, mineralogy, and chemistry of materials along traverses and at specific targeted sites, and (c) acquisition and analysis of subsurface samples at key sites, focused on gathering evidence for paleoclimatic conditions and the presence of biosignatures. Prioritization of the core payload needs to be viewed with these key objectives in mind.

4.3 Multidisciplinary Platform

The Platform mission concept focuses on maintaining a live lander after touch down. This platform would be used to support a drilling system capable of penetrating to and getting samples from 5 to 10 m depth, an *in-situ* instrument laboratory for sample analysis, and both meteorology and geophysics packages. The Platform emphasizes vertical mobility, in contrast to the lateral mobility emphasized by the Explorer. In addition, the Platform has in its high priority payload a better representation of the breadth of disciplines than does the Explorer mission concept. Note that the particular suite of *in situ* instruments is designed for measurements that focus on determination of ancient climatic conditions and searching for biosignatures from subsurface samples. If drilling to shallow ice at mid to high latitude sites becomes the mission focus, this payload would need to be reconsidered. A rover would be used to acquire soil and rock samples from the immediate vicinity of the landing site, to deliver the samples back to the lander for *in-situ* analyses, and to conduct traverse-based scientific measurements using mast-based remote sensing systems and ground penetrating radar.

The payload for the Platform would be:

a. Descent imaging system.

b. Mast-based remote sensing system with multi-spectral stereo imaging, hyperspectral mapper operating in reflected and/or thermal emission wavelengths, and a laser-induced breakdown spectrometer or other instrument capable of remote elemental abundance mapping.

c. Drill and sample retrieval system with capability of getting samples from 5 to 10 m depths.

d. Sample preparation and delivery system capable of partitioning (as a function of depth), grinding, and sending samples to an *in-situ* analysis laboratory.

e. *In-situ* laboratory that includes instrumentation designed to determine sample inorganic, organic, and isotopic chemistries (including atmosphere), oxidation state, and mineralogy, and to acquire high resolution imaging data.

f. Long duration radiation experiments including energies of relevance to human tissue damage and surface oxidation potential.

g. Meteorology package designed to monitor pressure, temperature, wind velocity, dust dynamics, and electromagnetic disturbances.

h. Geophysics package with seismic, heat flow, and active and passive electromagnetic sounding capabilities.

i. Rover with mast-based remote sensing system, ground penetrating radar, rock corer, and capability to deliver core samples to lander-based *in-situ* laboratory.

5.0 Detailed Surface Operations Scenarios

Given two mission concepts, the Explorer and the Platform, the next question asked by the SDT focused on whether or not a credible mission could be accomplished using solar power and a primary mission lifetime of 180 sols. To address this question, Smart Lander project personnel were tasked to generate a mission scenario for what was considered to be the more challenging mission concept, the Explorer. The Explorer has both a complex array of instrumentation and must traverse beyond the 5 km landing error ellipse, all within the 180 sol mission. The other reason for conducting the scenario study was to compare the activities that could be accomplished using solar as opposed to RPS systems for power and to evaluate the importance of autonomous operations for accomplishing a solar-powered mission within the 180 sol limit.

The bottom line is that the Explorer activities (with 3 locations and 6 km traverse) can be accomplished during a 180 sol mission using solar power, but only if improvements in autonomy above the levels to be used during the 2003 MER Mission are developed and incorporated in the mission. In fact, with rover traverse distances governed by available solar power, and not by the MER-like limitation based on what can be seen in mast-based imaging data, the preferred 9 km of traverse is well within reach during the primary mission. A summary of how the scenario conclusions were reached is now presented, with assumptions and detailed analyses included as Appendix 5 of this report. Appendix 5 also includes a comparison of power availability for solar and RPS-powered missions.

The scenario work was designed to estimate the necessary power and time needed to carry out a series of measurements and to cover given distances. Overall data volumes were approximated to determine if the telecom strategy would be adequate. In addition, the study was used to identify those elements that would most benefit from enhanced autonomy. Two types of scenarios were developed. The first, termed ‘A1’, was based on the capabilities of the MER rover. In this scenario performance levels were improved over MER by increasing the size of the rover to allow for more solar panel area to generate power, larger wheels and higher clearance to reduce the need to maneuver around obstacles, and a larger science payload. In the second scenario, termed ‘A3’, aggressive autonomy goals were set to define objectives for significantly improving the performance of the rover. As work on autonomy and rover design converges, the actual mission will likely have a capability described by an intermediate scenario – a yet to be determined ‘A2’ scenario. This ongoing work will define the capabilities for the rover and drill described for both the Explorer and Platform mission concepts. Clearly the goal is to come as close to the ‘A3’ scenario as time and funding levels permit.

The Explorer A1 and A3 scenarios examined 3 different locations, including the landing site and two other sites separated by 3 km, giving a total of 6 km traversed. The scenarios included a series of measurements to be made at each of three locations. First, a full image panorama and other remote sensing observations were acquired at each location. These data were used to choose targets for 4 rock cores and a 1 m soil drill hole at each location. The operational scenarios defined the time, power, rough data rate, and number of ground command cycles required for both traversing the two 3-km segments and carrying out the science measurements required by the Explorer mission concept. Detailed timelines were developed for different types of tasks, including traversing between locations, doing remote sensing and contact science measurements (those requiring a rock core or positioning of instruments on a rock surface), and drilling. In all cases a 33% margin on time was assumed, leaving 120 out of the 180 days to accomplish the objectives. Current MER scenarios were used to assess the time required to traverse and carry out science observations for the ‘A1’ case. Information was gathered from past planetary drill designs and ongoing study contracts. An additional 33% margin was added to estimated drill times because these scenarios have not been tested either in the field or in the lab. These times are quite uncertain, and could increase or decrease depending on the details of the drill design. For the ‘A3’ case, reasonable assumptions about achievable levels of autonomy were used, but will remain uncertain until they can be field tested and made consistent with the flight software standards.

A series of studies were carried out to look at the trade-off between science data acquired, distance traversed, and mission duration as a function of power level and assumed autonomy level. This analysis shows that the ‘A1’ scenario can carry out the specified series of measurements and traverse 6 km only if the mission duration is increased by approximately 60 days or the schedule margin is removed. In the ‘A1’ case, the limiting factor is the number of times that the rover must receive commands from Earth to proceed with such tasks as where to drive next, how to position instruments, and whether or not the drill is functioning. The analysis for the ‘A3’ scenario shows that investments in autonomy will dramatically improve the performance of the mission and greatly reduce mission risk. In particular, the greatest return would be produced by improvements in autonomous traversing, contact science, and drilling, in that order. Finally, comparison of solar and RPS missions clearly demonstrates the advantages of using nuclear power, a topic dealt with in detail in Section 6 of the report.

6.0 Programmatic Issues and Recommendations

In this section a number of programmatic issues are addressed and recommendations are made that pertain to the Smart Lander mission specifically and, in some instances, to the Mars Exploration Program in general.

6.1 Selecting Between the Explorer and the Platform

The Explorer and the Platform concepts as detailed in this report would be excellent missions that would enable exciting new science to be done and that would have enormous public appeal. The Explorer would focus on the overarching issues of ancient climate and the development and evolution of life. On the other hand, the Platform would cover a wider range of important scientific topics through its emphases on drilling and sample analyses, combined with atmospheric and geophysics payload packages. Both missions would address high priority scientific questions and provide opportunities for important new discoveries. Both would provide significant feed-forward to a sample return mission. In fact, the investigations and measurements associated with the Explorer and the Platform should all be implemented as part of a continued Mars Exploration Program.

Choosing between the two missions, or another scientifically exciting combination of the proposed investigations, will require continued study of the scientific benefits, costs, technology risks, and an evaluation of which mission concept is the best preparation for sample return. The SDT Report publication date is too early in the mission planning cycle to be able to make these complex judgments. Further, the SDT lifetime ends with publication of this report. It is thus recommended that a post-SDT science advisory board continue to exist and interact with NASA and the Smart Lander Project to ensure that science is represented in the deliberations that lead to the final mission and prioritized payloads.

6.2 Technology Development

Development of the following technologies will be mandatory for successful completion of the Smart Lander Mission, and will also feed-forward to sample return and other surface operations:

- Precision landing of a large payload, using terminal hazard avoidance systems and a touchdown that is resilient to failure due to local obstacles, is critical for the Explorer or Platform to get to key landing sites. The combination of precision landing and long-range mobility permits a new class of "go-to" mission, in which a rover can traverse beyond the landing error ellipse to get to key terrains and targets of geobiologic or other high scientific significance. These capabilities will also be of high utility for future landed missions, including sample return.
- Drilling technology development will need to be pursued and validated for flight in both the Explorer and the Platform missions. In addition, considerable work will be needed to design, test, and validate sample acquisition, processing, and delivery systems.
- Developments will also be needed in the area of science instrumentation to make either the Explorer or Platform payloads ready for flight.
- Development of autonomous operations is critical for success of the Explorer or Platform, particularly if the mission lifetime is limited by use of solar power sources. These developments would feed-forward directly into sample return and any other surface mission that includes complex operations. In particular, development of autonomous science operations will be needed for the Explorer to traverse autonomously using localization techniques, and to acquire and analyze data on-board in its search for key outcrops and targets. Autonomy will be needed to approach and drill into targets, to place contact sensors onto targets, and to acquire, prepare, and deliver samples for automated analyses. Similar developments will be needed for science operations associated with the Platform, particularly for the drilling and rover operations and sample delivery and analysis portions of the operations. These techniques will ensure identification and subsequent collection of a variety of rock and soil types.
- For either the Explorer or Platform with solar powered systems, dust mitigation techniques will need to be developed and used to ensure that mission duration is not dependent on power degradation associated with dust accumulation.

- Development of RPS as a power source will be of widespread importance for surface missions including and beyond the Explorer or Platform, as noted in this report.

6.3 Enhanced Mission Using Radioisotope Power System

As shown in the detailed scenarios developed as part of this report for the Explorer, a mission with exciting new science and enormous public appeal can be accomplished using solar power. A similar conclusion can be reached for the Platform. However, shifting to RPS systems will dramatically increase the science return for both the Explorer and the Platform for the following reasons:

- RPS would enable landings and subsequent operations at all latitudes, since the dependence on solar power is removed. For example, use of RPS would allow long-term operations at mid-latitudes where springs and seeps may have been active in the recent past, implying the presence of near-surface groundwater. The Explorer would rove to the vicinity of these discharge regions and investigate the alluvium deposited there. A mid to high latitude landing on fluvial, alluvial, or deltaic deposits by the Platform, with its drill system capable of 5 to 10 m penetration depths, would maximize the chance of encountering water ice.
- RPS would enable longer mission operations because of long-term, steady availability of power relative to a solar mission. For example, in this report a primary operational period of 180 sols is assumed for a solar-powered mission whereas 360 sols is allocated for an RPS-powered mission. Longer operational lifetimes will lower mission risk by providing more time to complete the complex operations expected for both the Explorer and the Platform. For the Explorer the longer lifetime would enable the rover to get to the edge of the landing error ellipse and far beyond, exploring deeply into rough terrains and associated deposits identified as having a high probability for sequestering evidence associated with ancient climates and life. The geophysics and meteorology packages could operate over a much longer time period and thus better characterize the planet's interior and define seasonal variations in atmosphere-dust-surface dynamics. The long duration, steady power source associated with RPS would also maximize opportunities to respond to major discoveries and extend the mission lifetime as appropriate. For example, use of RPS on the Viking Landers provided the opportunity for a number of extended missions during which the meteorology and imaging systems were used as long-term weather stations (3 Mars Years for The Thomas A. Mutch Memorial Station) [Arvidson *et al.*, 1983]. Of course, long duration missions would cost more than solar-powered missions for two reasons. First, engineering systems and payloads would need to be built for sustained operations (e.g., over 720 sols). Second, costs would be increased relative to solar powered missions because operations would need to be sustained over a long period of time.
- RPS would provide constant power over a diurnal cycle, thereby allowing more night-time operations, including environmental measurements (i.e., atmospheric

diurnal variations), drilling, and sample analyses, and perhaps even rover traverses. This assumes, of course, that batteries and other systems are designed to take advantage of this diurnal constancy. It would also provide the constant power availability during the martian diurnal cycle needed for maintaining warm thermal enclosures (well above survival temperatures) within the Explorer and Platform. Because of the constant power availability, communication periods would be less time-constrained, thus simplifying operations.

- RPS would mitigate the need for deployment of large solar panels and the dust accumulation mitigation systems required to keep the panels clean, and would lower mission risk for the Explorer by keeping the rover from having panels that extend beyond the body, which must be accounted for in obstacle avoidance operations.

Developing RPS technology now would be a high-payoff investment for the Smart Lander Mission and the Mars Exploration Program overall. This is certainly true if we wish to continue to explore the surface over extended periods, collect and return samples, and eventually implement human expeditions to the planet.

6.4 Precursor Measurements

The Explorer mission concept is focused on landing and exploring terrains and associated sedimentary deposits that maximize the preservation of evidence for ancient climatic conditions and biosignatures. The emphasis would be on traversing to key units, combined with both rock and soil drilling, and subsequent *in-situ* analyses of subsurface samples. For the Platform a main emphasis would be to land on terrain that maximizes the potential for preserving climatic and biosignature evidence and to drill deeply, retrieving samples from various depths for detailed *in-situ* analyses.

The twin MERs scheduled to operate on Mars in early 2004 will certainly provide extremely valuable lessons for science operations and for how to explore and characterize terrains and targets from robotic systems. Results from the twin MERs will also guide selection of a landing site for the Smart Lander that would maximize the probability of finding ancient sedimentary rocks that preserve original reducing conditions. Thus the twin MERs will provide valuable precursor measurements and results.

Landing at a site that maximizes the probability of finding the relevant samples will be paramount to the success of the Explorer and Platform Missions. Thus, precursor measurements are of major importance to help delineate the best landing site. Mars Global Surveyor MOC data certainly suggest a plethora of likely sites [Malin and Edgett, 2001], including many in the equatorial latitude belt, although it is highly desirable to have additional image coverage of these sites at spatial resolutions even better than the 1.5 to 3 m/pixel associated with MOC narrow angle frames. Unfortunately, the 3 km pixel size and dominance of igneous rocks on Mars have precluded identification of aqueous mineral deposits from TES data, perhaps with the exception of the hematite outcrops [Christensen *et al.*, 2000].

Odyssey and Mars Express will produce valuable data to help guide site selection for the Smart Lander Mission. The high spatial resolution camera (approximately 50 cm/pixel) and the hyperspectral imager (approximately 40 m/pixel with VISIR coverage) to be flown on the Mars Reconnaissance Orbiter [MRO, Zurek *et al.*, 2001] will provide the crucial observations that will be required to select the landing site for the Explorer or Platform. In particular the high-resolution images will be used to confirm the presence of layered deposits and associated environments of deposition, to help define detailed rover traverses to key outcrops, and to help choose the landing site that would maximize the Platform's chance of drilling into key layered deposits. Further, the MRO hyperspectral image data will provide the detailed maps of aqueous mineral occurrences, including deposits that are too small to be resolved in TES or Mars Express Omega data and that might be of a grain size that does not produce a discernable thermal infrared signature.

Finally, the Mars Express MARSIS and MRO sounding measurements will provide valuable precursor observations with which to help interpret electromagnetic sounding data from the Smart Lander Mission.

6.5 Planetary Protection

The recommended emphasis for the Explorer and a main emphasis for the Platform is to land, explore, acquire subsurface samples, and make measurements for materials that maximize the potential for formation and preservation of evidence of ancient climatic conditions and associated biosignatures. Key measurements will focus on identifying biosignatures that have changed the isotopic, elemental, or molecular (organic compounds and minerals) nature of the rocks. These measurements will produce exciting new discoveries that will be of direct relevance to questions associated with life on Mars. Direct life detection experiments are viewed as premature until the groundbreaking measurements proposed for the Smart Lander are accomplished and understood. Thus, the Smart Lander mission should be classified as Planetary Protection Class IV-A.

6.6 Facilities, Instruments, and Integrated Packages

Both the Explorer and the Platform would feature a complex array of instruments and systems. Recommendations are included below that detail the use of principal investigator-supplied instruments, principal investigator-supplied integrated instrument packages, and facilities, blended in ways that maximize delivery and use of the best possible payloads. A cornerstone of the recommendation is that every selection be competitive and include peer review.

Specific recommendations follow:

- The drill and sample recovery, preparation, and delivery systems should be a facility package since they will be used for a variety of purposes and because they will need to be highly integrated with the other Explorer or Platform systems.
- Integrated packages, proposed by principal investigators and associated teams, are recommended for (a) mast-based remote sensing system on the Explorer or Platform that would include stereo imaging and spectroscopic instruments working in coordination, (b) contact sensor systems on an arm, (c) Platform-based meteorology station focused on characterization of the dynamics of the atmosphere-dust-surface system, (d) Platform-based geophysics station.
- Principal investigator status is recommended for the ground penetrating radar instrument on the rover since it is a self-contained experiment.
- Principal investigator status is recommended for the Explorer or Platform for the individual *in-situ* instruments that would receive samples for high resolution microscopic imaging, mineralogical, elemental, isotopic, organic, and oxidation potential measurements. (Note that a principal investigator might also propose some clever combination of instruments that would maximize measurement synergy.)
- The sample acquisition systems (i.e., drills) and the rover (Explorer or Platform rover) will produce data of direct relevance to understanding rock and soil physical properties. Thus, investigators focused on use of these systems to infer physical properties should be chosen early enough in the project lifetime to help influence the design and operation of these systems to include relevant measurements that can be inverted to infer rock and soil parameters such as cohesion and angle of internal friction.
- A team leader and team members should be selected to help influence the design of the atmospheric EDL system and to analyze the data.

6.7 Education and Public Engagement

Both the Explorer and the Platform offer exciting opportunities for education and public engagement. Fundamental to any education and outreach activities should be use of the imaging and other data to provide students and the public a sense of presence on Mars and the sense that they are participating. It is recommended that near real-time data visualization capabilities be developed to allow the public to follow planning and implementation of the mission, and that immersion techniques be developed to allow them to simulate actually being on the surface of Mars. These functions should extend to active involvement of students in operations, use of the web and workshops to educate teachers and students about the solar system and Mars science, and widespread dissemination of data and results to the public using Internet capabilities.

7.0 Concluding Remarks

The Smart Lander Mission will be the Mars Exploration Program capstone for this decade. It will build on precursor measurements to find landing sites with maximum paleoclimatic and biological potential, exploring those sites and making measurements on samples collected from beneath the oxidation zone and that thus preserve depositional and diagenetic conditions. The Smart Lander Mission, either as the Mobile Geobiology Explorer or the Multidisciplinary Platform, will open new, exciting areas of scientific research that are of highest priority to the Mars Exploration Program. Further, the Mission offers stimulating opportunities for engaging the public and enabling a sense of participation. The mission will require significant resources and aggressive technology development to succeed as planned. These developments and the science to be accomplished are an excellent investment for the sample return and other surface missions, including those that involve humans. This statement is especially true for efforts focused on developing and using radioisotope power systems. Use of a radioisotope power system will greatly enhance the returns from the Smart Lander Mission and be an excellent investment for succeeding surface missions.

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Table 1 – Explorer Payload Traced to MEPAG Investigations: xxx=provides crucial data; xx=supporting data; x=ancillary data

	MEPAG Priority 1 Investigations	Explore and characterize sedimentary deposits	Search for complex organic molecules	Determine the processes controlling water, CO_2, dust distribution	Find physical and chemical records of past climates	Determine present state, distribution, and cycling of water	Characterize the configuration of Mars' interior	Determine surface radiation and oxidation environments	Demonstrate terminal phase hazard avoidance and precision landing	Determine atmosphere-dust-surface dynamic (SDT decision)
Investigation	**Measurements**	**Life**		**Climate**		**Geology/Geophysics**		**HEDS**		
EDL atmosphere measurements	Accelerometers; P, T sensors			**xx**		**xx**				**x**
Precision landing	Cornerstone of mission	**xxx**	**xxx**	**x**	**xxx**	**x**			**xxx**	
Descent Imaging	Landing site imaging	**xx**	**xx**	**x**	**xx**					
Mast-based remote sensing	Stereo, reflectance or emission, and elemental abundance spectroscopy	**xxx**	**xxx**	**x**	**xxx**	**x**		**x**		**x**
Characterize shallow structures	High frequency ground penetrating radar	**xxx**	**x**	**x**	**xx**	**x**	**x**			
Arm-based *in-situ* package	Rock abrasion tool, elemental and mineralogical analyzers, microscope	**xxx**	**xx**	**x**	**xx**	**x**				
Subsurface rock and soil acquisition, preparation, and delivery	5 cm rock cores; 1 m drilling; sample preparation and delivery to *in-situ* laboratory	**xxx**	**xxx**	**x**	**xxx**	**x**		**xx**		
In-situ Laboratory	Inorganic, organic, isotopic compositions, mineralogy and organic molecule identification, high resolution microscopy, oxidation potential	**xxx**	**xxx**	**x**	**xxx**	**x**		**xx**		
LDEF	Radiation dosimeters (x); surface oxidation potential (y)	**yy**	**yy**	**y**	**yy**	**y**		**xxx;yyy**		**y**
Climatology Package (Drop package or on rover)	Atmosphere P, T, V, opacity, dust accumulation, electrical measurements, imaging and LIDAR			**xx**		**xx**				**xxx**
Geophysics Drop Package	Electromagnetic sounding of lithosphere including ice-water transition depth; Short and long period seismometers to complement Netlander array	**x**	**x**	**x**	**x**	**xxx**	**xxx**			

Table 2 – Platform Payload Traced to MEPAG Investigations: xxx=provides crucial data; xx=supporting data; x=ancillary data

	MEPAG Priority 1 Investigations	Explore and characterize sedimentary deposits	Search for complex organic molecules	Determine the processes controlling water, CO_2, dust distribution	Find physical and chemical records of past climates	Determine present state, distribution, and cycling of water	Characterize the configuration of Mars' interior	Determine surface radiation and oxidation environments	Demonstrate terminal phase hazard avoidance and precision landing	Determine atmosphere-dust-surface dynamic (SDT decision)
Investigation	**Measurements**	**Life**		**Climate**		**Geology/Geophysics**		**HEDS**		
EDL atmospheric measurements	Accelerometers; P, T sensors			xx		xx				x
Precision landing	Cornerstone of mission	xxx	xxx	x	xxx	x			xxx	
Descent Imaging	Landing site imaging	xx	xx	x	xx					
Mast-based remote sensing	Stereo, reflectance or emission, and elemental abundance spectroscopy	xx	xx	x	xx	x		x		xxx
Subsurface rock and soil acquisition, preparation, and delivery	5 to 10 meter drill, sample systems to deliver prepared materials to *in-situ* laboratory	xx	xxx	x	xx	xx	xx	x		
In-situ Laboratory	Inorganic, organic, isotopic compositions, mineralogy and organic molecule identification, high resolution microscopy, oxidation potential	xx	xxx	x	xx	x	x	xx		
LDEF	Radiation dosimeters (x); surface oxidation potential (y)	yy	yy	y	yy	y		xxx;yyy		y
Climatology Package	Pressure, temperature, wind velocity, dust abundance and accumulation rate, electromagnetic disturbances, LIDAR			xx		xx				xxx
Geophysics Package	Short and long period seismometers, electromagnetic sounder, heat flow from drill hole measurements	x		x	x	xxx	xxx			
Rover to explore surroundings and to bring samples to lander for in-situ analysis	Mast-based remote sensing system, GPR, rock corer/soil sampler, system to deliver samples to lander	xx	xx	x	xx	x		x		

Table 3 – Investigation Measurement Requirements

INVESTIGATION	MEASUREMENT TYPE		MEASUREMENT REQUIREMENTS
EDL atmospheric profiles	Accelerometer, P, T		At least equivalent to Pathfinder measurements
Descent imaging	Images of the landing site		Monochromatic imaging of landing site with spatial resolutions ranging from approximately 1 m at high altitudes to several centimeters/pixel at low altitudes.
Mast-based remote sensing	Bore-sighted	Multispectral stereo imaging	Approximately 10 pass-bands between 0.4 and 1.0 micrometer to map iron mineralogy; Spatial resolution of at least 0.30 mrad/pixel; Stereo baseline of at least 20 cm.
		Reflectance or emission spectroscopy for thermophysical properties and mineral mapping	Sufficient spectral resolution, wavelength coverage, and radiometric accuracy to map primary igneous and aqueous minerals at the 5% abundance level; For thermal high enough radiometric fidelity to detect 1 degree Celsius temperature differences in near field.
		Laser-induced breakdown or alternative spectroscopy to map elemental abundances	Map elemental abundances to better than 10% accuracy.
Arm-based contact *in-situ* measurements	Surface cleaner		Abrasion system capable of removing rock coatings to 0.5 mm, with 4 cm radius.
	Elemental abundances		Map elemental abundances to at least 2 to 3% level in equivalent oxide concentrations.
	Mineralogy		Detect and determine primary rock forming and alteration minerals to 2 to 3% abundance level.
	Microscopy		Close up color imaging with pixel size of 30 micrometers.
Subsurface rock and soil acquisition, preparation, and delivery	Explorer	Rock drill	5 cm penetration into rocks, acquiring core 1 cm wide by 5 cm long cores.
		Soil drill	1 m penetration into soil/semiconsolidated sediments, with capability to extract material from 10 cm depth intervals with <2% by weight of contamination of recovered material from above or below recovery depth.
		Sample system	Ability to accept cores, samples, partition, process, and deliver to *in-situ* instrument laboratory.
	Platform	Platform drill	5 m (minimum depth, with 10 m goal) penetration into subsurface, with capability to extract samples from 10 cm depth intervals with <2% by weight of contamination of recovered material from above or below recovery depth. Instrument hole with temperature sensors for heat flow determination.
		Sample system	Ability to accept cores, samples, partition, process, and deliver to *in-situ* instrument laboratory.
		Rover rock drill and core delivery system	5 cm penetration into rocks, acquiring core 1 cm wide and 5 cm long, and deliver to sampling system on lander.
In-situ laboratory	Elemental analysis		Map elemental abundances to at least 2 to 3% level in equivalent oxide concentrations.
	Mineralogical analysis		Detect and determine igneous and aqueous minerals to 2 to 3% abundance level.
	Oxidation potential		Detect oxidizing compounds with sensitivity of 40 ppb and accuracy of +/-15%.
	Microscopy		Deep UV (220-249 nm) imaging with 1 micrometer spatial resolution.
	Organics detection		10^{-14} mole/100 mg sample sensitivity for organic compounds and chirality.
	Isotopic analysis		Noble gas, and C, N, H, O isotopic compositions evolved from various species and atmosphere to better than 1% precision.

Long Duration Exposure Facility	Radiation dosimeter	Same as MARIE on 2001 Lander.
	Environmental oxidation potential	Oxidation detection with sensitivity 10^{10} cm^{-3} number density of oxidizing species.
Geophysics	500-1000 MHz ground penetrating radar	At least 10 m penetration with horizontal resolution better than 1 m and vertical resolution of 10 cm.
	Short and long-period seismometers (0.01 mHz – 50 Hz)	Sensitivity to better than (and system noise less than) 10^{-8} m/s^{2} (0.1 to 10 Hz) and 10^{-9} m/s^{2} (<0.1 Hz).
	Passive and active induction electromagnetic sounders	Passive: Measure ambient time varying electric and magnetic fields from 10 µHz to 10 kHz in way that radiated and eddy-current electromagnetic interferences are isolated from signal. Needed to detect and characterize ground water table to depth of 10 km. Active: High fidelity detection and characterization of ground water from 0 to 500 m depth.
	Heat flow from drill hole measurements	Vertical thermal gradient measured at a depth below the annual wave (typically 3-5 m in regolith) or run experiment long enough to measure the annual wave. Overall accuracy of the heat flow measurement must be 5 mW/m^{2} or better.
Climatology	Atmosphere pressure	Measurement range from 0.001 to 15 mB with resolution of 0.001 mB.
	Temperature	Range from 150 to 310 K, with 0.1 K resolution.
	Wind velocity	0.1 to 50 km/s with resolution of 0.1 m/s.
	Dust Properties	Dust mass flux, size distribution, and velocity determinations (system to be designed to measure to within few percent accuracy 3×10^{-10} g/cm^{2} deposition rates, 1 to 100 micrometer sizes, 1 to 100 m/s velocities)
	Electrical measurements	AC electrical field measurements from radiating fast currents and dust impacts in frequency range from 1 to 100 MHz with 10 µV/m sensitivity. DC electrical field measurements from dust grain charges and locally induced currents in range 10 µV/m to 1000 V/m.
	Camera & LIDAR	Camera: 0.5 mrad/pixel, 24 filters from 0.4 to 1.0 micrometers, 14 deg FOV, for imaging dust storms and devils and opacity determination. LIDAR: Range from 0 to 2 km with scan every 30 s.

9.0 Appendix 1 - Science Definition Team Charter

2007 Science Definition Team (SDT) Charter

NASA's Mars Exploration Program (MEP) is currently formulating plans for a landed mission to be implemented in the 2007 launch opportunity. The strategic aim of this mission is in situ science aligned with the highest priority investigations outlined in the report of the Mars Exploration Payload Analysis Group (MEPAG: cf. Greeley, editor, Dec. 2000). In addition, the 2007 surface mission is intended, to the maximum extent possible, to demonstrate precision landing (i.e., landing within a 6 km x 3 km error ellipse), active terminal hazard avoidance, and a level of surface mobility commensurate with landing precision errors (i.e., 6 km or greater). These latter goals are pivotal to implementing, at the earliest possible date, the Mars Sample Return (MSR) mission. These goals also address NASA's desire to enable "next generation" in situ investigations on the surface.

The 2007 mission Science Instrument Definition Team (SDT) is chartered to prioritize the investigations that are to be accomplished as part of the landed 2007 mission. In addition, the SDT will examine the implications of these priority science investigations on the design of the 2007 spacecraft systems. Specifically, SDT recommendations are needed for surface mobility, the degree of subsurface access, if any, and the duration of surface operations. The SDT will work closely with the 2007 engineering team as they evaluate mission design options during the next several months. This work will assist NASA in the definition of the technology development requirements for this mission.

The SDT should consider the following key issues:

1) an appropriate balance of the need for surface-based experience with martian sample collection and handling in preparation for the Mars Sample Return (MSR) with the requirement that the 2007 landed mission achieve major scientific breakthroughs via a new generation of in situ measurement systems;
2) how the 2007 surface mission might exploit the legacy of remote sensing information from earlier orbiter missions and the experience in surface operations gathered by the 2003 Mars Exploration Rovers;
3) whether in situ life detection experiments are justified in 2007, or whether precursor experiments are needed to further set the stage for in situ biological investigations (e.g., detection of organics, oxidants, prebiotic chemistry); and
4) the extent to which any recommended experiments require pre-flight sterilization, as a stepping-stone to what may be necessary for MSR missions.

It is anticipated that this SDT will function for approximately 5-6 months through a series of meetings, electronic communications, and teleconferences. A final report outlining recommendations and strategies for implementing the 2007 mission is required by NASA on or about September 30, 2001.

DELIVERABLES:

A Final Recommendation to NASA (i.e., to Dr. J. Garvin) with prioritized payload and surface mission capabilities (mobility range, longevity, subsurface access, arm dexterity, descent imaging, landing site considerations, etc.) is the desired deliverable. This report should specify science priorities and possible instrument implementation scenarios as it will be used as the framework for a NASA Announcement of Opportunity that will solicit the science associated with this mission. As part of the recommendations, a minimum set of science requirements must be provided (at least at the level of measurements desired) in order to define the minimum science scope of the mission. Finally, the report should discuss how the recommended scientific measurements and the instruments most suitable for delivering them fit into the path to an “informed” Mars Sample Return, and should identify any required technology developments to support both the 2007 landed mission and the necessary feed-forward to MSR.

10.0 Appendix 2 - Science Definition Team Membership

Members

NAME	AFFILIATION
Raymond Arvidson	SDT Chair, Washington University in St. Louis
Suzanne Smrekar	SDT Deputy Chair; Jet Propulsion Laboratory
Jeffery Bada	Scripps Institution of Oceanography
David Beaty	Jet Propulsion Laboratory
Alain Berinstain	Canadian Space Agency
Jean-Pierre Bibring	Insitut d'Astrophysique Spatiale (Centre Nationale d'Etudes Spatiales)
Michael Carr	United States Geologic Survey
Luigi Colangeli	Agenzia Spaziale Italiana
Douglas Cooke	Johnson Space Center
Angioletta Coradini	Agenzia Spaziale Italiana
Michael Duke	Johnson Space Center (Retired)
Erick Dupuis	Canadian Space Agency
William Farrell	Goddard Space Flight Center
Matthew Golombek	Geology and Landing Site Selection Subgroup Chair Jet Propulsion Laboratory
John Grant	Smithsonian Center for Earth and Planetary Studies
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Robert Haberle	NASA Ames Research Center
Gentry Lee	Mobility and Acquisition Subgroup Chair; Consultant
Laurie Leshin	Arizona State University
Duncan MacPherson	Jet Propulsion Laboratory
Paul Mahaffey	Goddard Space Flight Center
Tim McCoy	National Museum of Natural History
Douglas Ming	Chemistry/Mineralogy Subgroup Chair; Johnson Space Center
Kenneth Nealson	Biology Subgroup Chair; Jet Propulsion Laboratory
David Paige	Climatology Subgroup Chair ; University of California Los Angeles
Ted Roush	NASA Ames Research Center
Everett Shock	Washington University in St. Louis
Peter Smith	University of Arizona
Claude d'Uston	Centre d'Etude Spatiale des Rayonnements (Centre Nationale d'Etudes Spatiales)
Michelle Viotti	Jet Propulsion Laboratory
Aaron Zent	NASA Ames Research Center

Ex-officio

James Garvin	Lead Scientist for Mars Exploration Program, NASA Headquarters
Daniel McCleese	Chief Scientist for Mars Exploration Program, Jet Propulsion Laboratory
Joe Parrish	2007 Mission Program Executive, NASA Headquarters

Invited Observers

Peter Ahlf	NASA Headquarters
Carlos Carrion	Jet Propulsion Laboratory
Alok Chatterjee	Mission/System Architect, Jet Propulsion Laboratory
Sylvie Espinasse	Agenzia Spaziale Italiana
Sarah Johnson	Truman Scholar, NASA Headquarters
David Lavery	NASA Headquarters
Daniel Limonadi	Project Liaison, Jet Propulsion Laboratory
Michael Meyer	NASA Headquarters
Jennifer Mindock	Project Liaison, Jet Propulsion Laboratory
Stephanie Nelson	Washington University in St. Louis
John Rummel	NASA Headquarters
Michael Sander	2007 Mission Manager, Jet Propulsion Laboratory
Leslie Tamppari	2007 Mission Science Office, Jet Propulsion Laboratory
Sam Thurman	2007 Mission Study Manager, Jet Propulsion Laboratory

11.0 Appendix 3 - Science Definition Team Activities

DATE	MEETING TYPE	TOPICS
May 1, 2001	Teleconference	• Mission overview • Subgroups formed
May 15, 2001	Teleconference	• Planned meetings • MEPAG overview • Status of instruments flown on past missions • Power considerations • MPSET questions
May 29, 2001	Teleconference	• Landing site studies • Large rover concept • Power considerations • Subgroup reports • June meeting planning
June 12-13, 2001	Face-to-face, Pasadena, CA	• Project overview • MER overview • Rover round-up • Drilling Report • International Space Agency Reports • Landing sites for scenario development • SDT Report outline • Planetary Protection issues • EDL/terrain information acquisition • Subgroup work
June 26, 2001	Teleconference	• Mission concepts discussions • Autonomy recommendations • Scenario planning report • NASA RPS Initiative report
July 10, 2001	Teleconference	• July meeting planning • MEPAG traceability table review • Mission Scenarios
July 18-19, 2001	Face-to-face, Arlington, VA	• Power estimates • Mission scenarios • Example rover payloads • Drilling recommendations • MSR reed-forward discussion • Measurement and instrument candidates • Subgroup updates • Programmatic issues discussions
July 31, 2001	Teleconference	• Final report discussions • Mission options review
September 2001	Email exchanges	• Report generation and review

12.0 Appendix 4 - Example Payloads

Example Payload for the Mobile Geobiology Explorer

INVESTIGATION	MEASUREMENTS		EXAMPLE INSTRUMENTS	MASS* (kg)	POWER (W)	INFORMATION SOURCE FOR MASS & POWER
Descent Imaging	Images of landing site		MARDI	0.7	3.5 imaging 0.1 standby	MARDI: descent imager on Mars Polar Lander
Mast-based remote sensing	Bore-sighted	Stereo imaging	Athena Pancam/Mini-TES with mast assembly; ASI MA-MISS	17.6	2.5-8.5	Athena Payload on MER per S. Squyres
		Reflectance or emission spectroscopy for thermophysical properties and mineral mapping				
		Elemental abundances	LIBS (Laser-induced breakdown spectroscopy) on mast assembly	2.2	3	MIDP per R. Wiens
Characterize subsurface structures	500-1000 MHz ground penetrating radar		Smithsonian system at constant frequency or JPL stepped frequency system	3	~5 peak ~0.5 avg.	MIDP per J. Grant
Contact *in-situ* measurements	• Elemental abundances • Mineralogy • Microscopy on natural and "cleaned" surface • Instrument Deployment Device		Athena 5 DOF arm with Rock Abrasion Tool, APXS, Mössbauer Spectrometer, Raman Spectrometer, Microscopic Imager; ASI IRMA, MA-FLUX	10.7	RAT = 17 APXS = 0.34 MB = 1.6 MI = 3 Raman = 10	Athena Payload on MER per E. Baumgartner; Raman per L. Haskin
Rock drilling system	Drill to 5 cm, retrieve samples, prepare, deliver to *in-situ* analysis laboratory		Athena Mini-Corer plus sample handling system; SD2-Rosetta	11	15	Athena Payload on 2003 MSR; best guess for sample handling
Regolith/soil drilling system	Drill to 1 m, retrieve samples, prepare, deliver to *in-situ* analysis laboratory		ASI DEEDRI/Champollion Drill; MIDP drills	25	200 Whr/sol	D. Beaty, S. Thurman
In-situ laboratory	Receive prepared rock and soil samples for elemental and isotopic analysis, mineralogical analysis, oxidation potential, organics detection, microscopy		Raman Spectrometer; ASI IRMA	4.3	10	Athena Instrument
			Pyrolysis oven integrated w/ GC/MS, amino acid detector	14.3	2 (MOD) 15 (GCMS) 12 (oven)	P. Mahaffy and J. Bada
			TOF-Laser desorption MS	3.6	4	P. Mahaffy

		APXS; ASI MA-FLUX	0.8	0.3	Athena Instrument
		Microscopic imager	0.3	3	D. Ming
		MOI (Oxidation potential)	2.1	1	D. Ming
Long Duration Exposure Facility	Radiation dosimeter	MARIE; ASI MARE DOSE	5.7	8	MARIE
	Surface oxidation potential	Mars Atmospheric Oxidant Sensor (MAOS)	0.2	1(peak) 0.1 (average)	A. Zent, Mars ‘96
Climatology package (dropped or on rover)**	Atmosphere P, T, V, opacity, dust accumulation, electrical measurements, imaging and LIDAR	Pressure gauge	0.7	0.5	W. Farrell
		Double probe/field mill	1.4	1	
		LIDAR	4.3	25	
		MAGO Dust Analyzer	2.1	6	
		Anemometer	0.7	1.5	
		Thermocouples	0.4	0.2	
		Radio	1.4	1	
		Camera	7.1	3	
EM sounding drop package	Active/passive induction electromagnetic system	Broadband electric and magnetic field sensors with transmitter loop	4.3	3 peak 0.3 average	R. Grimm
	Time domain electromagnetic measurements	ASI MASTER	0.83	3.6	A. Coradini
	Soil characterization by quadrapole analysis (first 50 cm) <10 kHz	ASI ACQUA	0.6	0.05	A.Coradini
Seismometer drop package	Seismic records using long and short period seismometers (0.01 mHz – 50 Hz)	Netlander Seismic Package	2.8	0.5 (+0.3 for heater)	S. Smrekar

Total mass, including contingency, for science payload=119.6 kg; with geophysics drop packages=128.13 kg. Does not include EDL atmospheric structure investigation or drop package masses, i.e., structures, communication systems, etc.

*Includes mass plus contingency, calculated as follows: Mass = CBE/0.7, where CBE = current best estimate.

**Shown is full climatology package. Rover option could be a subset of full package.

Example Payload for the Multidisciplinary Platform

INVESTIGATION	MEASUREMENTS		EXAMPLE INSTRUMENTS	MASS* (kg)	POWER (W)	INFORMATION SOURCE FOR MASS & POWER
Mast-based remote sensing	Bore-sighted	Stereo imaging and reflectance or emission spectroscopy for thermophysical properties and mineral mapping	Athena Pancam/Mini-TES with mast assembly; ASI MA_MISS	17.6	2.5-8.5	Athena Payload on MER per S. Squyres
		Elemental abundances	LIBS (Laser-induced breakdown spectroscopy) on mast assembly	2.2	3	MIDP per R. Wiens
Subsurface rock and soil acquisition, preparation, and delivery	5-10 m drill system with sample retrieval, processing and delivery to *in-situ* analysis laboratory		MIDP drills; ASI DEEDRI, SD2-ROSETTA drills	40	200 Whr/sol	D. Beaty, S. Thurman
In-situ laboratory	Receive prepared rock and soil samples for elemental and isotopic analysis, mineralogical analysis, oxidation potential, organics detection, microscopy		Raman Spectrometer	4.3	10	Athena Instrument
			Pyrolysis oven integrated w/ GC/MS, amino acid detector	14.3	8 – 29 (MOD) 15 (GCMS) 12 (oven)	P. Mahaffy and J. Bada
			TOF-Laser desorption MS	3.6	4	P. Mahaffy
			APXS; MA_FLUX	0.8	0.3	Athena Instrument
			Microscopic imager	0.3	3	D. Ming
			MOI (Oxidation potential)	2.1	1	D. Ming
Long Duration Exposure Facility	Radiation dosimeter		MARIE; ASI MARE DOSE	5.7	8	MARIE
	Surface oxidation potential		Mars Atmospheric Oxidant Sensor (MAOS)	0.2	1 (peak) 0.1 (ave.)	A. Zent, Mars '96
Climatology Package	Atmosphere P, T, V, opacity, dust accumulation, electrical measurements, imaging and LIDAR		Pressure gauge	0.7	0.5	W. Farrell
			Double probe/field mill	1.4	1	
			LIDAR	4.3	25	
			MAGO Dust Analyzer	2.1	6	
			Anemometer	0.7	1.5	
			Thermocouples	0.4	0.2	
			Radio	1.4	1	
			Camera (Pancam)	---	---	

Geophysics Package	Seismic records using long and short period seismometer (0.01 mHz – 50 Hz)	Netlander Seismic Package	2.8	0.5 (+0.3 for heater)	R. Grimm, A. Coradiani and S. Smrekar
	Active/passive induction electromagnetic system	Broadband electric and magnetic field sensors with transmitter loop	4.3	3 0.3 average	
	Time domain electromagnetic system	ASI MASTER	0.83	3.6	
	Soil characterization by quadrapole analysis (first 50 cm) < 10 kHz	ASI ACQUA	0.6	0.05	
	Heat flow from drill hole measurements	Temperature sensors	0.5	0.4	
		ASI MAST_PRO	0.7	4	
Rover • collect and deliver samples to lander for preparation for in-situ analysis lab • traverse terrains while conducting mast-based remote sensing and GPR measurements	Bore-sighted Stereo imaging	Athena Pancam/Mini-TES with mast assembly; ASI MA_MISS, IRMA	17.6	2.5-8.5	Athena Payload on MER
	Reflectance or emission spectroscopy for thermophysical properties and mineral mapping				
	500 – 1000 MHz ground penetrating radar	Smithsonian system at constant frequency or JPL stepped frequency system	3	~5 peak ~0.5 average	MIDP per J. Grant
	Rock corer	Mini-Corer plus sample handling system	11	15	Athena instrument

Total mass for payload=111.83 kg, excluding sample handing system for platform drill; with rover instruments=143.43 kg. Does not include EDL atmospheric structure investigation or rover mass.

*Includes mass plus contingency, calculated as follows: Mass target = CBE/0.7, where CBE = current best estimate.

13.0 Appendix 5 – Detailed Mission Scenarios for Mobile Geobiology Explorer

(The Appendix consists of three parts: 5.1 Assumptions, 5.2 Power curves, and 5.3 Mission Scenario Results. Note that the instruments included are meant as representative examples only and should not be construed as indicating a preference for a particular measurement technique or specific instrument.)

5.1 Assumptions for 2007 Mars Smart Lander Surface Operations Study

I. Autonomy Levels

- A1 – Capabilities similar to the Mars Exploration Rover (MER) but scaled to the large rover
- A3 – See Sections X, XI, and XII for detailed assumptions on autonomy levels for the science analyses, drilling, and traverse

II. Power

- Radioisotope Power System (RPS) – 4800 W-hrs / sol assuming 2 Radioisotope Thermoelectric Generators (RTG's)
- Solar
  - 6 m^2 solar arrays (vehicle presently has 6.4 m^2 of array area, 7% is deducted for shadowing losses)
  - Triple junction, 85% packing, 27% efficiency
  - Dust degradation model included in solar array output beginning at Ls = 110 (maximum of 17% degradation after 90 sols based on data from Pathfinder)
  - See Appendix 5.2 for solar energy available as a function of Ls and latitude
- 30% energy margin held on all available power

III. Reference Mission

- Duration of mission = 180 sols (note: an RPS mission is assumed to last 360 days; thus science data collected and traverse distance could be potentially doubled)
  - Ls = 110 to 200 (a solar mission at Lat = -45° would have to be shifted to Ls = 140 to 230 to assure sufficient power)
  - 33% margin held on mission duration
- Distance Traversed = 6km total (two 3km traverses)
- Science Accomplished:
  - 3 locations total including landing site
  - At each location: 4 rock targets including coring, 1 soil or soft rock target with a 1m drill hole, and remote science
  - The scenario for this analysis assumes once the rover arrives at the location, the remote science is performed first to choose the targets

IV. Reference Payload

- Mass: 100 kg total allocation including drill, arm, and mini-corer
- Analysis does not currently include science during traverse (although ground penetrating radar is recommended by the SDT, it was not included in this evaluation as

the power and data rate are low; subsequent iterations will incorporate this instrument as well as consider others).

- On Mast
    - Pancam
    - Mini-TES
    - LIBS
    - Navcam (engineering instrument for planning rover path)
- On Arm
    - Elemental – APXS
    - Mineralogy – Raman & Moessbauer
    - Imaging – Microscopic Imager
- On Rover
    - Mini-corer
    - Regolith sampling device (1m drill)
    - Imaging – Microscopic Imager
    - Organics – MOD
    - Isotopes – Mass spectrometer
    - Oxidants – MOI
    - Hazcams (engineering instruments to place contact science instruments)
    - GPR – (not included in autonomy analysis because science during traverse was not addressed)

V. Reference Vehicle

- Physical:
    - Mass = 600kg
    - Wheel diameter = 0.5m
    - Average velocity = 6cm / s (derived from traverse requirements and large rover test data)
    - Energy for climbing = 6 W-hr / m (from large rover test data)
    - Odometry is 1.5 times greater than distance driven toward goal
- Subsystems:
    - Command and Data Handling:
        - Prime Computing Platform: 1 RH Power PC (PPC) 750 with 0.5MB L2 cache, 128 MB RAM, Compact PCI (cPCI)
        - Science Platform: 1 PPC G4, COTS, enabled by Remote Exploration and Experimentation Program (REE)
    - Power:
        - Solar as defined in Section II
        - Large battery (~3500 W-hrs)
    - Telecom:
        - 0.75m high gain antenna (HGA)
        - X-band Direct-to-Earth (DTE) with 3 dB margin
        - Electra package for UHF with 9dB margin
    - Thermal:
        - Loop heat pipe
        - Heater
        - 20W supplied by Radioisotope Heater Units (RHU’s)
    - Navigation and Attitude Control:

        - Inertial Measurement Unit (IMU) is the MER LN200 or better
        - Navcams, Hazcams, Suncam

VI. Reference Terrain

- 10° constant slope (this is a high estimate, but does not significantly affect results)
    - Assuming rover is always traveling up the slope
- 20% rock coverage (i.e. 20% of the time the rover is climbing over rocks)

VII. Reference Day

- 2 Direct-to-Earth (DTE) sessions/sol
    - 39 Mbit/sol total available for use (overhead already removed) at 2.5 AU (worst case)
    - Each session duration: 1 hour (one in morning and one in afternoon)
    - Nominally used for engineering and critical sequence planning data
    - X-band DTE with 3 dB margin
    - 0.75m HGA
- 2 UHF sessions/sol
    - 97.3 Mbit/sol total available for use (overhead already removed)
    - Each pass duration: 7.5 minutes
    - Time in UHF power mode: 20 minutes for each pass
    - Link to Mars Reconnaissance Orbiter (MRO) spacecraft assuming it has a low gain antenna
    - 15° elevation of orbiter above horizon
    - Rate is stepped up once during the link for 50% of duration of pass
- 3 hours of battery charging
- Drive duration depends on energy available
- Sleep duration is remaining time

VIII. Reference Power States

- Determined by design team work:

DTE Power	216W
UHF Power	199W
Charge Power	24W
Driving Support Power	159W
Sleep Power	42W

IX. Power Analysis

- Latitudes from –45° to 45° analyzed in 15° increments
- Mission divided into 3 “average days”:
    - Ls = 110 to 140: Power available is that of Ls = 125
    - Ls = 140 to 170: Power available is that of Ls = 155
    - Ls = 170 to 200: Power available is that of Ls = 185
    - Needed for Lat = –45S only, Ls = 200 to 230: Power available is that of Ls = 215
- Assume energy available is enough to perform science at full power at the beginning of the mission at all latitudes.
    - This assumption needs to be verified for latitudes below –15S.

- Assume uplink capabilities can support science and engineering data rates without limiting progress
- Thermal variations by latitude are included by varying amount of energy required to keep rover warm.

X. Autonomy Levels for Science Analyses

- Two levels of autonomy have been examined. The first is 'A1', and represents the MER state-of-the-art. Specifically, requirements for command cycles drive the number of days required to position instruments. The second is 'A3', which represents a combination of what is likely to be achievable based on autonomy studies and the desired capabilities.

XI. Autonomy Levels for Drilling

- 30% margin added to number of days required to complete hole and analyses
- Appendix 5.3 gives an example of an A1 and an A3 scenario for different levels of drilling autonomy, which translate into the number of necessary command cycles and thus days to accomplish drilling. This work is still preliminary.

XII. Autonomy Levels for Traverse

- A1
  - Assume rover will not be driven farther than terrain seen via Navcam images (a maximum of 100 m / sol)
  - Navcam images are used in analysis on the ground to command next traverse
  - MER capability is ~ 40m / sol (100m / sol quoted in MER Flight System CDR)
  - Applied to rover with larger wheels and mast, assume capability of 100m / sol progress (150m / sol odometry)
  - May be less distance traversed if energy is not available for 100m / sol traverse
- A3
  - Assume rover will drive further than operations team sees in daily Navcam images
  - Waypoints along traverse are defined by operations team in advance
  - Rover will take several Navcam images each day, autonomously choosing its path toward the next waypoint
    - For contingency commanding, assume a check-in with ground daily or every other day using Navcam images
    - This allows ground to send a "go / no-go" command based on rover status
  - Distance driven only limited by energy available at that latitude
  - See Appendix 5.3 for example calculation of power and time requirements

5.2 Power Performance Summary

Power Performance Summary

(Relative to reference rover)

Ops Scenarios, W-Hr/Sol		Energy Required				
Enhanced science or mobility		3500	>	energy	>	tbd
Nominal science/mobility (>230m/sol traverse)		3000	>	energy	>	3500
Degraded mobility, nominal science [2]		2300	>	energy	>	3000
Minimal "high power" science [2,3]		1900	>	energy	>	2300
Quiescent Day/Engineering only w/ Telecom		1700	>	energy	>	1900
Hibernation w/ Tx		570	>	energy	>	1700
Dead mans land [1,4]		0	>	energy	>	570

Notes:

[1] The rover could be designed to recover after weeks in this mode (TBR)

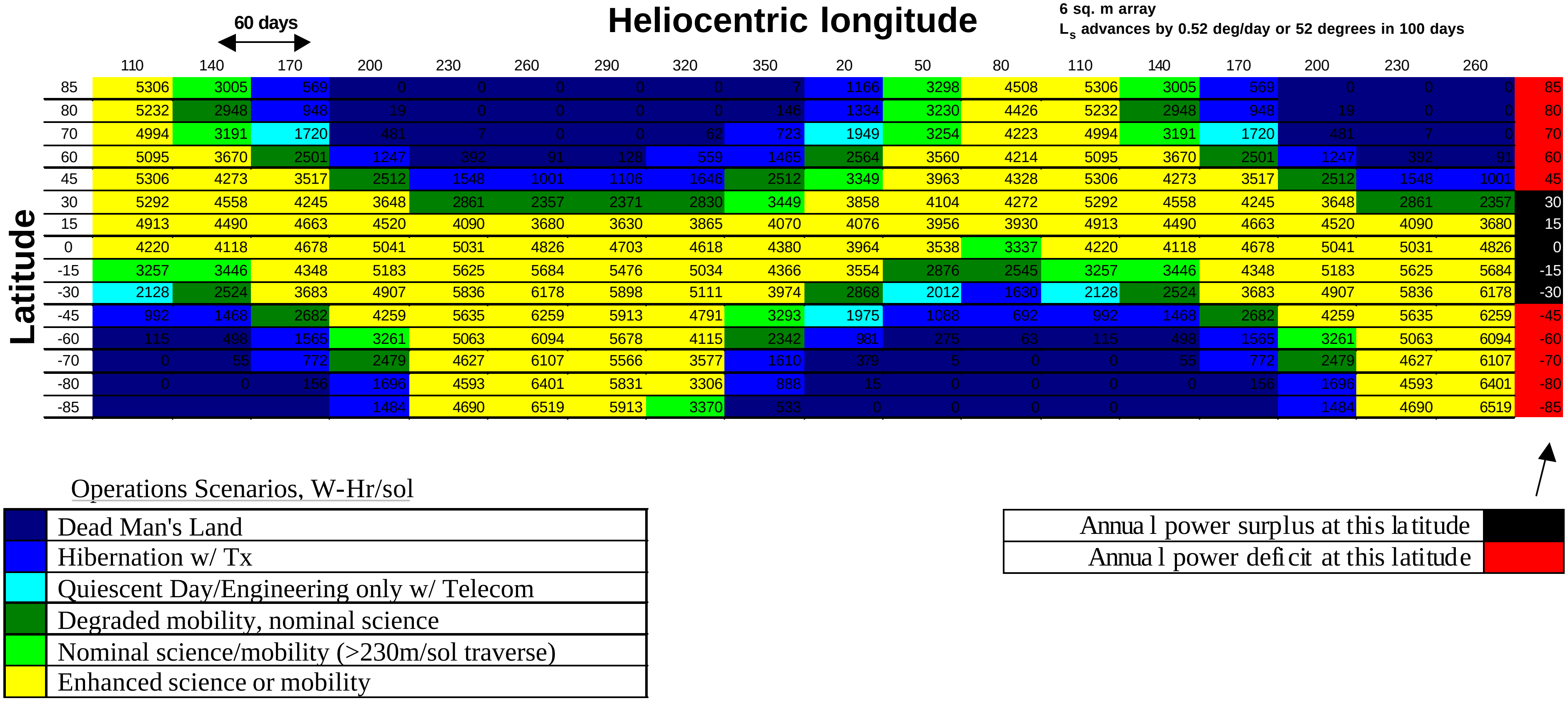
[2] Little to no traversing

[3] Little to no drilling, but imaging and sample analysis probably feasible

[4] No activity

Power Performance Summary

Dust accumulation starting at Ls = 110 peaks at 17% power loss
Cell efficiency = 27%; packing factor = 0.85
6 sq. m array
L_s advances by 0.52 deg/day or 52 degrees in 100 days



Latitude	110	140	170	200	230	260	290	320	350	20	50	80	110	140	170	200	230	260	
85	5306	3005	569	0	0	0	0	0	7	1166	3298	4508	5306	3005	569	0	0	0	85
80	5232	2948	948	19	0	0	0	0	146	1334	3230	4426	5232	2948	948	19	0	0	80
70	4994	3191	1720	481	7	0	0	62	723	1949	3254	4223	4994	3191	1720	481	7	0	70
60	5095	3670	2501	1247	392	91	128	559	1465	2564	3560	4214	5095	3670	2501	1247	392	91	60
45	5306	4273	3517	2512	1548	1001	1106	1646	2512	3349	3963	4328	5306	4273	3517	2512	1548	1001	45
30	5292	4558	4245	3648	2861	2357	2371	2830	3449	3858	4104	4272	5292	4558	4245	3648	2861	2357	30
15	4913	4490	4663	4520	4090	3680	3630	3865	4070	4076	3956	3930	4913	4490	4663	4520	4090	3680	15
0	4220	4118	4678	5041	5031	4826	4703	4618	4380	3964	3538	3337	4220	4118	4678	5041	5031	4826	0
-15	3257	3446	4348	5183	5625	5684	5476	5034	4366	3554	2876	2545	3257	3446	4348	5183	5625	5684	-15
-30	2128	2524	3683	4907	5836	6178	5898	5111	3974	2868	2012	1630	2128	2524	3683	4907	5836	6178	-30
-45	992	1468	2682	4259	5635	6259	5913	4791	3293	1975	1088	692	992	1468	2682	4259	5635	6259	-45
-60	115	498	1565	3261	5063	6094	5678	4115	2342	981	275	63	115	498	1565	3261	5063	6094	-60
-70	0	55	772	2479	4627	6107	5566	3577	1610	379	5	0	0	55	772	2479	4627	6107	-70
-80	0	0	156	1696	4593	6401	5831	3306	888	15	0	0	0	0	156	1696	4593	6401	-80
-85				1484	4690	6519	5913	3370	533	0	0	0	0			1484	4690	6519	-85

Operations Scenarios, W-Hr/sol

■	Dead Man's Land
🟦	Hibernation w/ Tx
▢	Quiescent Day/Engineering only w/ Telecom
🟩	Degraded mobility, nominal science
🟩	Nominal science/mobility (>230m/sol traverse)
🟨	Enhanced science or mobility

Annual power surplus at this latitude	⬛
Annual power deficit at this latitude	🟥

5.3 Mission Scenario Results