The following text is proposed to replace the current description of Goal IV in the document:

MEPAG (2008), Mars Scientific Goals, Objectives, Investigations, and Priorities: 2008, J.R. Johnson, ed., 37 p. white paper posted September, 2008 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/index.html.

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IV. GOAL: PREPARE FOR HUMAN EXPLORATION

<u>Introduction</u>

Goal IV refers to the use of robotic flight missions (to Mars) to prepare for the first human missions (or set of missions) to Mars. Robotic missions serve as logical precursors to eventual human exploration of space. In the same way that the Lunar Orbiters, Ranger and Surveyor landers paved the way for the Apollo Moon landings, a series of robotic Mars Exploration Program missions is charting the course for the future robotic-assisted human exploration of Mars.

It is obvious that preparing for the human exploration of Mars will involve precursor activities in several venues, including on Earth (e.g., in laboratories, in computers, and in field analogs), in low Earth orbit (including the International Space Station), and probably on nearby celestial objects such as the Moon and asteroids. Although all are important, the scope of this document is limited to precursor activity related to the Mars flight program. Connectivity between all of this precursor activity needs to be maintained separately.

Also recommended to be maintained separately is a technology demonstration roadmap which may utilize the above venues, as well as Mars itself, to prove critical technologies in a "flight-like" environment. Demonstrating technologies necessary to conduct a human mission to Mars is a necessary part of the forward path and can be considered complementary to the required science data cited in this document..

After the first human mission (or set of human missions) to Mars, many people believe that our goal will evolve to achieving sustained human presence on Mars. To give this a name, we refer to this as Goal IV+ (see also Drake et al., 2009). Note that some activities associated with Goal IV (preparation for the first crewed mission) may also support Goal IV+. Although Goal IV+ is a useful concept to help organize potential long-range thinking, it is so far in the future that it does not affect the near term Mars flight priorities, and it is not discussed further in this document.

<u>History, this revision</u>

The last major revision of Goal IV was in 2005, as the culmination of some concentrated planning carried out in 2004-2005 that was launched by the 2004 National Vision for Space Exploration. Two parallel MEPAG study teams prepared major reports (Beaty et al., 2005; Hinners et al., 2005) that became the foundation of Goal IV Objective A (a prioritized listing of the investigations and measurements of Mars needed to safely and effectively carry out the first human missin to Mars), and Goal IV Objective B (a roadmap of the demonstrations of critical technologies and establishment of martian infrastructure as part of the build up to the first human mission), respectively. More recently, a list of mission critical atmospheric measurements that would reduce mission risk and enhance overall science return that was previously carried in Goal II was added as Objective C.

The 2010 revision of Goal IV is based on analysis conducted over a period of about four months in 2009-2010 by Lim et al. (2010). It considers both (1) new scientific and exploration data about Mars and (2) planning information related to the Design Reference Architecture (DRA) 5.0 document which was released in late 2009.

- Objective A, which is organized into a prioritized list of investigations, has been updated. This structure is parallel to that of all of the objectives in Goals I, II, and III.
- Former Objective B has been removed, because it is not a good fit with the overall structure and purpose of the MEPAG Goals Document. The planning information contained in former Objective B is critical, as it consists of an integrated roadmap of the sequence of missions that establish the necessary technology and infrastructure that must be present before the first human landing. However, this roadmap is best maintained as a separate document in order to give it greater visibility. For example, the content formerly in Objective B was not something that could be prioritized in the same way that flight investigations can—to first order, EVERYTHING on a roadmap needs to be done and in a certain order. We recommend establishing this as an additional living "sister" document maintained by MEPAG. The periodic maintenance of this document will allow consideration of specific target dates as they evolve with time, and connection to specific NASA initiatives as they become available.
- Former Objective C, which relates to a set of atmospheric measurements, has been merged into Investigation IVA-1B ("Determine the atmospheric fluid variations from ground to >90 km that affect Aerocapture, Aerobraking, EDL and TAO including both ambient conditions and dust storms"). There was an unnecessary high degree of overlap between the two, and this resolves a complication in the logical structure.

Priorities

Goal IV addresses issues that have relatively specific metrics related to increasing the safety, decreasing the cost, and increasing the performance of the first crewed mission to Mars. In this respect, Goal IV differs significantly from Goals I-III, all of which relate to answering scientific questions. Priorities among the multiple investigations in Objective A were determined by first assessing the impact of new (since the last revision) data relevant to each investigation, followed by assessing the value of new precursor data against two criteria:

1. Impact of new precursor data on mission design
    - MISSION ENABLING: Data that engineers and designers absolutely need and could not reasonably perform a human Mars mission without (as bound by physics)
    - MAJOR: Data that would help greatly reduce cost or increase performance of major elements of the architecture and help meet the most important mission objectives
    - SIGNIFICANT: Data that could reduce cost, increase performance, help increase science return, or prevent "over-engineering

2. Impact of new precursor data on risk reduction.
    - LOSS OF CREW/ PUBLIC SAFETY
    - LOSS OF MISSION
    - LOSS OF MAJOR MISSION OBJECTIVE

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Lim, D., Tripathi, A.B., Beaty, D.W., Budney, C., Delory, G., Eppler, D., Kass, D., Rice, J., Rogers, D., and Segura, T. (2010), A reevaluation of the robotic precursor objectives and priorities related to preparation for the human exploration of Mars, 49 p. document posted March, 2010 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/index.html.

A. Objective. Obtain knowledge of Mars sufficient to design and implement a human mission with acceptable cost, risk and performance.

Investigations #1A-1B are judged to be of indistinguishable high priority.

1A. Investigation. Determine the aspects of the atmospheric state that affect aerocapture, EDL and launch from the surface of Mars. This includes the variability on diurnal, seasonal and inter-annual scales from ground to >80 km in both ambient and various dust storm conditions. The observations are to directly support enginnering design and also to assist in numerical model validation, especially the confidence level of the tail of dispersions (>99%).

Measurements:

a. Make long-term (> 5 martian year) observations of the global atmospheric temperature field (both the climatology and the weather variability) at all local times from the surface to an altitude >80 km. The global coverage needs observations with a vertical resolution ≤ 5 km as well as observations with a horizontal resolution of ≤ 10 km (the horizontal and vertical resolutions do not need to be met by the same observation). Occasional temperature or density profiles with vertical resolutions < 1 km between the surface and 20 km are also necessary (see "Assumptions" below).

b. Make global measurements of the vertical profile of aerosols (dust and water ice) at all local times between the surface and >60 km with a vertical resolution $\leq$ 5 km. These observations should include the optical properties, particle sizes and number densities.
c. Monitor surface pressure in diverse locales over multiple martian years to characterize the seasonal cycle, the diurnal cycle (including tidal phenomena) and to quantify the weather perturbations (especially due to dust storms). The selected locations are designed to validate global model extrapolations of surface pressure. The measurements need to be continuous with a full diurnal sampling rate > 0.1 Hz and a precision of 10^{-2} Pa [TBV]. Surface meteorological packages (including temperature, surface winds and relative humidity) and upward looking remote sounding instruments (high vertical resolution temperature and aerosol profiles below ~10 km) are necessary to validate model boundary schemes.
d. Globally monitor the dust and aerosol activity, especially large dust events, to create a long term dust activity climatology (> 10 martian years).

Assumptions:

- We have not reached agreement on the minimum number of atmospheric measurements described above, but it would be prudent to instrument all Mars atmospheric flight missions to extract required vehicle design and environment information. Our current understanding of the atmosphere comes primarily from orbital measurements, a small number of surface meteorology stations and a few entry profiles. Each landed mission to Mars has the potential to gather data that would significantly improve our models of the Martian atmosphere and its variability. It is thus desired that each opportunity be used to its fullest potential to gather atmospheric data. Reconstructing atmospheric dynamics from tracking data is useful but insufficient. Properly instrumenting entry vehicles would be required.

1B. Investigation. Determine if the martian environments to be contacted by humans are free, to within acceptable risk standards, of biohazards that may have adverse effects on the crew who may be directly exposed while on Mars, and on other terrestrial species if uncontained martian material is returned to Earth. Note that determining that a landing site and associated operational scenario is sufficiently safe is not the same as proving that life does not exist anywhere on Mars.

Measurements:

a. Determine if extant life is widely present in the martian near-surface regolith, and if the air-borne dust is a mechanism for its transport. If life is present, assess whether it is a biohazard. For both assessments, a preliminary desription of the required measurements is the tests described in the MSR Draft Test Protocol (Rummel et al., 2002). This test protocol will need to be regularly updated in the future in response to instrumentation advances and better understandings of Mars and of life itself.
b. Determine the distribution of martian special regions (see also Investigation IV-2E below), as these may be "oases" for martian life. If there is a desire for a human mission to approach one of these potential oases, either the mission would need to be designed with special protections, or the potential hazard would need to be assessed in advance.

Assumptions:

- It is assumed that for a human mission to the martian surface it will not be possible to break the chain of contact with Mars on the return journey. Thus, uncontained martian material would come back to the Earth's biosphere.
- Furthermore, it is assumed that if a surface mission has EVA activity, the astronauts will come into contact with uncontained martian material in the form of dust that enters their habitation environment.
- While a confirmation of extant life in either the near-surface regolith or globally circulating dust from in situ experiments would likely be deemed acceptable, by contrast an acceptable negative identification of similar properties could only be determined through returned sample analysis.
- The samples needed to test for dust-borne biohazards could be collected from any site on Mars that is subjected to wind-blown dust.
- At any site where dust from the atmosphere is deposited on the surface, a regolith sample collected from the upper surface would be sufficient--it is not necessary to filter dust from the atmosphere.

Rummel, J.D., Race, M.S., DeVincenzi, D.L., Schad, P.J., Stabekis, P.D., Viso, M., and Acevedo, S.E., editors. (2002) A Draft Test Protocol for Detecting Possible Biohazards in Martian Samples Returned to Earth [NASA=CP-20-02-211842], NASA Ames Research Center, Moffett Field, CA.

Investigations #2A-2E are judged to be of indistinguishable medium priority.

2A. Investigation. Characterize potential sources of water to support In Situ Resource Utilization (ISRU) for eventual human missions.

Measurements:

Hydrated minerals

a. High spatial resolution maps of mineral composition and abundance. ISRU power estimates depend on mineral composition because of the different heating needs to extract water from each mineral type.

b. High spatial resolution maps of physical properties of H-bearing materials. Mechanical properties affect ISRU power estimates because of different power needs to process rock, soil, cemented soils, etc.

c. In-situ measurements at the landing site chosen for the human mission: a) in-situ verification of mineral volume abundance within the upper meter of the surface, b) measurement of the energy required to excavate/drill the H-bearing material and c) measurement of the energy required to extract water from the H-bearing material.

Subsurface ice

d. High spatial resolution maps of subsurface ice depth and concentration within the upper 2 meters of the surface.

e. In-situ measurements at the landing site chosen for the human mission: a) in-situ verification of ice volume abundance within the upper 2 meters of the surface, b) measurement of the energy required to excavate/drill the H-bearing material and c) measurement of the energy required to extract water from the H-bearing material.

Atmospheric H-bearing trace gases

f. Higher spatial resolution maps of H-bearing trace gases within 2 meters of the surface.
g. Assessment of the temporal (annual, seasonal, daily) variability of these gases.

Additional Information:

Critical resources for DRA 5.0 are C, O, and H for both life support and ascent propellant. A key trade is the mass and power of the equipment needed to acquire and process these three commodities from martian sources compared to simply delivering them from Earth. The present state of knowledge from MGS, Mars Odyssey, MEx, MER, Phoenix and MRO are that H resources exist on Mars of sufficient quantity for ISRU. However, the understanding of the vertical and spatial distribution and the concentration of H in these resources is not sufficiently understood to be included in the latest DRA. DRA 5.0 was structured such that C and O would be obtained from the martian atmosphere and hydrogen would delivered from Earth.

It has been determined that additional reconnaissance and characterization of H resources could provide enough information to include H resource utilization in a future version of the reference architecture. Because of the significant mass that could be saved, H-ISRU could have substantial impact on mission affordability and duration.

At this time it is not known where human exploration on Mars may occur. However, a key implication is that delivery of high-mass ISRU processing equipment to a single site on Mars would likely cause future missions to return to the same site. Returning to a single site may not be in line with mission objectives and this must be taken into account.

For H-ISRU to be further considered and possibly incorporated into a future version of the reference architecture, the preceding measurements of H resources are recommended. These resource types were prioritized based on geological potential, ease of characterization, and likely latitudinal and/or planetary protection constraints on the mission. Note that subsurface liquid water and subsurface gas hydrates/clathrates were considered as potential H resources, however a) these theorized deposits have not yet been identified and b) their likely depths exceed ISRU access capabilities. Thus no measurements of these resource types are called for at this time.

Hydrogen resource types:

A. Hydrated minerals. Numerous deposits of hydrated silicate and sulfate minerals have been identified on Mars from spectroscopic measurements [e.g., Bibring et al. 2005]. These deposits are attractive candidates for ISRU because 1) they exist at the surface and therefore their spatial distributions are easy to constrain remotely, 2) they exist in a variety of locations across the globe and therefore provide many choices for mission landing sites, and 3) the low activity of water in these minerals precludes planetary protection issues. Limitations on existing measurements include: 1) uncertainty of volume abundance within the upper meter of the surface, 2) best available spatial resolution (~20 m/pixel) may not be sufficient for ISRU processing design, and 3) mechanical properties of H-bearing materials are not sufficiently constrained.

Measurements needed (deposits in equatorial regions are of highest priority):

B. Subsurface ice. Hydrogen measured at high latitudes by Mars Odyssey is likely in the form of subsurface ice [Boynton et al., 2002; Feldman et al. 2002; Mitrofanov et al. 2002]. In addition, theoretical models predict subsurface ice in some mid-latitude regions, particularly on poleward facing slopes [Aharonson and Schorghofer, 2006]. Indeed, ice at northern latitudes as low as 42° has been detected in fresh craters using high resolution imaging and spectroscopy. Based on observed sublimation rates and the color of these deposits, the ice is thought to be nearly pure with <1% debris concentration [Byrne et al. 2009]. Pure subsurface ice and other ice-cemented soil were also detected by the Phoenix mission [Smith et al., 2009]. Clearly subsurface ice deposits have ISRU po-

tential, but are ranked lower than deposits of hydrated minerals because 1) low-latitude ice deposits are currently thought to exist only in glacial deposits that are associated with high elevations and difficult topography, 2). Mid-latitude deposits have substantial overburden that would make mining difficult (and in some cases are also in areas of difficult topography), and 3). Although high-latitude ices exists in flat-lying deposits at or near the surface, these locations would cause severe thermal and other problems for the mission.

C. Atmospheric H-bearing trace gases (such as methane gas seeps and transient ground fogs of water). Elevated concentrations of transient methane have been observed in specific regions of Mars, suggesting the possibility of methane gas seeps [Mumma et al., 2009]. At the Phoenix landing site, ground-level water ice clouds were observed to form via sublimation in the early morning hours and would dissipate during the day [Whiteway et al., 2009]. These types of localized, elevated concentrations of H have ISRU potential. These are ranked lower than hydrated minerals and subsurface ice because 1) the concentrations are probably not high enough to satisfy mission H needs alone, and 2) they apparently only occur in limited areas and would therefore limit landing site choices. However, clearly more observations are needed to substantiate or refute these claims and to evaluate their ISRU potential.

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2B. Investigation. Characterize in detail the ionizing radiation environment at the martian surface, distinguishing contributions from the energetic charged particles that penetrate the atmosphere, secondary neutrons produced in the atmosphere, and secondary charged particles and neutrons produced in the regolith.

Measurements:

a. Identify charged particles from hydrogen to iron by species and energy from 10 to 100 MeV/nuc, and by species above 100 MeV/nuc.

b. Measurement of neutrons with directionality. Energy range from $\leq$10 keV to $\geq$100 MeV.
c. Simultaneous with surface measurements, a detector should be placed in orbit to measure energy spectra in Solar Energetic Particle events.

<u>2C. Investigation.</u> Determine the possible toxic effects of martian dust on humans.

<u>Measurements:</u>

a. Assay for chemicals with known toxic effect on humans. Of particular importance are oxidizing species (e.g., CrVI) associated with dust-sized particles. May require a sample returned to Earth as previous assays haven't been conclusive enough to retire risk.
b. Fully characterize soluble ion distributions, reactions that occur upon humidification and released volatiles from a surface sample and sample of regolith from a depth as large as might be affected by human surface operations. Previous robotic assays (Phoenix) haven't been conclusive enough to significantly mitigate this risk.
c. Analyze the shapes of martian dust grains with a grain size distribution (1 to 500 microns) sufficient to assess their possible impact on human soft tissue (especially eyes and lungs).

<u>2D. Investigation</u>. Assess atmospheric electricity conditions that may affect TAO and human occupation.

<u>Measurements:</u>

a. Measure the magnitude and dynamics of any quasi-DC electric fields that may be present in the atmosphere as a result of dust transport or other processes, with a dynamic range of 5 V/m-80 kV/m, with a resolution ΔV=1V, over a bandwidth of DC-10 Hz (measurement rate = 20 Hz)
b. Determine if higher frequency (AC) electric fields are present between the surface and the ionosphere, over a dynamic range of 10 uV/m – 10 V/m, over the frequency band 10 Hz-200 MHz. Power levels in this band should be measured at a minimum rate of 20 Hz and also include time domain sampling capability.
c. Determine the electrical conductivity of the Martian atmosphere, covering a range of at least 10^{-15} to 10^{-10} S/m, at a resolution ΔS= 10% of the local ambient value.
d. Determine the electrical conductivity of the ground, measuring at least 10^{-13} S/m or more, at a resolution ΔS of 10% of the local ambient value
e. Determine the charge on individual dust grains equal to a value of 10^{-17} C or greater, for grains with a radius between 1-100 μm
f. Combine the characterization of atmospheric electricity with surface meteorological and dust measurements to correlate electric forces and their causative meteorological source for more than 1 martian year, both in dust devils and large dust storms (i.e., may be combined with objective 1A. c.)

<u>2E. Investigation.</u> Determine the martian environmental niches that would meet the definition (as it is maintained by COSPAR) of "special region*". It is necessary to consider both naturally occurring special regions, and those that might be induced by the (human-

related) missions envisioned. Evaluate the vulnerability of any special regions identified to terrestrial biological contamination, and the rates and scales of the martian processes that would allow for the potential transport of viable terrestrial organisms to these special regions.

Measurements:

a. Map the distribution of naturally occurring surface special regions as defined by COSPAR (see note below). One key investigation strategy is change detection.
b. Characterize the survivability at the martian surface of terrestrial organisms that might be delivered as part of a human landed campaign, including their response to oxidation, desiccation, and radiation.
c. Map the distribution of trace gases, as an important clue to the potential distribution and character of subsurface special regions that cannot be directly observed either from the surface or from orbit.
d. Determine the distribution of near-surface ice that could become an induced special region via a human mission. Orbital and landed measurements may be required to characterize such properties as thermal conductivity, structure, composition (soil probes, heat flow, electromagnetics, GPR).

**Note: A Special Region is defined as "a region within which terrestrial organisms are likely to propagate, or a region which is interpreted to have a high potential for the existence of extant martian life. As of 2010, no Special Regions had definitively been identified, however as of this writing, HiRise has only covered 1% of the martian surface. It is presumed that the policy of protecting special regions from terrestrial contamination will continue into the era of human exploration.*

Additional Information:

In the previous Goal IV document, a series of terrestrial based activities were proposed to meet the investigation objectives. As an example, it was suggested that modeling experiments involving thermodynamics and geologic principles be applied to determine how organic material communicates from the surface into the subsurface. To remain consistent with other sections of this document, which only suggest measurements that will affect future flight opportunities to Mars, all of these previous suggestions have been removed in the 2010 Goal IV Objective A4 details.

3. Investigation. **Characterize the particulates that could be transported to hardware and infrastructure through the air (including both natural aeolian dust and other materials that could be raised from the martian regolith by ground operations), and that could affect engineering performance and *in situ* lifetime. Analytic fidelity sufficient to establish credible engineering simulation labs and/or performance prediction/design codes on Earth is required.**

Measurements

a. A complete analysis of regolith and surface aeolian fines (dust), consisting of shape and size distribution, density, shear strength, ice content and composition, mineralogy, electrical and thermal conductivity, triboelectric and photoemission properties, and chemistry (especially chemistry of relevance to predicting corrosion effects), of samples of regolith from a depth as large as might be affected by human surface operations.

b. Repeat the above measurements at a second site in different geologic terrane. Note this is not seen as a mandatory investigation/measurement.**
***Note: Significant data from MER (Opportunity and Spirit) and Phoenix has been obtained on both the regolith and dust in response to the above desired measurements.*

Additional Information:
Three primary anthropogenic dust raising mechanisms in order of increasing importance; astronaut walking, rover wheels spinning up dust, and landing and take-off of spacecraft.

The best means of control is to keep equipment exposed to dust/granular materials separate from the living areas of the habitat. Airlocks or similar attached storage areas are important in providing the space for maintenance of suits and other equipment. The role of tightly sealed connectors and covers to keep the dust out of the suit and the habitat is key. This emphasis on isolating exposed materials, complemented by the elimination of dust through cleaning, vacuuming, mesh floors, etc. and strict enforcement of maintenance procedures is seen as the primary approach to dust management.

A secondary line of defense is to avoid disturbing the dust in the first place and preparing areas where high traffic is anticipated (e.g., around the habitat) so that a stable and non-deteriorating surface could be maintained. Materials might be selected with dust-avoidance or dust control capabilities in mind, such as smooth surfaces and materials that are dust-repelling rather than dust-attracting.

4. Investigation. Determine traction/cohesion in martian regolith (with emphasis on trafficability hazards, such as dust pockets and dunes) throughout planned landing sites; where possible, feed findings into surface asset design requirements.

Measurements:

a. Determine vertical variation of *in situ* regolith density within the upper 30 cm for rocky areas, on dust dunes, and in dust pockets to within 0.1 g cm^{-3}.
d. Imaging of selected potential landing sites to sufficient resolution to detect hazards at the scale of rovers.