

MARS PRECURSOR MISSION INFORMATION

PHASE 1: INFORMATION GATHERING / DATA COLLECTION

Purpose: To characterize human and system interactions with the natural environment and to aid in design of human supporting systems and technology.

I. Engineering Design Information

- A. Mars Atmosphere**
- B. Surface Dust and Soil**
- C. Martian Surface Characterization**
- D. Subsurface Soil & Physical Characteristics**
- E. Radiation Measurement, Characterization, and Modeling and Radiation Effects on Materials & Humans**
- F. Crew Biomedical Concerns**
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- H. Micrometeoroid flux**

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- B. Aeroassist Technology and Capabilities**
- C. Mars Surface Power Technology**
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Operations Information & Experience to Build Human Exploration Common Capabilities

- A. Global Space Environment Forecasting (e.g., SPEs)**
- B. Non-Contaminating Sample Collection**

PHASE 2: HUMAN MISSION PREPARATION / INFRASTRUCTURE EMPLACEMENT

Purpose: To provide the physical and operational foundation at the destination (both on-orbit and on the surface) to support a crewed mission and ensure crew safety and mission success.

Precursor Mission Phasing: (from Jeff George/JSC EX)

- Mission 1: Mars “Diviner” Mission (multidisciplinary geophysical subsurface explorer) (~2,800 kg)
- Mission 2: “Site Characterization and Preparation/Virtual Tourist” Mission (~3,011 kg)
- Mission 3: “200 m Drill” Mission (~1,879 kg)
- Mission 4: “Subsurface Sample Return” Mission (~3,000 kg)
- Mission 5: “Mars’ Deep Aquifers and Search for Life” Mission

A. Orbit-Based Assets

- 1. Communications / Navigation Infrastructure (coupled to Mars Surface) / Mars Network**
- 2. Space Weather Monitoring “Sentinels”**

B. Surface-Based Assets

- 1. Surface & Subsurface Drilling**
- 2. Mars Surface Weather Monitoring / Forecasting / Communicating**
- 3. Site Selection & Preparation**
- 4. EVA and Surface Mobility / Rovers**
- 5. Supply caches (e.g., food, potable water)**
- 6. Power (Solar & Nuclear)**
- 7. Crew Habitat Pre-Deployment**

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Purpose: To characterize human and system interactions with the natural environment and to aid in design of human supporting systems and technology.

I. Engineering Design Information

A. Mars Atmosphere

Purpose: To collect data to enable the detailed characterization and modeling of the Martian atmosphere structure and chemistry. The information is primarily required for (1) ISRU production, (2) aeroassist/precision landing, and (3) Next Generation EVA/EMU suit.

Precursor Needs:

- (1) Atmospheric Profile (constituents, layers, global variation)
- (2) Trace gas composition of the lower atmosphere (surface to about 10 km) and its variation with altitude and time of day, including major and minor components. Particular gases of interest: water vapor, ozone, atomic oxygen, the hydroxyl radical, the hydroperoxyl radical.
- (3) Pressure gradients
- (4) Wind speed / wind loads
- (5) Solar Insolation (?)
- (6) Atmosphere voltage breakdown
- (7) Seasonal and daily variation of atmosphere composition, visibility, and dust
- (8) Variation of atmosphere pressure with elevation
- (9) Why is the surface of Mars so highly chemically active? What is responsible for the high chemical activity of the surface? Is the high reactivity of the Mars surface controlled by reactive trace atmospheric gases, i.e., ozone, atomic oxygen, the hydroxyl radical, the hydroperoxyl radical.
- (10) What is the effect of atmospheric dust on incoming solar radiation? The vertical distribution of atmospheric dust. How does atmospheric dust vary with season, latitude, and time of day?
- (11) What is the flux of ultraviolet radiation incident at the surface Mars? What is the flux of cosmic rays at the surface of Mars.
- (12) What are the horizontal and vertical winds at the surface of Mars and their variability with season, latitude, and time of day.
- (13) Detailed measurements of the atmospheric boundary layer above a couple of meters have yet to be made.

Requires:

“EOS-like” orbiter

Many of these questions may be addressed with the following instrumentation aboard an aerial platform, i.e., an airplane or balloon, flying at altitude of between 0.5 and 5 kilometers above the surface of Mars:

- (1) Mass spectrometer for atmospheric composition analysis.
- (2) Solar ultraviolet spectrometer.
- (3) Solar visible photometer.
- (4) Atmospheric dust particle counter.
- (5) Cosmic ray counter.
- (6) Surface infrared spectrometer to understand the chemical composition and mineralogy of the surface of Mars.
- (7) Accelerometers for atmospheric wind measurements

Existing Relevant Information & Missions:

- (1) Mars atmosphere modeling is currently funded. Mars '05 planned to have “aeromaneuvering.”
- (2) ARC generates Global Circulation Model (GCM) (provides detailed detailed climate and global models for Martian year).
- (3) Dr. Jere Justis/MSFC developed Mars Global Atmosphere Surface Model ('01, '03, '05) “MARSGRAM” (Mars Global Reference Atmosphere Model 2000). The surface definition within the model is coarse right now; MOLA data ties the model to the surface definition.

POCs:

Dr. Joel Levine/LaRC (atmosphere chemistry)

Dr. Jere Justis/MSFC (atmosphere modeling & turbulence; “MARSGRAM” Model

Dr. Jim Garvin/Hqtrs (MOLA)

Joe Kosmo/JSC (EVA/EMU)

Mike Tauber/ARC (Mars dust erosion of vehicle TPS)

Atmosphere Background Information: (from Dr. Jere Justis/MSFC)

Although we know a great deal about the atmosphere of Mars, it is considerably more variable with season, location, and time of day than is the atmosphere of Earth. Atmospheric data have come from surface-based sensors (Viking and Pathfinder, with Viking providing about a full Mars year of data. Remote sensing systems on Mariner, Viking and Mars Global Surveyor have provided some low resolution data over wide spatial areas up to heights of about 30 km. Instruments that will fly on Mars Express will provide

significantly better remote sensing data than we have obtained thus far. All missions have used radio occultation methods to get atmospheric soundings (again up to about 30 km) that have good vertical resolution, but are rather "hit and miss" in their geographical and seasonal coverage.

Some areas about which we know very little are:

The middle atmosphere (~ 50 to 100 km). Although we have three entry profile measurements (Viking 1&2 and Pathfinder), these do not characterize the variability of this region well enough. For example, Pathfinder showed temperatures at some altitudes that were super-cooled with respect to carbon dioxide condensation temperature. This was apparently due to wave perturbations, the properties of which are not well understood.

Longitude-dependent waves in the upper atmosphere (~ 100 km and higher) were observed by Mars Global Surveyor. Variations of up to a factor of two or more were seen to depend on longitude (terrain?), even when measured at a fixed time of day. Over the course of the year and as satellite latitude changed, the characteristics of these waves varied in ways that are not understood. Height variation of the longitude-dependent waves below ~100 km is not known at all. General Circulation Models are being studied to see if these waves can be explained by these models.

B. Surface Dust and Soil

Purpose: To collect data to enable the detailed characterization and modeling of the Martian surface dust and soil. This information would primarily be used for site selection for engineering design and emplacement of infrastructure prior to crew landing, selecting safe crew landing sites, and determining the biological potential of Mars surface sites (e.g., for finding extant or extinct life; for growing food for the human crew).

Precursor Needs:

- (1) Dust particle size distribution, shape, & mass distribution
- (2) Reactivities with Earth-like atmosphere constituents (i.e., O₂, N₂, water)
- (3) Chemical composition; concentrations; major and minor soil & dust components
- (4) Toxic elements and trapped volatiles, halogens, and other potential toxic contents
- (5) Genotoxic potential
- (6) Soil bearing strength/loading capability, penetration resistance, cohesion, adhesion
- (7) Soil magnetic & electrostatic properties / conductivity of dust and surface particles, electrostatic charging
- (8) Surface thermal properties: local thermal cycling; heat capacity, conductivity, emissivity; touch temperature of rocks; average sink temperature; effects of dust on radiation heat transfer and solar flux on Mars surface; effects of dust and wind on convective heat transfer on Mars surface
- (9) Dust particle erosion effects

Existing Relevant Information & Missions:

(1) MITCH: Mars Investigation of Total Climatological Hazards (originally proposed for 2003 lander); considered Martian “weather station”

MITCH would examine hazards associated with radio disturbances, high winds, dust devils and dust storms, and electrostatic charging. MITCH will demonstrate the capability to detect approach and impact of these natural but harsh events. MITCH contains three experiments:

- (1) MAD DAWG (Martian Dust Devil Advanced Warning gizmo): tracks the motion of dust devils;
- (2) CABARET: Meteorology station that monitors pressure, temperature, 3-D wind information, airborne particle size and density, ionization, particles, and electrical breakdown.
- (3) STOMP (Seismic Test of Mechanical Properties): Consists of sensors on top of Mars Lander footpads which seismically sound the soil to determine its stability.

(2) ECHOES: Electrical Charging Hazard Originating from the Surface

Crafted to investigate dust devil action and resulting electrical activity on the Martian surface. Include in the package is a meteorological package, DC electric field system, electrometer chain, atmospheric breakdown experiment, and chemical reactivity sensor. ECHOES has wide-angle mirrors providing the camera the ability to scan a wider area for dust devil activity.

Major Objectives:

- (1) Determine if dust clouds are electrical phenomena and if they are truly a hazard to equipment and human exploration of the surface.
- (2) Obtain information on rates of dust devil formation.
- (3) Map the Lander potential, on flat surfaces and near sharp corners.
- (4) Determine atmospheric breakdown potential as a function of environmental conditions.
- (5) Specify ground conductance locally and remotely and determine surface use as a universal electrical reference.

(3) MECA: Mars Environmental Compatibility Assessment

MECA is an integrated suite of instruments for dust and soil investigation on the MSP '01 Lander Mission

MECA Objectives:

- (1) Identify harmful substances on the surface that may come from the soil when it is exposed to water in the human habitat.
- (2) Determine the size and shapes of particles that attach to surfaces of interest and how these may be hazardous to the human crew.
- (3) Investigate the adhesion, abrasion, and electrostatic behavior of Mars surface particles.

The MECA payload includes:

- a Wet Chemistry Lab to evaluate soil samples in water (pH, redox potential, heavy metal ion detection, hazardous gas, corrosion, total dissolved solids);
- a microscope station (atomic force and optical microscopes; abrasion tool to study minute particles);
- patches of material in front of the Lander camera to demonstrate properties of soil particle wear, adhesion, and hardness; and
- an Electrometer on the robot arm to detect triboelectric charging and atmospheric ionization.

(4) Mars Global Surveyor (?)

POCs:

John Connelly / JSC (Exploration)

Joe Kosmo/JSC (EVA/EMU)

C. Martian Surface Characterization

Purpose: To collect data to enable detailed characterization and modeling of the Martian surface. This information would be used primarily for site selection for engineering design and emplacement of infrastructure prior to crew landing, selecting safe crew landing sites, and selecting sites of primary science interest for robotic and human exploration.

Precursor Needs:

- (1) Terrain features: rock fields, sand dunes, slope inclinations, cliffs, etc.
- (2) Illumination and lighting conditions, daily and seasonally
- (3) Existence of water & CO₂ ice
- (4) Albedo
- (5) Seasonal and daily variation of ambient temperature, pressure, wind speeds and directions

Existing Relevant Information & Missions:

(1) Mars Global Surveyor:

(2) MOD: Mars Organic Detector

Looks for signs of life and evaluation water inventory for In-Situ Resource Utilization; proposed for Mars '03 Lander

Designed to detect organic compounds in rock and soil samples on the Mars surface and to assess the biological potential of the planet. A Tunable Diode Laser (TDL) spectrometer component provides information on desorption and decomposition temperatures, release rates and quantities of H₂O and CO₂ that can be freed from the Martian regolith samples, which will help in the design of future resources for in-situ water extraction. MOD detects organic compounds at very low concentration levels (~100X more sensitive than the Viking instrumentation) and it can examine Martian sub-surface composition as well.

POCs:

JSC/EX

D. Subsurface Soil & Physical Characteristics

Purpose: To collect data to enable the detailed characterization and modeling of the Martian subsurface soil and physical characteristics. This information is used primarily for site selection for engineering design and emplacement of infrastructure prior to crew landing (including determination of potential subsurface water supplies), selecting safe crew landing sites, and selecting sites of primary science interest for robotic and human exploration (including sites of potential biological activity).

Precursor Needs:

- (1) Existence, distribution, and characterization of water & CO₂ ice (
- (2) Subsurface physical characteristics, such as mineral & chemical composition, concentrations, reactivities; toxic elements, trapped volatiles (including genotoxin potential); size and depth of interesting and useful structures; load bearing capabilities & distribution; magnetic & electrostatic properties; and thermal properties at depths.

Existing Relevant Information & Missions:

(1) Mars Global Surveyor

(2) Mars Express

(3) MOD: Mars Organic Detector

Looks for signs of life and evaluation water inventory for In-Situ Resource Utilization; proposed for Mars '03 Lander
Designed to detect organic compounds in rock and soil samples on the Mars surface and to assess the biological potential of the planet. A Tunable Diode Laser (TDL) spectrometer component provides information on desorption and decomposition temperatures, release rates and quantities of H₂O and CO₂ that can be freed from the Martian regolith samples, which will help in the design of future resources for in-situ water extraction. MOD detects organic compounds at very low concentration levels (~100X more sensitive than the Viking instrumentation) and it can examine Martian sub-surface composition as well.

POCs:

JSC/EX

E. Radiation Measurement, Characterization, and Modeling and Radiation Effects on Materials & Humans

Purpose:

To characterize & model the radiation environment both in Deep Space and in the Martian environment (both orbital & surface). To demonstrate and test new radiation shielding methods and materials. Information would primarily be used for radiation shielding during Earth-Mars transit and on the Mars surface, for biomedical modeling and countermeasures development, and in the design of the Mars EVA suit/EMU.

Background:

“...The radiations are described by field functions for each particle type over some spatial domain as a function of time. The radiations are associated with different sources identified as those of galactic origin (galactic cosmic rays, GCR) and particles produced by the acceleration of solar plasma by strong electromotive forces in the solar surface and acceleration across the transition shock boundaries of propagating coronal mass ejection (solar energetic particles, SEP). The GCR constitutes a low level background which is time invariant outside the solar system but is modulated over the solar cycle according to changes in the interplanetary plasma which excludes the lower energy galactic ions from the region within several AU of the sun... The SEP are associated with some solar flares which produce intense bursts of high energy plasma propagating into the solar system along the confines of the sectorized interplanetary magnetic field...producing a transition region in which the SEP are accelerated. SEP have always been a primary concern for operations outside the Earth’s protective magnetic field and could deliver potentially lethal exposures over the course of several hours...”

In the usual context, shielding implies an alteration of the radiations through interactions with intervening materials by which the intensity is decreased. This understanding is to some degree correct in the case of the relatively low energy particles of the SEP wherein the energy deposited in astronaut tissues can be easily reduced by adding shield material. As one would expect, some materials are more effective than others as the physics of the interactions differ for various materials. The high energies associated with the GCR are distinct in that the energy absorbed in astronaut tissues is at best unchanged by typical spacecraft shielding configurations and many materials will even increase that energy absorption. For GCR, one must abandon the concept of “absorbing” the radiation by the use of shielding. The protection of the astronaut in this case is not directly related to energy absorption within their body tissues but rather depends on the mechanism by which each particle type transmitted through the shield results in biological injury. Even though the energy absorption by the astronaut can be little affected, the mixture of particle types is strongly affected by the choice of the mixture of particles behind a shield and the modification of that mixture by choice of materials is then a critical issue in protecting the astronaut in future human exploration ...

Understanding the biological effects of GCR behind intervening material is then key to protection in future deep space activity.... In the present paper, we ... choose a good performing shield material for estimation of exposures on a Mars mission profile chosen to minimize the exposure for that mission. The mission is for 2.5 years with only six months transit times and 1.5 year surface stay. The highest exposure rates will occur during transit since the Martian atmosphere provides added protection during the long surface stay...

Outside the geomagnetosphere, astronauts are subject to the full galactic and solar cosmic ray environments except for what protection is afforded by the vehicle, habitat, rover, spacesuit, and overhead atmosphere during surface operations....The Martian atmosphere reduces crew exposures during the surface stay....

Dose equivalent as an indicator of risk has known large uncertainties... and furthermore may falsely indicate even the relative effectiveness of shielding as compared to biological response models ... Further study of biological response to HZE ion beams on a systematic basis and the development of risk models for extrapolation to the space environment are required. In this context, other space environmental factors may result in important modifications of the biological response not the least of which is microgravity and the associated physiological changes... It is necessary that adequate time be allowed to perform critical tumor induction experiments in the best available animal strains and underlying biomolecular studies to develop new methods of risk assessment. Only then can an adequate means be available to develop exposure limits for exploratory class missions....”

From: Simonsen, L.C. and Wilson, J.W. (2000) *Radiation Exposure for Human Mars Exploration*. in publication.

- “...the GCR are of low intensity and were not of concern in the Apollo mission which were of short duration (less than two weeks). The main concern was the possibility of a solar particle event in which acute effects may occur as we reflected in the design exposure limits... As future space exploration is towards Mars and there is the possibility of a lunar colony, the long term exposures to galactic cosmic rays are a critical issue... There are no exposure standards for such missions established since the biological cancer risks and other adverse effects of exposures to the HZE [high charge and energy] ions are largely unknown...

... The biological risks depend on the local environment of the astronaut within the vehicle and the sensitivity of specific tissues to those radiations present... Only twice have astronauts been in deep space during a solar particle event (Apollo 14 and 16...), although an extraordinary event occurred on August 4, 1972, between Apollo 16 and 17. Estimated exposures for this event are quite high if inadequate preparation is made...This event had the clear potential for disturbing biological effects especially in relation to other space stress factors to which the astronaut is subjected... An important issue in solar particle event exposures is that these exposures occur over a several hour period and repair and recovery of the affected tissues are simultaneously in progress...

... Deep space mission exposures from background are dominated by NZE ions and the corresponding risk uncertainties are large... Traditional construction materials like aluminum probably increase the health risks but polymeric materials show some usefulness in shielding the astronaut from HZE ions.

... Solar particle event exposures in LEO are limited by the natural precessional motion of the spacecraft even in the event of a concurrent large geomagnetic storm. Crew rotation may be required after such an event but health risks are manageable. In deep space, solar events can present a serious health hazard and adequate monitoring with a warning system and storm shelter design is required. Large exposures are possible if adequate shelter is not acquired in a timely fashion. Still, lethality is not likely since tissue repair greatly reduces the effect of exposure and especially if adequate medical planning is part of the mission design. Space stress could greatly alter the biological response to such exposures and an adequate understanding of space stress affects is necessary to mission planning.”

(from: Wilson, J. *Overview of Radiation Environments and Human Exposures.*)

See also:

- Wilson, J.W. et al. (1999) *Shielding from solar particle event exposures in deep space.* Radiation Measurements 30 (1999), 361-382.
- *Radiation and the International Space Station: Recommendations to Reduce Risk.* (2000) National Academy of Science National Research Council, Space Studies Board.

Precursor Needs:

(1) Materials: Radiation impact on materials during Earth-Mars transit, in Mars orbit and on the Mars surface.

- Issues:

- Deep space transit vehicles:

- GCR (low intensity of ions of all known elements with broad range of energies; cancer induction rates behind aluminum shielding are high, so new shielding materials and approaches are required)
- Occasional solar particle events (high intensity of ions of hydrogen to iron)
- UV, X-ray, solar wind, and solar storm particles

- Deep space orbiters:

- Deep space radiations reduced by shadow
- Induced albedo from atmosphere and surface interactions
- Induced chemically active species from atmospheric interactions

- Lander vehicles:

- Deep space environment filtered by atmospheric components
- Induced albedo from surface interactions
- Induced chemically active species from atmospheric components

- Requires:
 - Demonstrations & testing of candidate shielding materials; perform flight validation on multiple Mars missions (e.g., '01, '03, '05)
 - Radiation Technology Demonstration (RTD) mission? (“Laboratory and flight validation of shield design technology and materials database. 2012” within Materials Technology Roadmap)
 - Repetitive ISS dosimetry measurements
 - Should also directly evaluate the ability of the Martian regolith for radiation shielding (boron bricks concept?)

- (2) Humans: Radiation impact on humans during Earth-Mars transit, in Mars orbit, and on Mars surface
 - Require:
 - Dose rates; LET (Linear Energy Transfer, energy lost per ion path length) spectra by particle type; 0.1 to 20 MeV neutrons
 - Mars '01, 03, 05 measurements within Mars transit environment and Mars surface environment
 - Mars surface radiation environment:
 - GCR on Mars surface and interactions with Martian terrain. Requires placing detectors at multiple locations
 - Measurements of backscattering (particles with higher atomic mass filtered by Mars' atmosphere).
 - Concerns: (1) Deterministic effects (e.g., acute radiation sickness, CNS damage, cataracts); and (2) Stochastic effects (where the probability is proportional to radiation dose) (e.g., cancer, hereditary effects, neurological disorders)
 - Must obtain information on living tissues (folding of genetic material; cell communication modifies radiation impact).
 - The most useful precursor? Sending 50-150 rats into Deep Space (i.e., beyond Earth's protective magnetic field) for six months (includes transit time), return them to Earth, then record the incidence of radiation problems over their two-year lifespan, then use this information to predict rates in humans.
 - Could potentially use living cells in a bioreactor sent to Mars orbit or L2, then returned to Earth for analysis.
 - Consider using “gene chips” to measure radiation effects on genetic complement

- (3) Generic Radiation Information:
 - GCR measurement in Deep Space (not required to go to Mars to measure this; measurements just need to be beyond the Earth's magnetic field). Note: The Sun's magnetic field attenuates cosmic rays and solar particles; radiation is ~20% higher at Pluto than at Earth. There is presently a model for GCR (RMS = 10%; quite good prediction. Information required is how to model this beyond one year and reduce prediction error in present models (RMS error = ~ 20-25%).
 - Solar Radiation Environment / SPEs (Solar Particle Events): Need to understand the trajectory of solar particles with regard to Mars.

Existing Relevant Information & Missions:

(1) Many radiation measurements can be done in facilities on Earth's surface; there are a few specific issues that must be addressed in the space environment. The biomedical radiation issues are described more broadly in the Code U Strategic Plan (inputs from Dr. Walter Schimmerling) and in the Bioastronautics Program Plan.

Note: Platforms for testing deep-space radiation effects on materials:

- Ground-based facilities: full range of particle and energy testing and induced environment impractical; provides test of major components with high-resolution diagnostic devices
- ISS: dynamic range limited by geomagnetic cutoff; trapped radiation is a confounding factor; impractical to test induced environment conditions; allows validation of engineering design tools.
- Deep space transit vehicles: Impractical to test induced environment conditions; provides full dynamic range of particles and energies. Provides: (1) Environmental measurements; (2) Shielding transmission properties (for crew and devices protection); and (3) Materials degradation
- Deep space orbiters: Allows testing in the induced orbital environment; would be enhanced by sample return missions. Provides: (1) Environmental measurements; (2) Shielding transmission properties (for astronaut and devices protection); and (3) Materials degradation in Martian induced orbital environment.
- Lander vehicles: Allows testing in the induced surface environment; would be enhanced by sample return missions. Provides: (1) Environmental measurements; (2) Shielding transmission properties (for astronaut and devices protection); and (3) Materials degradation on Martian surface environment.

(2) ISS:

- There is significant radiation shielding on ISS (e.g., ~300 lbs on each sleep station). There are also scopes on the ISS exterior to view the radiation environment in 3-D. A portable scope will be used to measure interior radiation and the energy spectrum. ISS astronauts are to wear personal dosimeters to measure ISS interior ambient radiation. ISS provides measurements of radiation belts and GCR in LEO.
- ISS Advanced Radiation Monitors;
 - Tissue Equivalent Proportional Counter (TEPC)
 - Charged Particle Directional Spectrometers (CPDS)
 - Passive Dosimetry

(3) MARIE: Martian Radiation Environment Experiment (proposed for 2001 Orbiter mission)

Primary Objectives:

- Characterize Martian near-space radiation environment;

- Characterize Martian surface radiation environment as related to radiation-induced risk to human exploration; and
- Determine and model Mars radiation atmosphere to predict human dose and radiobiological effectiveness.

Secondary Objectives:

- MARIE will also measure and monitor components of solar particle events (SPEs) to determine the contribution of protons and helium (spectra from 30 MeV per nucleon to 500 MeV per nucleon) to the overall radiation environment on Mars.

Lander science and measurement goals:

Measure accumulated tissue-equivalent absorbed dose and dose rate as a function of time (with resolution of minutes), and determine the various contributions of protons, neutrons, and galactic radiation nuclei.

Correlated mission studies:

These surface measurements will be correlated with simultaneous measurements on the Orbiter and data from the Advanced Composition Explorer at L1 to determine the contribution of SPEs to total surface dose on Mars, contribution of GCR to total Mars dose, contribution of induced radiation-like neutrons to total dose, shielding and radiation properties of Mars atmosphere, and contribution of Mars soil from several LET spectra during Lander descent.

Issues: (1) Measurement of neutrons will be less than accurate/ideal. (2) Establishing directionality of radiation is only marginally possible with the power and mass constraints.

(4) MANES: Martian Neutron Energy Spectrometer (was scheduled for Mars '03 Lander mission)

Goals:

- measure neutron energy spectra from 100 KeV to 50 MeV with the goal of extending the range from 20 KeV to 100 MeV, monitoring time variations over the Mars '03 Lander mission life;
- measure the fluence ratio of protons to alpha particles to heavy ions for comparison with MARIE data;
- measure gamma ray sources and depth in soil;
- compare measure neutron spectra to models propagating the incident cosmic ray spectrum through the Mars atmosphere and layers of soil;
- determine descriptors of carcinogenesis according to particle type, energy, and time;
- using models to determine results for radiation does and dose rates of concern, calculate dose, dose rate and dose equivalent, and dose equivalent rate expected on Mars.

(5) STEREO mission: To identify a solar event and warn crew to seek shelter in a timely way.

- Within four hours of solar event, there is a buildup of radiation (so human crew can be notified and seek shelter) (Note: After about eight hours after solar flare, humans will be exposed to about 10 rads/hr)

(6) Three satellites are presently doing GCR measurements

- ACR
- CRES
- SoHO

(7) RTD Franklin Chang-Diaz plasma propulsion project: Plans to rotate five types of materials in front of detector to measure the degradation by radiation.

(8) Dr. Walt Schimmerling's Strategic Plan (Code U) coverage of Radiation

POCs:

Frank Cucinotta, Dr. Walter Schimmerling, & Joe Kosmo (EVA) / JSC

Dr. John Wilson & Dr. Lisa Simonsen (radiation) & Dr. Charles Harris (materials)/LaRC

F. Crew Biomedical Concerns

Purpose: To ensure crew health maintenance, medical capabilities, and countermeasures during all mission phases and on return to Earth.

Note: The Bioastronautics Program Plan addresses all aspects of research and technology development. The following primary issues are addressed:

- Bone Loss
- Cardiovascular Alterations
- Human Behavior & Performance
- Immunology, Infection, & Hematology
- Muscle Alterations & Atrophy
- Neurovestibular Adaptation
- Radiation Effects (see the Radiation section of this report)
- Clinical Capability
- Other (e.g., nutrition; post-landing alterations)

Precursor Needs:

No precursors required (all R&D conducted on Earth) other than Radiation Effects (covered in the Radiation section).

POCs:

Dr. John Charles (biomedical & Bioastronautics Program Plan) & Frank Cucinotta (radiation)/JSC

G. Materials Assessments

Purpose: To measure the effects of the Martian orbital and surface environment on materials. The materials address multiple areas (e.g., vehicle structures and habitats; TPS).

Note: Details of materials technology requirements are given in the Materials Technology Roadmap in DPT Technology Package. Materials Technology Demonstrations will be conducted within the Materials Technology Roadmap activities.

Precursor Needs:

- (1) Reactive soil effects on materials (surface)
- (2) Short and long term corrosion and abrasion effects on materials (including EVA suit materials) (orbital and surface)
- (3) Radiation effects on materials (see the Radiation section of this report) (orbital and surface)

Requires:

- (1) “LDEF-type” exposed materials (for ~18 months of exposure)
 - in Mars orbit, and
 - on the Mars surface

Issue: How to obtain the information from the exposed materials. Via: (1) camera on the spacecraft, to periodically send video imaging of the materials to Earth for review; (2) actually return the exposed materials to Earth for analysis.

POCs:

Dr. Charles Harris & Dr. John Wilson/LaRC

H. Micrometeoroid flux

Purpose: To collect data to enable modeling of the micrometeoroid flux at the Martian surface. This information is primarily required for site selection (for infrastructure emplacement and crew landing).

Note: The micrometeoroid flux at Mars is so low, it is not firmly established that these data are required.

Precursor Needs:

(1) Measurement of micrometeoroid flux at Martian surface over time.

Requires:

A mission similar to the Lunar Clementine Mission.

POCs:

Dr. William Kinard / LaRC

JSC/EX

?/U.Arizona

Technology & Systems Demonstrations

A. ISRU -- In Situ Resource Utilization

Purpose: To test technologies for and demonstrate engineering approaches to the production and use of Mars in-situ resources for O₂ and propellant production.

Note: This topic is covered in a DPT Technology Roadmap. All technology demonstrations should be conducted within the Mars In-Situ Resources Development Roadmaps.

Precursor Needs:

- (1) Propellant Production
 - demonstration scale
 - sample return scale
- (2) Cryogenic Liquifaction
- (3) Long-Term Cryogenic Storage
- (4) Propulsion Demonstration
- (5) N₂O, N₂, Ar production
- (6) End-to-end production
- (7) Propulsion test

Existing Relevant Information & Missions:

- (1) PROMISE: Production of Resources on Mars In Situ for Exploration (proposed for Mars Surveyor Lander '03)

Primary Objectives:

- Produce CH₄, CO, and O₂ for use as propellants
- Produce O₂, buffer gas (N₂ and Ar), and H₂O as life support consumables

Secondary Objectives:

- Use the O₂ generator to demonstrate energy storage, operating at night as a fuel cell running on stored methane and oxygen.
- Storage of propellant using a sorbent.
- Storage of consumables in gaseous form in inflatable bags.
- Deployment of inflatable structures using Mars-generated buffer gas.

The top priority for PROMISE is to store propellant by liquefaction using a cryocooler. Also, two additional options for PROMISE are: (1) Use compressed Mars CO₂ to collect airborne dust and measure the amount of water condensed on particles (PROMISE may also collect airborne dust for Earth return as part of the Athena science sample return package); and (2) collect engineering data (humidity and air velocity) to design plants for water extraction from the Martian atmosphere.

(2) MOD: Mars Organic Detector

Looks for signs of life and evaluation water inventory for In-Situ Resource Utilization; proposed for Mars '03 Lander

Designed to detect organic compounds in rock and soil samples on the Mars surface and to assess the biological potential of the planet. A Tunable Diode Laser (TDL) spectrometer component provides information on desorption and decomposition temperatures, release rates and quantities of H₂O and CO₂ that can be freed from the Martian regolith samples, which will help in the design of future resources for in-situ water extraction. MOD detects organic compounds at very low concentration levels (~100X more sensitive than the Viking instrumentation) and it can examine Martian sub-surface composition as well.

(2) MIP: Mars In-Situ Propellant Production Experiments

A set of five instruments planned to launch as a payload on the Mars surveyor 2001 Lander.

Primary Objectives:

- Test systems and technologies for in-situ resource utilization in the Martian environment.
- Verify the production of oxygen from the carbon dioxide in the Martian atmosphere.

Instruments:

- Oxygen Generation Subsystem: to produce propellant-grade, pure oxygen on Mars using carbon dioxide from the Martian atmosphere that has been gathered by the Mars Atmosphere Acquisition and Compression experiment.
- Mars Atmosphere Acquisition and Compression: capture carbon dioxide from the atmosphere of Mars (for use for breathing and for fuel).
- Mars Array Technology Experiment: to test the performance of advanced, low-mass solar cells on the Martian surface.
- Dust Accumulation and Repulsion Test: to prevent the degradation of solar array performance on the surface of Mars due to dust, by both measuring the loss of power caused by dust as well as testing methods for repelling dust.
- Mars Thermal Environment Radiator Characterization: to provide data to enable understanding of how radiators perform on Mars.

B. Aeroassist Technology and Capabilities

Purpose: To gather relevant information and to demonstrate aeroassist technologies, capabilities, and engineering approaches, including aerocapture, orbit, entry, and precision landing with active hazard avoidance, advanced TPS, vehicle structures, and GNC, within the Martian environment.

Note: This may be covered by a DPT Technology Roadmap under 2.5 Space Transportation. There was no 2.5 Space Transportation Technology Roadmap for review.

Precursor Needs:

- (1) Precision landing with active hazard avoidance / Aerodynamics
 - NASA has traditionally mispredicted aerodynamics. Vehicle shapes for Mars are more complex and NASA has little experience with them. Mars vehicle shape will most likely be based on a “Viking-type” shape (~1976). The “Viking shape” could withstand ~15-18g’s, obviously not acceptable for human missions, so research and technology development are required to modify/optimize the shape and understand the aerodynamics & aerothermodynamics.
 - Require: pressures; temperatures; flow fields and control surfaces; and accelerations
 - Instrumentation required: accelerometers; pressure tapes, pressures and temperatures along vehicle; IR cameras to show global temperatures, thermal couplers for local temperatures; measurements of control surfaces angles and vehicle flow fields.
- (2) GNC / Terminal navigation / Active guidance / Optical guidance
 - Instrumentation to send data to Earth from accelerometers and vehicle attitude data from IMUs
 - Demonstrate precision landing and hazard avoidance (choose particularly difficult landing target; JPL suggests “pinpoint landing” within TBD km (LaRC uses 3 km target range)
 - Examine parachute technologies: only other viable option (beyond engines & fuel) to decelerate during entry; parafoil is sub-optimal for Mars; provides potential for great inaccuracies (e.g., steady wind can blow vehicle severely off target)
 - Note: Mars ’05 Lander was to demo rudimentary precision landing and hazard avoidance, but would be landed in relatively safe area (aim is 3-4 km to target); rover gets to exact location
- (3) HEDS g-limited Entry Profile
- (4) Vehicle Structures / HEDS aeroshell definition ($0.3 < L/D < 1.0$) / Advanced TPS testing
 - Weight must be minimized to get to LEO
 - Demonstrate protection from radiation shielding materials
 - Demonstrate minimized TPS requirements
 - Instrumentation: strain gauges to measure thermal loads and internal forces
- (5) Advanced TPS

- Requires inexpensive and reliable multiuse TPS (required for both aerocapture and aeroentry)
 - Ablaters (heat shield takes heat by receding, or ablating, removing heat from behind) will be used (demonstrated technology from Apollo and robotic Jupiter missions)
 - Technology Demo: Test a subscale integrated TPS/Aeroshell article (~2006)
 - Technology Demo: Ablative TPS for planetary exploration vehicles; integrated TPS/aeroshell for operation to 2500 F (~2020)
- (6) Aerobraking
- (7) Vehicle structures issues:
- Building large heat shield in LEO?
 - Inflatables?

Information required:

- (1) Define L2 launch window from LEO (~1 month)
- (2) Determine required orbital maneuvers; use STK
- (3) Entry velocity at Earth from L2
- (4) Type of vehicle used for both Mars and L2 missions (e.g., X-38-like with parafoil, or with wings)
- (5) Steps to Earth return
 - aerocapture to LEO
 - pick amount of time to land back on Earth (e.g., if delay due to storms, etc., plan for 2-3 day delay in LEO)
 - bring entire vehicle down (with crew) or transfer crew to capsule, then bring capsule down, leaving vehicle in LEO
- (6) Atmosphere information required: density, time of day, winds (velocity and direction)
- (7) GNC: set of nav orbits to set IMUs (“Mars GPS” not required)

Proposed Pathfinder Aeroassist Precursor Missions for Mars Precision Landing: (POC: Dr. M.K. Lockwood/LaRC)

- (1) “Pathfinder X” ½ or 1/3 scale demonstration vehicle
 - Purpose: Demonstrate technology for aeroassist precision landing on Mars for human and robotic missions.
 - Perform a precision aerocapture at Mars and precision landing to Martian surface:
 - Aerocapture at Mars (not presently demonstrated; assume ~7 km/sec Mars atmosphere entry), acquire Mars orbit, send aero data back to Earth (to ensure some data capture), deorbit (based on Martian weather information?), land in a rocky field to test hazard avoidance maneuvers.
 - Aerocapture: non-propulsive hyperbolic entry orbit; aim for atmosphere point (margin of error depends on size and shape of vehicle; non-maneuverable capsule provides little margin for error)
 - Requires ~4 m vehicle size

- (2) Pathfinder X” full-scale demonstration vehicle (i.e., human sized, instrumented) prototype vehicle Pathfinder mission
- Demonstrate aeroassisted orbit and precision landing with active hazard avoidance on Martian surface
 - Team X/JPL have provided vehicle cost package

(3) Earth Return from L2 Demo Mission

- Different vehicle to deal with Earth atmosphere and higher velocities of entry (e.g., ~11 km/sec); assume winged vehicle/capsule
- Note: Compare Mars-Earth Return and L2-Earth Return velocities and choose the higher velocity for demonstration
- Demo includes aerobrake

Proposed Pathfinder Aeroassist Precursor Missions for L2 return to Earth Precision Landing: (POC: Dr. M.K. Lockwood/LaRC)

(1) “Pathfinder X” Mission for M

- Purpose: Demonstrate technology for aeroassist precision landing on Mars for human and robotic missions.
- Perform a precision aerocapture at Mars and precision landing to Martian surface:
 - Aerocapture at Mars (not been done), acquire Mars orbit, send data about aerocapture to Earth (to ensure some data capture), deorbit (based on Martian weather information?), land in a rocky field to test hazard avoidance maneuvers.
- Requires ~4 m vehicle size

Existing Relevant Information & Missions:

- Mars’05 was to have aeromaneuvering
- Vehicle would be more ‘aero’ capable than at present, can deal with wider variation in the Martian atmosphere. Little variation in flight path angle. Martian dust storms probably won’t affect unmanned missions. Surface weather sentinels are not required, but they would be used if they are present. Demos would predict pitching angle (NASA has typically been poor at this part of flight design). Provide true pitch control (e.g., with body flap). Vehicle roll provided by 3-axis RCS control.
- Present scenarios have parachute; would prefer to remove chutes (not as reliable, move vehicle away from landing target). Landing and approach will be fully automated (for robotic and human missions).
- Require enough L/D to place vehicle at specific target point.
- NASA & CNES proposed Mars sample return mission; CNES designed aerocapture orbiter and return vehicle; not required to design for precise path constraints or to test for g load constraints (as required for human mission); Orbiter to remain in high orbit, sample in low orbit; samples to slowly approach orbiter

POCs:

Claude Graves & Doug Cooke / JSC

Dr. Mary Kae Lockwood & Dick Powell / LaRC (aeroassist)

Mike Tauber (retired) / ARC (mars dust eroding TPS)
Judith Watson / LaRC (aeroshell structure)

C. Mars Surface Power Technology

Purpose: To demonstrate and test Mars surface power technologies and approaches via technology demonstrations and prototype systems within the Martian surface environment.

Note: This topic is covered in DPT Technology Roadmap 2.2 Space Power & Utilities. All technology demonstrations should be conducted within this Technology Roadmap.

Precursor Needs:

- (1) Advanced solar arrays
- (2) Control Electronics & Power Distribution
- (3) Compact Array Stowage/Deployment
- (4) Advanced, Low Temperature Energy Storage Demo
- (5) Solar Array Dust Mitigation Experiment

POCs:

Jeff Landis / GRC

JSC/EX

D. Advanced EVA Suit / EMU Technologies

Purpose: To test enabling technologies and demonstrate design approaches to the Mars Advanced EVA Suit/EMU in the Martian surface environment (including refurbishing, maintenance, and consumables management; and dust mitigation techniques)

Note: This topic is covered in the DPT Technology Roadmaps: 2.3 Habitation and Operations, 2.3.1 EVA). All technology demonstrations should be conducted within that Technology Roadmap.

Precursor Needs:

- EVA suit technology: Precursor mission information required by EVA suit technology is gathered under the following precursor categories: (1) Radiation, (2) Materials Assessments, (3) Atmosphere, & (4) Surface Characteristics. No EVA-specific precursor missions are required.

POCs:

Joe Kosmo & Gretchen Thomas (EVA)/JSC

JSC/EX

Greg Harbaugh(EVA)/JSC CB

E. Materials Technology Demos

Purpose: To demonstrate the use of selected advanced materials and engineering design approaches to solving materials-related problems within the Earth-Mars transit, Mars orbital, and Mars surface environments.

Note¹: This topic is to be addressed in a TBD DPT Technology Roadmap. A draft Materials Technology Roadmap is available (via Dr. Charles Harris/LaRC). All technology demonstrations should be conducted within the Materials Technology Roadmap.

Note²: Radiation effects on materials is addressed within the Radiation precursor topic.

Precursor Needs (and Technology Demonstrations, from the proposed Materials Technology Roadmap):

- Integration and flight demonstration of integrated communication and sensors for on-board health monitoring (~2005)
- Integration and flight demonstration of communication, sensor, data handling, and distributed control for smart on-board health management (~2010)
- Integration and flight demonstration of power, communication, sensor, data handling and distributed control for self-powered smart systems (~2015)
- Demonstration of integrated system with microthrust, power, communication, sensor, data handling and distributed control for smart deployable self-powered systems (~2020)

POCs:

Dr. Charlie Harris (materials)/LaRC

F. Dust Mitigation Technologies and Design Methods

Purpose: To demonstrate technologies (e.g., moving mechanisms) and design methods for the mitigation of Mars dust on personnel and supporting equipment (e.g., EMU), habitats, vehicles and rovers, and ground support systems (e.g., solar panels).

Note: This topic may be covered in the DPT Technology Roadmaps: 2.3 Habitation and Operations (including 2.3.1 EVA); 2.2.1 Solar Power Generation; and 2.3.4 Human Factors & Habitability. All technology demonstrations should be conducted within those Technology Roadmaps. Dust mitigation technologies and methods may need to be added to roadmaps for specific vehicles, rovers, and ground support systems.

Precursor Needs:

- (1) EVA suit technology: Precursor mission information required by EVA suit technology is gathered under the precursor categories Radiation, Materials Assessments, Atmosphere, & Surface Characteristics. No EVA-specific precursor missions are required. Dust mitigation techniques for Advanced EVA suits are included in the EVA technology roadmap.
- (2) Crew Habitation: see 2.3.1 Habitation Technology Roadmap and 2.3.4 Human Factors and Habitability (dust mitigation techniques needs to be added)
- (3) See 2.2.1 Solar Power Generation (dust mitigation techniques needs to be added to the technology roadmap)

Note:

- Data collected under early precursor missions may enable the construction of Earth-based “Mars simulation facilities”; issues such as dust mitigation techniques may be able to be addressed in these ground-based simulators and therefore wouldn’t require actual technology demonstration missions for proofs of concepts and design approaches.

POCs:

Joe Kosmo & Gretchen Thomas (EVA)/JSC

Greg Harbaugh(EVA)/JSC CB

JSC/EX

JSC (Human Factors and Habitation)

GRC/Solar Power

G. In-Space Transportation Demo to Mars

Purpose: To demonstrate new advanced technologies for crew and cargo in-space transportation methods and vehicle approaches.

Note¹: ETO transportation methods are not addressed in this topic; it is assumed ETO transportation technologies are developed within the Next Generation RLV Program.

Note²: In-Space Transportation is addressed within the TBD DPT Technology Roadmap 2.5 Space Transportation. All in-space transportation technology demonstrations should be conducted within the Materials Technology Roadmap.

Note³: Aeroassist technology demonstrations are addressed within the Aeroassist precursor topic in this report.

Precursor Needs: None

POCs:

Les Johnson/MSFC

Operations Information & Experience to Build Human Exploration Common Capabilities

A. Global Space Environment Forecasting (e.g., SPEs)

Purpose: To develop the operations experience and capabilities to enable global space environment forecasting in support of human exploration missions.

Note¹: Much of this operations experience and capability involves planned Code S Science missions to measure the space environment for modeling and for Earth early warning.

Note²: This topic should be blended with the Space Weather Monitoring/Sentinels Infrastructure Emplacement precursor topic.

Note³: Will this topic be included in the 2.3 Habitation and Operations Technology Roadmaps?

Precursor Needs:

- (1) Multiple spacecraft strategically placed (e.g., at Earth-Sun L1, L2, and L3 points) to collect data, image, and communicate a 3-D model of the global space environment to Earth and to Mars.
- (2) SPE forecasting capability, with communications to Earth and to Mars. Communication must be in a timely manner (time TBD) to enable the Mars crew to seek shelter if required.

Existing Relevant Information & Missions:

- (1) Living with a Star program
- (2)

POCs:

Dr. Richard Fisher (solar astronomy)/GSFC
Dr. George Withbrow
Dr. Harley Thronson/Code S/Hqtrs

B. Non-Contaminating Sample Collection

Purpose: To develop and demonstrate techniques for non-contaminating (both forward and backward) collection of Mars surface samples and their safe return to Earth.

Note¹: This is a broad engineering issue, not unique to manned missions (to Mars or elsewhere). That is, this issue needs to be addressed and the engineering and technology issues solved for robotic missions prior to human missions.

Note²: This issue may need to be represented in the DPT Technology roadmaps.

Precursor Needs:

There are no precursor missions required to support this task. It is expected that the engineering and technology issues involved will be solved on Earth and they do not require a robotic mission to test this sample return technology.

Existing Relevant Information & Missions:

POCs:

Dr. John Rummel/Planetary Protection Officer/Hdqtrs.

JPL

PHASE 2: HUMAN MISSION PREPARATION / INFRASTRUCTURE EMPLACEMENT

Purpose: To provide the physical and operational foundation at the destination (both on-orbit and on the surface) to support a crewed mission and ensure crew safety and mission success.

Precursor Mission Phasing: (from Jeff George/JSC EX)

- Mission 1: Mars “Diviner” Mission (multidisciplinary geophysical subsurface explorer) (~2,800 kg)
 - Primary Objectives: Locate groundwater; Perform subsurface mapping; Support site selection
 - Uses: Orbiter with improved radar sounder; Small geophysical landers (each ~60 kg) deployed at ~3-5 promising sites (perform seismic, radar, meteorology, & video analysis)
 - Product: Mars subsurface mapping; location of deep aquifers

- Mission 2: “Site Characterization and Preparation/Virtual Tourist” Mission (~3,011 kg)
 - Primary Objectives: Tour several candidate landing sites from Mars orbit and surface; Provide a detailed characterization of 3-5 candidate landing sites; Relay information to Earth for public engagement
 - Uses: Initial aerial reconnaissance of 3-5 sites using orbiter with improved radar sounder; extended duration “HEDS Utility” rover lands at high candidate surface site, identifies “clear” landing sites and marks with nav beacons; HDTV video returned; sample “cache” prior to crew landing

- Blend Missions 3 & 4? (~6,251 kg)
- Mission 3: “200 m Drill” Mission (~1,879 kg)
 - Primary Objectives: Demonstrate 200 m depth drilling through Martian surface; observe stratigraphy; obtain subsurface core samples; demonstrate drilling techniques; observe Mars subsurface water
 - Uses: Drill to 200 m down in Mars subsurface and obtain measurements through drillhole; retrieve and analyze core samples; store cores for later analysis or sample return; establish advanced solar power capability

- Mission 4: “Subsurface Sample Return” Mission (~3,000 kg)
 - Primary Objectives: Return multi-kg samples (each ~1 kg) from Martian subsurface; Demonstrate full end-to-end in-situ propellant production; Use propellant for return and regenerate fuel for rover; Perform downhole stratigraphy & water analyses
 - Secondary Objectives: Demonstrate HEDS-type aerobrake system and precision landing (TBD target distance)
 - Uses: ISPP plant producing propellant; acquire samples from drill or rover; develop advanced solar power capability

- Mission 5: “Mars’ Deep Aquifers and Search for Life” Mission

Primary Objectives: Reach and tap liquid groundwater zone; analyze samples for life; investigate Martian site geostructure and geochemistry; establish initial water and power oasis; store water cache in empty lander propellant tanks

Uses: Drill to ~4,000 m and perform investigations in drillhole; retrieve and analyze samples; initiate advanced nuclear or solar power capability

A. Orbit-Based Assets

1. Communications / Navigation Infrastructure (coupled to Mars Surface) / Mars Network

Purpose: To provide a full capability for communications between Earth and Mars and (1) during Earth-Mars transit, (2) from Mars orbit, and (3) from points on the Mars surface and communications between multiple points on the Martian surface. To provide navigation to vehicles (1) during Earth-Mars transit, (2) performing aeroassist maneuvers from Mars orbit to the Martian surface, and (3) on the Martian surface.

Precursor Needs:

- (1) Full motion video bandwidth demo (for remote medical purposes between Earth and Mars and between Mars surface locations)
- (2) Optical communications demo
- (3) Aerosynchronous satellites required?

Existing Relevant Information & Missions:

- (1) MARS Network: MicroSats (JPL) and MARSats (GSFC) Suite of communication and navigation capabilities planned to be replaced by Code S to support robotic exploration missions and future human exploration missions.
 - Possible future element of Mars Surveyor Program, designed to support Mars global reconnaissance, surface exploration, sample return missions, robotic outposts, and eventual human exploration by:
 - Developing a communications capability to provide a substantial increase in data rates and connectivity from Mars to Earth;
 - Developing an in situ navigation capability to enable more precise targeting and location information on approach and at Mars.
 - Secondary objectives to provide increased data rates and connectivity to enhance public engagement in Mars missions.
 - Architecture:
 - Constellation of multiple “Microsats” to serve as communications relays between Mars exploration elements (e.g., landers, rovers, balloons etc.) and the Earth, and as navigational aids for the exploration elements. Planned for 800 km altitude circular Mars orbit. Planned to have deep space transponder and pointed high-gain dish antenna for X- and Ka-band signals, a radio system operating in X-band (8.4 GHz) for Earth communications. For Mars communications, it is planned to have a UHF transceiver and one or more omni-directional antennas. Later MicroSats will carry a higher frequency Ka-band radio system.
 - Plans: Deployment of prototype Microsat tentatively scheduled for 2003, with one equatorial and one polar Microsat planned for each subsequent launch opportunity, providing an operational in situ navigation-capable three satellite MicroSat constellation by late 2005. A fully operational six-satellite constellation would occur by 2009. (JPL)

- One (or possibly more) large Mars Areostationary Relay Satellites or MARSats, very high bandwidth “aerostationary” communications satellites (like geostationary satellites in Earth orbit). Planned to add a MARSat to the MicroSat constellation in 2007 and a second one in late 2009.(GSFC)
- Using standard Internet communications protocol
- May further require over-the-horizon communications, high-fidelity sustained virtual presence, and high-rate two-way HDTV between Earth and Mars, providing the public a virtual presence on Mars.

POCs:

John Durning & Tim Rykowski / GSFC

B. Space Weather Monitoring “Sentinels”

Purpose: To develop and emplace the infrastructure to enable global space environment forecasting and communications to Earth and to Mars in a timely manner in support of robotic and human exploration missions.

Note¹: This capability will be provided by planned Code S Science missions to measure the space environment for modeling and for Earth early warning.

Precursor Needs:

- (1) Multiple spacecraft strategically placed (e.g., at Earth-Sun L1, L2, and L3 points) to collect data, image, and communicate a 3-D model of the global space environment to Earth and to Mars.
- (2) SPE forecasting capability, with communications to Earth and to Mars. Communication must be in a timely manner (time TBD) to enable the Mars crew to seek shelter if required.

Existing Relevant Information & Missions

- (1) Living with a Star Program

POCs:

Dr. Richard Fisher / GSFC

Dr. George Withbrow

B. Surface-Based Assets

1. Surface & Subsurface Drilling

Purpose: To test technologies for and demonstrate engineering design approaches to Mars surface drilling operations (including moderate depth drilling to ~2 m and depth drilling to ~10-20 m below the Martian surface). Drilling provides resources (e.g., liquid groundwater), Martian climate/geologic/hydrologic history, and samples for analysis, and supports the exploration for extinct and extant life.

Note: This topic is covered in the DPT Technology Roadmap, 2.1 Space Resources Development, 2.1.1 In-Situ Resource Excavation & Separation Technology Roadmaps. All technology demonstrations should be conducted within that Technology Roadmap.

Precursor Needs:

- (1) Moderate depth drilling demos (~2 m)
- (2) Depth drilling (~10-20 m)
- (3) Challenges: verifying location and distribution of subsurface water; remote operations; environment/climate; scarcity of water for “mud” during drilling; power; and mass

POCs:

Bret Drake & Jeff George/JSC

2. Mars Surface Weather Monitoring / Forecasting / Communicating

Purpose: To collect Mars surface weather and regularly communicate this information to the crew, in a timely manner, enabling them to take shelter if required. Particular attention should be paid to Mars winds and moving dust devils. To provide the crew with Mars surface weather monitors, capable of basic forecasting and communicating information over distance to the crew (for preparation purposes)

Precursor Needs:

(1) Multiple autonomous Mars surface meteorology ground stations, distributed in strategic locations across the Martian surface, with specific capabilities TBD. Must include capability to regularly communicate and send data to locations on the Mars surface and to Earth communications relay in Mars orbit (through Mars Network). Must have long term power capability.

(2) A Mars weather orbiter, with Earth and Mars communications capability?

Existing Relevant Information & Missions:

POCs:

JSC EX

3. Site Selection & Preparation

Purpose: To scout for potential Mars surface landing sites. To perform detailed geophysical analyses of identified downselected potential landing sites. To prepare landing site(s) for eventual human landing by emplacing navigation beacons.

Precursor Needs:

- (1) Early site selection precursor mission: performs geophysical measurements; aerial vehicles and scout rovers
- (2) Site characterization and preparation mission: uses HEDS utility rover (teleoperable and refuelable); scouts and lays landing beacons; camera analysis; seismic analysis; ground penetrating radar kit; sample containers
- (3) Deploy multiple small aero-capable landers from Orbiter (“mother-ship”) for close in aerial scouting and landing at potential sites

Existing Relevant Information & Missions:

POCs:

Jeff George / JSC

4. EVA and Surface Mobility / Rovers

Purpose: To provide the human crew with pressurized and unpressurized mobility across the Martian surface at TBD km distance and for TBD duration from the primary habitat area. To provide teleoperable & refuelable/rechargeable rovers for performing analyses and science exploration across the Martian surface in remote locations. EVA development is addressed in the Advanced EVA Technology Roadmap.

Precursor Needs:

- (1) HEDS Utility Rover: ~864 kg; teleoperable; refuelable; retrofitted for human operations; used to characterize Mars surface sites; may identify potential landing sites and mark with nav beacons; potential to retrofit for pressurized rover
- (2) Multiple rovers: distance, capabilities, pressurization, operating characteristics, & durations TBD.

Existing Relevant Information & Missions:

POCs:

Jeff George & John Connelly / JSC

5. Supply caches (e.g., food, potable water)

Purpose:

Precursor Needs:

- Cache contents and types TBD (includes potable water from Mars groundwater supply; O₂ from ISRU system)
- Self-contained remote field camp: small pressurized habitat, power system, support systems; may serve as temporary base camp at remote sites of interest; houses 2-4 crew for ~2-3 weeks; predeployable at remote site; accessed by rover; may also serve as contingency habitat

Existing Relevant Information & Missions:

POCs:

JSC EX

6. Power (Solar & Nuclear)

Purpose: To emplace and bring to operational status power generation facilities on the Martian surface prior to landing the human crew. Early power facilities will support Phase 2 precursor missions.

Precursor Needs & Objectives:

- Small Nuclear Power Module (~3,000 kg): provides constant power output
- Generate power safely and reliably (provides power first during Phase 2 infrastructure emplacement missions and during Phase 3 human landing missions)

Existing Relevant Information & Missions:

POCs:

??/GRC

7. Crew Habitat Pre-Deployment

Purpose: To emplace and bring to operational status the Mars crew habitat. Perform initial safing, checkout, and verification of habitat prior to crew landing (i.e., crew does not land until habitat systems are operational and verified).

Precursor Needs & Objectives:

- Small Nuclear Power Module (~3,000 kg): provides constant power output
- Generate power safely and reliably (provides power first during Phase 2 infrastructure emplacement missions and during Phase 3 human landing missions)

Existing Relevant Information & Missions:

POCs:

??/GRG