A reevaluation of the robotic precursor objectives and priorities related to preparation for the human exploration of Mars

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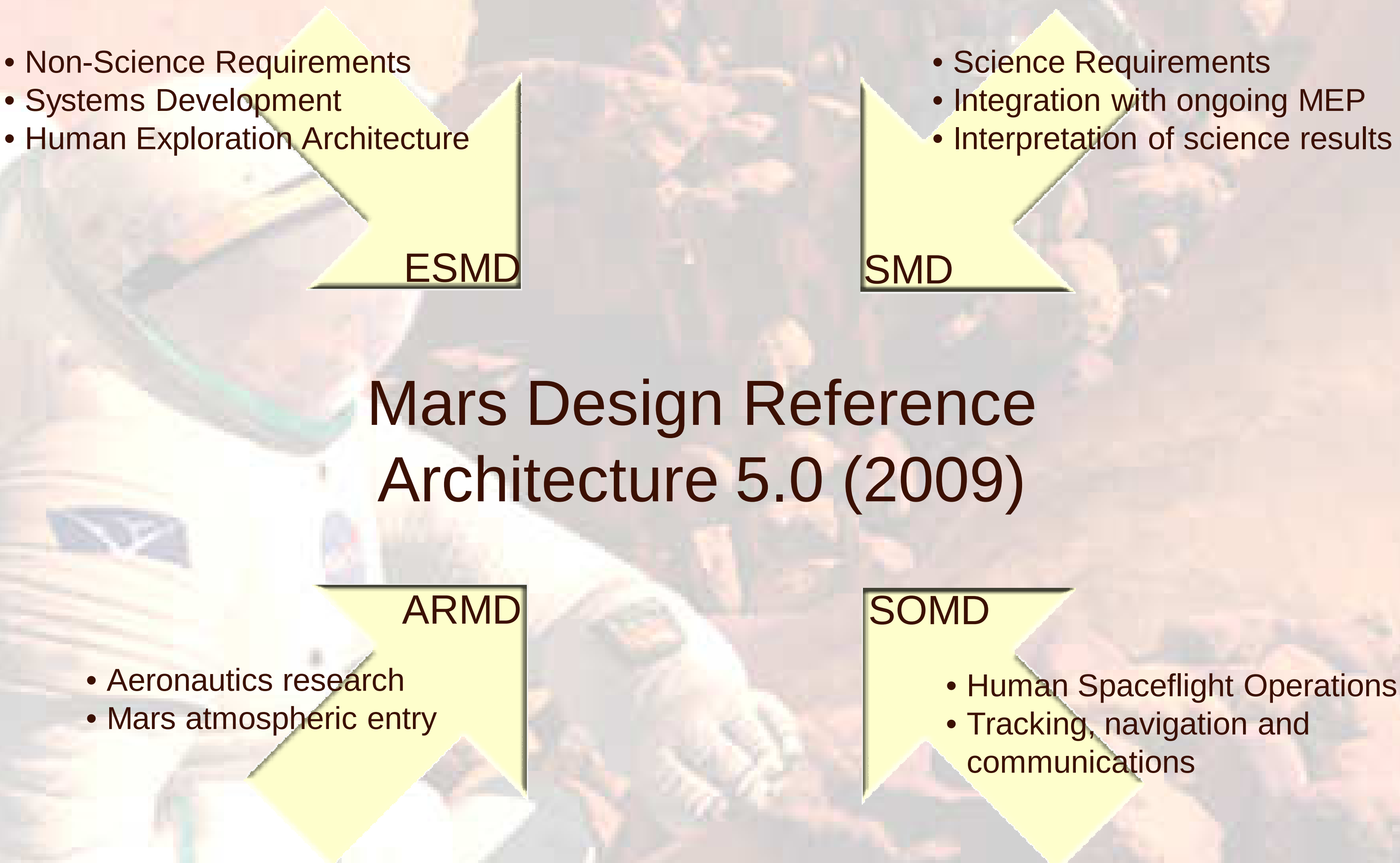
Goal IV Revision: Informed by Mars DRA 5.0 and MEP Results

- MEPAG held off updating Goal IV until DRA 5.0 was completed in 2009
- Goal IV members and selected subject matter experts reviewed new information (MER, Phoenix, etc.)
- Re-prioritization of investigations based upon latest inputs from Mars robotic missions and DRA 5.0 findings



AT16

Goal IV Organization Simplified and Reorganized

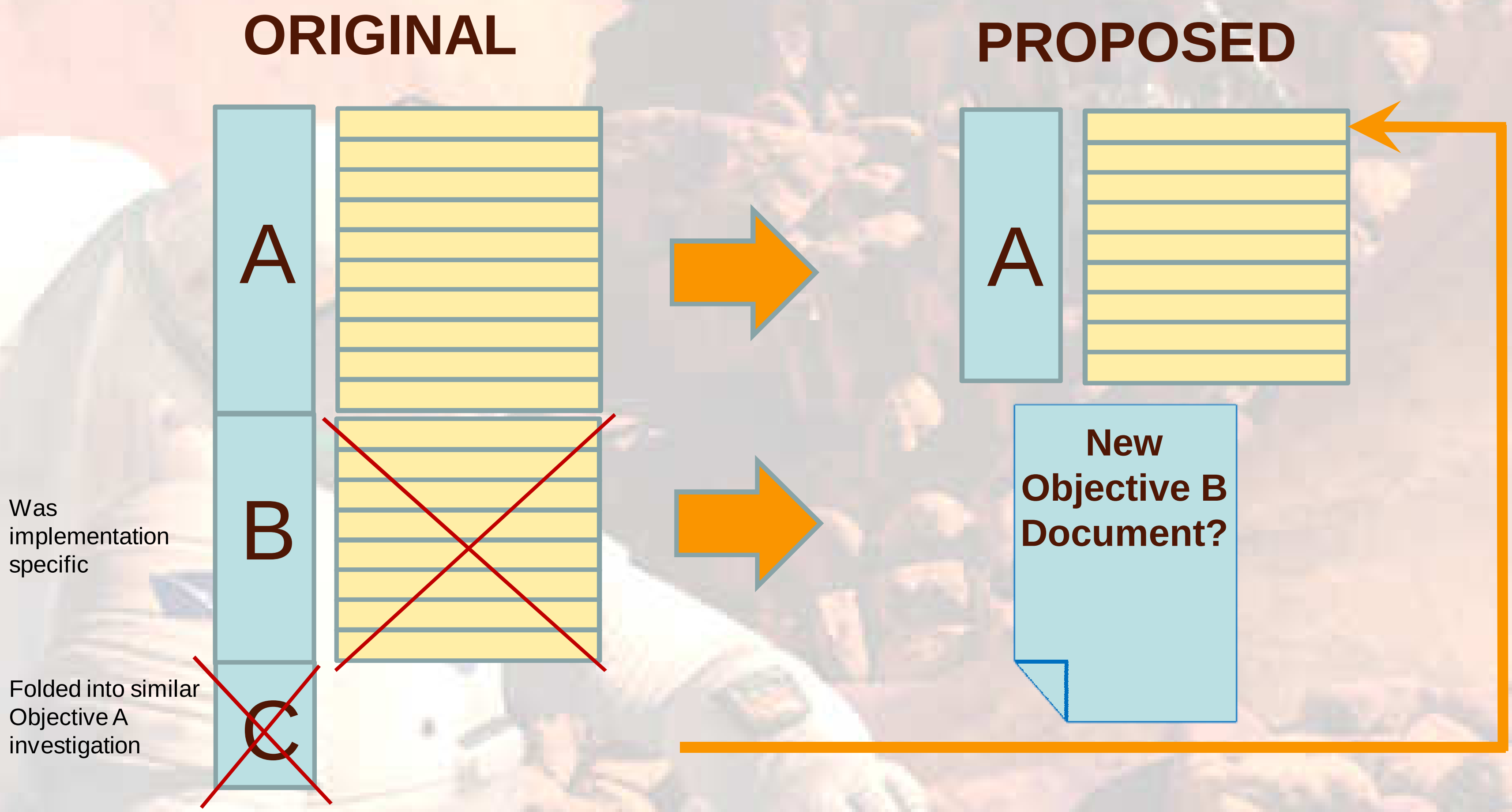
Former Objectives B and C have been **removed** from the 2010 Goal IV update for consistency and simplicity

- *Objective B: Conduct risk and/or cost reduction technology and infrastructure (T/I) demonstrations in transit to, at, or on the surface of Mars.*
  - This section formerly recommended specific technology demonstrations; implementation-specific recommendations are excluded from the other 3 MEPAG Goals
  - "Investigation" areas in *B* more closely resembled a technology demonstration roadmap
  - Goal IV committee recommends that an implementation-specific roadmap, with ties to Goal IV, is of high importance but should be captured in a new "sister" document
- *Objective C: Characterize the State and Processes of the Martian Atmosphere of Critical Importance for the Safe Operation of Both Robotic and Human Spacecraft*
  - Content pulled into the similar new Objective A-1A ("Determine the atmospheric fluid variations from ground to >90 km that affect Aerocapture, Aerobraking, EDL and TAO including both ambient conditions and dust storms")
  - Re-write of Objective A-1A included conversations with human spacecraft EDL experts

Slide 4

AT16 Sensetivity about Objective C
Abhi Tripathi, 3/3/2010

Quick-look Reorganization of Goal IV



MEPAG Goal IV 2010 Revision
New Data Since 2004

Ref. #	Short Title	Data Obtained since 2004
1A	Effect of dust on surface systems	MER and PHX: data on dust properties and dust accumulation rates and effects on mechanical surface systems
1B	Atmospheric Measurements	New engineering studies of human class (40t) aerocapture and landing systems significantly change required precursor observations; TES and MCS data has been useful but insufficient
1C	Biohazard and back planetary protection	No new investigations
1D	ISRU	Spectroscopic and morphologic data from ODY, MEX, MER, MRO, and telescopic observations indicate potential for Hydrogen ISRU
2	Effects of dust on human health	Surface Chemistry and Perchlorate data from MER, PHX
3	Atmospheric electricity	No new mitigating data (via ground based observations)
4	Forward planetary protection	Planetary-scale imaging from ODY, MEX, and MRO integrated into SR-SAG analysis
5	Radiation	No new mitigating data
6	Trafficability	MER and HiRISE: data from tracks and trenches through various surface materials (angles of internal friction and regolith cohesion); rover scale hazards from orbit and angle of repose measurements on various loose sedimentary deposits
7	Effect of dust storms	MER observations combined with orbital weather monitoring

DATA/INFO RELEVANT TO SEVERAL INVESTIGATIONS HAS BEEN COLLECTED

Evaluation Considerations

1. What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?

2. What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?

MEPAG Goal IV 2010 Revision
Impact of New Data on Prioritization

Ref. #	Short Title	Original Priority	Comments/Observations	G4-SAG POC
1A	Effect of dust on surface systems	HIGH	Priority has dropped because increased knowledge from MER and PHX	Rice/ Budney
1B	Atmospheric measurements	HIGH	New engineering studies emphasize need for atmospheric data to improve Loss of Crew and Loss of Mission prob. for Aerocapture/EDL	Kass
1C	Biohazard and back planetary protection	HIGH	No new data; Putative risk of back contamination remains unconstrained by data.	Lim/ Segura
1D	ISRU	HIGH	H-ISRU Not utilized in DRA 5.0 due to low TRL of associated tech. Reduction in IMLEO could be mission enabling and limited data on its potential exists	Rogers/ Tripathi/Beaty
2	Effects of dust on human health	MEDIUM	Recent data only reduced risk slightly. Difficult to retire risk through remote investigation only	Tripathi/ Rice/Eppler
3	Atmospheric electricity	MEDIUM	Some indication of atmospheric electricity from remote measurements, but not conclusive enough to impact G4 measurement requirements	Delory
4	Forward planetary protection	MEDIUM	"Special Regions" policy (as defined by COSPAR) is new and needs to be incorporated	Lim/ Segura
5	Radiation	LOW	No new data; MSL will assess risk due to GCRs. Due to solar variability and lack of an orbital reference, MSL may not effectively assess risk from SEPs	Delory
6	Trafficability	LOW	MER has contributed to better understanding. HiRISE also contributing relevant data	Rice/ Budney
7	Effect of dust storms at ground level	LOW	Main questions have been retired using MER data	Rice/ Budney

NO NEW INVESTIGATIONS HAVE BEEN IDENTIFIED

Former Investigation Reference Number: IVA-1A
2010 Updated Reference Number: 2C
Effect of dust/granular material

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - Allow mitigations to be designed to reduce the risk of adverse effects on engineering performance and *in-situ* lifetime

2. *What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?*
   - 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.*

Former Investigation Reference Number: IVA-1B
2010 Updated Reference Number: 1A
Atmospheric Measurements

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - Would reduce risk (pLOC and pLOM) for aerocapture, EDL and Mars launch by improving knowledge of environments
     - Provide validation for numerical atmospheric models
     - Observations and models provide the atmospheric constraints for engineering design that would reduce risk to crew and cargo during critical mission phases

2. *What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?*
   - Global measurements of the atmospheric temperature and aerosol profiles. Coverage from surface to ~80 km, at 5 km vertical and 10 km horizontal resolution over multiple Mars years and at multiple local times.
   - Global surface pressure measurements capturing seasonal, diurnal and meteorological variability.
     - Surface and near surface measurements of temperature, aerosols and winds will be useful for model validation.
   - Global climatology of dust storm occurrence
   - High resolution (~1 km) density profiles below 20 km

Former Investigation Reference Number: IVA-1C
2010 Updated Reference Number: 1B
Biohazard and Back Planetary Protection

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - The acquisition of data relevant to better understanding, explaining, and managing the putative human health risk associated with back planetary protection would have a beneficial effect on reducing risk
   - An example of relevant data would include the determination of whether extant life is widely present in the Martian near-surface regolith, and if the air-borne dust is a mechanism for its transport.

2. *What specific parameters need to be measured using the robotic flight program (and this includes MSR), and to what degree of accuracy and precision, in order to realize this benefit?*
   - Sample return of martian dust and regolith to assess if
     - Extant life is widely present in the Martian near-surface regolith, and if life is present, assess whether it is a biohazard.
     - Extant life is present in the globally circulating dust and if life is present, assess whether it is a biohazard.
   - For both assessments, the required measurements are the tests described in the Draft Test Protocol.

Former Investigation Reference Number: IVA-1D
2010 Updated Reference Number: 2A
ISRU

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - Significantly reduce the masses required for round trip travel to Mars, provided adequate power and infrastructure
   - C- and O- ISRU would be enabling; Hydrogen ISRU may have major positive performance impact (reduction of Initial Mass in Low Earth Orbit)

2. *What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?*
   - High resolution spatial maps of:
     - Mineral composition and abundance and corresponding physical properties
     - Subsurface ice abundance and corresponding physical properties
     - Trace gas abundance and temporal variability
   - At site of manned mission, *in situ* measurements of:
     - Mineral composition and abundance, vertically resolved, and corresponding physical/mechanical properties
     - Subsurface ice abundance, vertically resolved, and corresponding physical/mechanical properties

Former Investigation Reference Number: IVA-2
2010 Updated Reference Number: 2C
Toxic effects of Martian dust on humans

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - Quantifies health risk that dust might pose and helps inform system design to mitigate this risk (pLOC) throughout mission
   - The potential for both chronic (like silicosis) and acute effects should be addressed

2. *What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?*
   - Determine if there are hazardous levels of CrVI concentrations in dust (thus far only found at toxic levels in some rocks, not soil)
   - Further investigate oxidized forms of chlorine and sulfur and determine their abundance in dust
     - Phoenix conducted investigation of perchlorates but continued investigation is needed
   - Subject Matter Expert communicated that a thorough understanding of dust toxicity is difficult via remote robotic investigations which are incapable of applying the level of rigor needed to quantify this risk most effectively

Former Investigation Reference Number: IVA-3
2010 Updated Reference Number: 2D
Atmospheric Electricity

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - Would reduce the risk of damage to crew or mission elements from atmospheric electricity during landing, takeoff, and operations on the surface.
   - Could avoid the cost and complexity of implementing mitigations for discharges landing/launch craft and surface systems (suits, equipment, communications gear, etc)
   - If hazard is present, measurements would constrain the degree of mitigation necessary

2. *What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?*
   - Atmospheric electric fields, conductivity of ground and atmosphere, dust properties
     - DC E-fields: 5 V/m-80 kV/m, ΔV=1 V, bandwidth 0-10 Hz, rate = 20 Hz
     - AC E-fields: 10 uV/m – 10 V/m, bandwidth 10 Hz-200 MHz, rate = 20 Hz
     - Atmospheric Conductivity: 10^{-15} to 10^{-10} S/m, ΔS = 10% of local ambient value
     - Ground Conductivity: >10^{-13} S/m, ΔS= 10% of local ambient value
     - Grain charge: >10^{-17} C, grain radius: 1-100 mm, simultaneously with meteorological measurements for a period of 1 Mars year.

Former Investigation Reference Number: IVA-4
2010 Updated Reference Number: 2E
Forward Planetary Protection

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - Informs mitigation strategy that would reduce the risk of contamination
   - Minimize biological contamination of specific areas on Mars to preserve major program science objective of looking for Martian life

2. *What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?*
   - Map the distribution of naturally occurring surface special regions as defined by COSPAR (see note below). One key investigation strategy is change detection.
   - 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.
   - 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.
   - 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).

Former Investigation Reference Number: IVA-5
2010 Updated Reference Number: 2B
Radiation

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - Measurements would help to characterize potential health risks posed by ionization radiation encountered by the crew during long term surface stays
   - Measurements would determine the type and amount of shielding required to protect the crew (i.e., habitat design)
   - Assuming robust space weather infrastructure and safe shelter, radiation risk during Earth-Mars-Earth transit phase could be mitigated without further precursor data

2. *What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?*
   - Properties of energetic charged particles that penetrate the atmosphere, and their secondaries, including neutrons, from both the atmosphere and the regolith
     - Identify charged particles from hydrogen to iron by species and energy from 10 to 100 MeV/nuc, and by species above 100 MeV/nuc.
     - Measurement of neutrons with directionality. Energy range from <10 keV to >100 MeV.
     - Simultaneous with surface measurements, a detector should be placed in orbit to measure energy spectra in Solar Energetic Particle events.

Former Investigation Reference Number: IVA-6
2010 Updated Reference Number: 4
Trafficability

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - MER missions have provided useful data about angles of internal friction and regolith cohesion
   - Ability to identify soft material could prevent rover from getting bogged down.
   - Orbital identification of hazards at the rover scale would allow efficient planning of surface traverses.

2. *What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?*
   - 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}.
   - Imaging of selected potential landing sites to sufficient resolution to detect hazards at the scale of rovers.

Former Investigation Reference Number: IVA-7
2010 Updated Reference Number: N/A
Properties of dust storms affecting EVA

1. *What is the specific way in which precursor knowledge would have a beneficial effect on reducing risk?*
   - Inform design to allow crew and critical equipment to avoid the hazard
   - Properly plan number and length of EVAs (cost savings)

2. *What specific parameters need to be measured using the robotic flight program (including analysis of returned samples), and to what degree of accuracy and precision, in order to realize this benefit?*
   - Atmospheric opacity measured on MER; MER operations continued even during the worst dust storms
   - Main remaining risks are due to dust affecting suits and potential of danger from atmospheric electrical discharges.
     - Dust affects covered in Investigation IVA-1A
     - Atmospheric electricity covered in Investigation IVA-3

RECOMMEND DELETING AS AN <u>INDEPENDENT</u> INVESTIGATION

Additional Prioritization Criteria

IMPACT OF NEW PRECURSOR DATA ON MISSION DESIGN

1 = MISSION ENABLING

2 = MAJOR – significant cost savings or performance improvement; enables major objective(s)

3 = SIGNIFICANT – increases margins (safety, cost, mass, performance), efficiency, or science return

IMPACT OF NEW PRECURSOR DATA ON RISK REDUCTION

1 = LOSS OF CREW/ PUBLIC SAFETY

2 = LOSS OF MISSION

3 = LOSS OF MAJOR MISSION OBJECTIVE

lower number = higher ranking

PRIORITY RANKING

Prioritization Criteria
Impact of New Precursor Data on Mission Design

1. Enabling: Data that engineers and designers absolutely need and could not reasonably perform a human Mars mission without (as bound by the laws of physics)

2. 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

3. Significant: Data that could reduce cost, increase performance, help increase science return, or prevent “over-engineering” of systems

Prioritization Criteria
Impact New Precursor Data on Risk Reduction

1. Loss of Crew/Public Safety: Data that contributes to lowering the probability of the loss of crew (pLOC) or that better quantifies a putative risk to the general public
   - Example: Data about atmospheric variability would help prevent an EDL system failure for the crewed vehicle
   - Example: Data that would help reduce the putative risk of planetary back-protection

2. Loss of Mission: Data that contributes to lowering the probability of the loss of a mission (pLOM)
   - Example: If we don't gather enough data to successfully implement ISRU, then the pre-deployed ISRU asset(s) would fail, thus ending the entire mission

3. Loss of Major Mission Objective
   - Example: Quantifying the effect of dust on major surface systems (pressurized surface rover) would help designers prevent those surface systems from failing and ending the ability to meet major mission objectives

MEPAG Goal IV 2010 Revision
Applied Prioritization Criteria

Former Ref. #	Short Title	Impact of Data on Design	Impact of data on Risk Reduction	Δ	New Priority	New Ref. #
1B	Atmospheric measurements	1	1	↔	HIGH	1A
1C	Biohazard and back planetary protection	2	1	↔	HIGH	1B
1D	ISRU	2	2	↓	MEDIUM	2A
5	Radiation	3	1	↑	MEDIUM	2B
2	Effects of dust on human health	3	1	↔	MEDIUM	2C
3	Atmospheric Electricity	3	1	↔	MEDIUM	2D
4	Forward planetary protection	2	3	↑	MEDIUM	2E
1A	Effect of dust on surface systems	2	3	↓	LOW	3
6	Trafficability	3	3	↓	LOW	4
~~7~~	~~Effect of dust storms at ground level~~	-	-	↓	DELETE	-

NEW PRIORITY ORDER OF INVESTIGATIONS AS RECOMMENDED BY GOAL-IV COMMITTEE

Goal IV Revision & 2011 Proposed NASA Budget

Goal IV Investigations remain consistent with the new direction for NASA as outlined in the 2011 budget request

- Cancellation of Constellation program does not significantly impact Goal IV
  - Precursor measurement objectives are still required for any future human exploration of Mars
  - Most DRA 5.0 major trade study results were architecture independent

- $3.0B outlined for robotic precursor missions over 5 years
  - A new, sustained set of missions could address many of the investigations cited in Goal IV
  - Increased potential for Exploration Systems Mission Directorate (ESMD) participation

- Current goal IV revision is consistent with some “flexible path” options for human exploration

Goal IV: Synthesis by Platform

1. **Investigations from Orbit** (listed in approx. priority order)

- **Atmospheric data for large system EDL**. Global measurements of the atmospheric temperature and aerosol profiles. Coverage from surface to ~80 km, at 5 km vertical and 10 km horizontal resolution over multiple Mars years and at multiple local times. Also, high resolution (~1 km) atmospheric density profiles below 20 km.
- **Water-based ISRU potential**. High resolution spatial maps of Mineral composition and abundance and corresponding physical properties [10 m/pixel] to assess ISRU potential and to plan accordingly.
- **Special region distribution**. Map the distribution of naturally occurring surface "special regions" (as defined by COSPAR) . Detect surface changes to 'special region(s)', improve planetary coverage of high-resolution orbital surface characterization data,
- **Subsurface ice**. Determine the distribution of subsurface ice (and perhaps other kinds of relevant deposits) that could either become an induced special region via a human mission, or a natural resource for that mission.
- **Dust storm hazard**. Global climatology of dust storm occurrences.
- **Radiation hazard**.(Simultaneous Orbital and Landed) Measure the properties of energetic charged particles that penetrate the atmosphere, and their secondaries, including neutrons, from both the atmosphere and the regolith.
- **Landing site safety**. Imaging of selected potential landing sites to sufficient resolution to detect hazards at the scale of rovers.
- **Trace gases**. Map the distribution of trace gases and their temporal variability (for special region and ISRU interest)

Goal IV Synthesis by Platform

2. **Investigations from a Single Lander or Rover** (listed in approx. priority order)
   - **Atmospheric data for large system EDL**.
     - High resolution (~1 km) atmospheric density profiles below 20 km
     - Surface and near surface measurements of pressure, temperature, aerosols and winds will be useful for model validation.
   - **Water-based ISRU potential**. At potential site of manned mission, *in situ* measurements of:
     - » Mineral composition and abundance, vertically resolved, and corresponding physical/mechanical properties
     - » Subsurface ice abundance, vertically resolved, and corresponding physical/mechanical properties
   - **Atmospheric electricity**. Atmospheric electric fields, conductivity of ground and atmosphere, dust properties
   - **Radiation hazard**. (Simultaneous Orbital and Landed) Properties of energetic charged particles that penetrate the atmosphere, and their secondaries, including neutrons, from both the atmosphere and the regolith
   - **Trafficability hazard**. 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}.
   - **Special Region protection**. Determine how any organic material (if found) communicates from the surface into the subsurface

Goal IV Synthesis by Platform

3. Investigations from a Landed Network

- **Atmospheric data for large system EDL**. Global surface pressure measurements capturing seasonal, diurnal and meteorological variability.
  - Surface and near surface measurements of temperature, aerosols and winds will be useful for model validation.

Goal IV Synthesis by Platform

4. **Investigations involving the analysis of returned samples** (listed in approx. priority order)
   - **Back Planetary Protection**. Analyze martian dust and regolith to assess if
     - Extant life is widely present in the Martian near-surface regolith, and if life is present, assess whether it is a biohazard.
     - Extant life is present in the globally circulating dust and if life is present, assess whether it is a biohazard.
   - **Dust hazard**. 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.
   - **Toxicity of martian environment to humans**. Determine if there are hazardous levels of
     - CrVI concentrations in dust (thus far only found at toxic levels in some rocks, not soil)
     - Further investigate oxidized forms of chlorine and sulfur and determine their abundance in dust