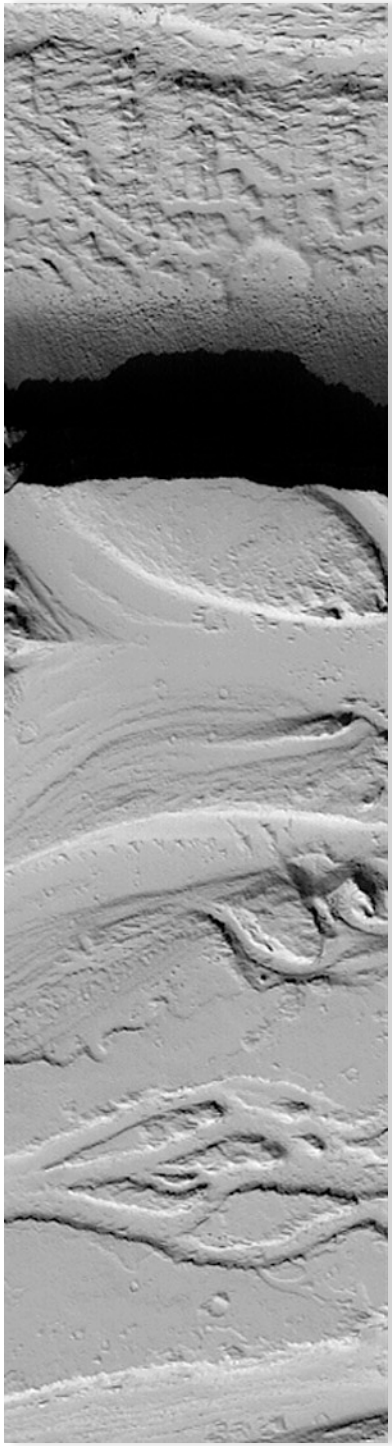


Planetary Protection Constraints on MSL Landing Sites

5th MSL Landing Site Workshop

John D. Rummel

East Carolina University USA

17 May 2011

Basic Planetary Protection Policy

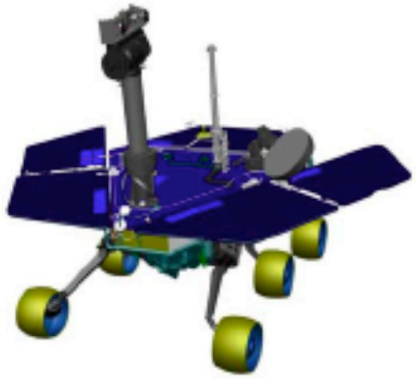
(NASA, COSPAR: Paraphrased)

- Preserve planetary conditions for future biological and organic constituent exploration
  - *avoid forward contamination; preserve our investment in scientific exploration*
- To protect Earth and its biosphere from potential extraterrestrial sources of contamination
  - *avoid backward contamination; provide for safe solar-system exploration*

Comply with Article IX of the Outer Space Treaty of 1967

Evolution of MSL

Sojourner



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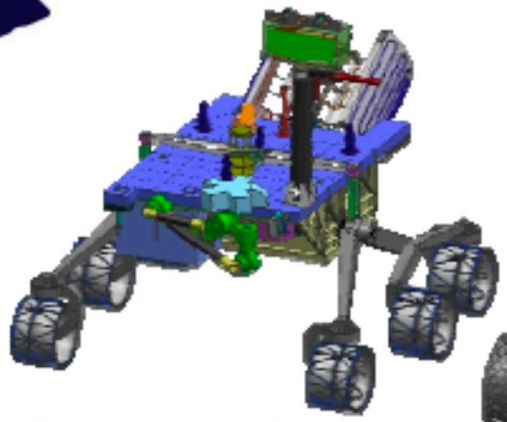
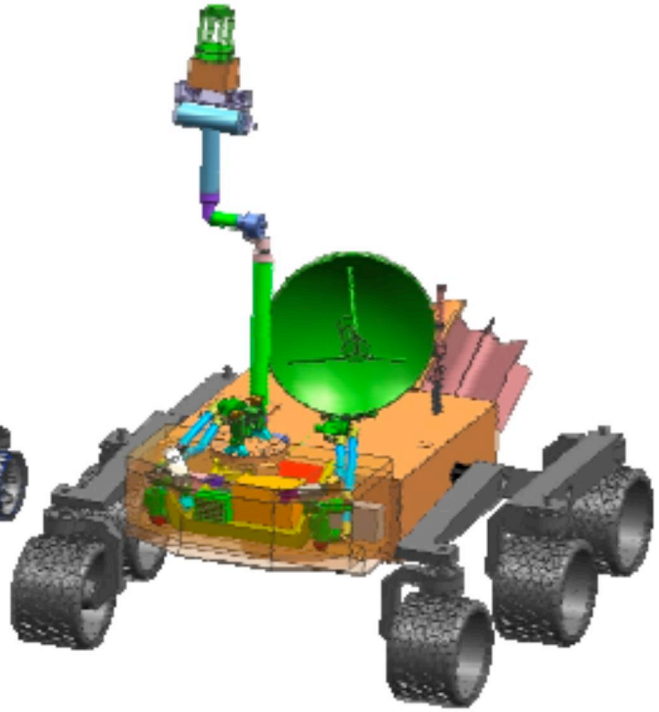
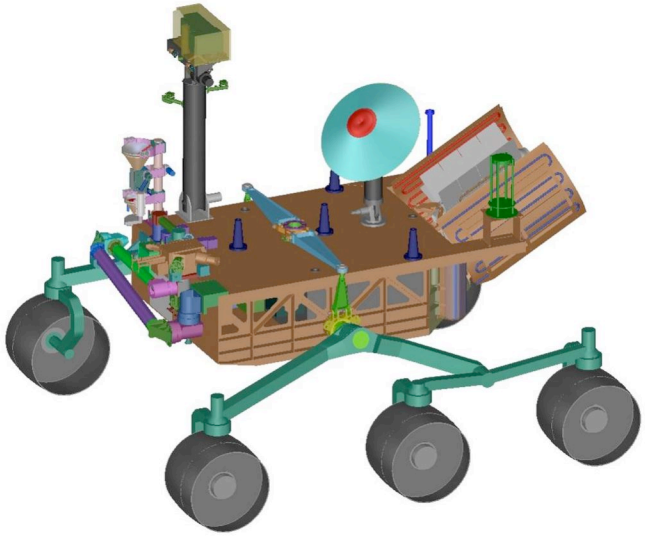


MSL – Dec 2004

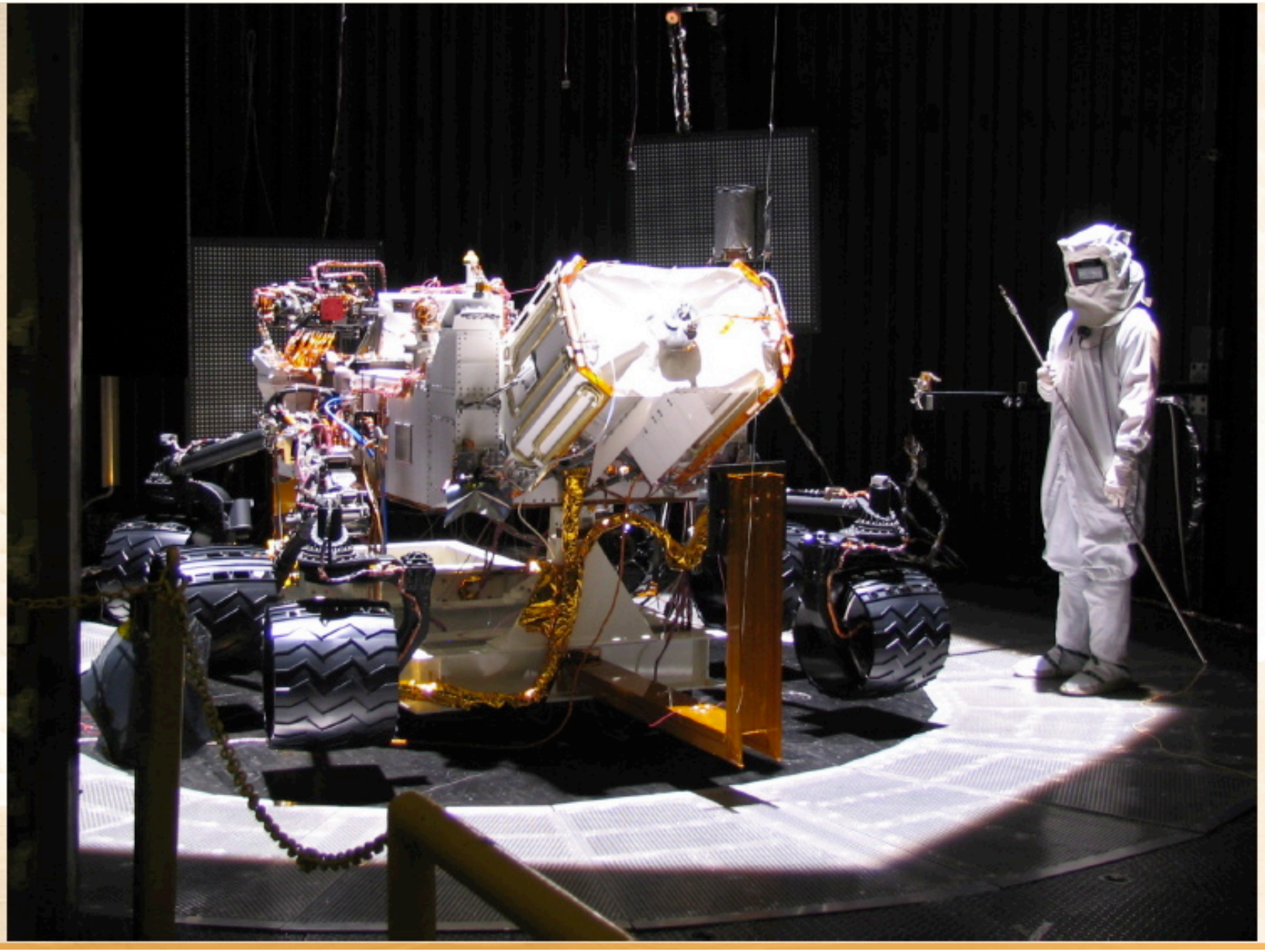


MSL – Oct 2003

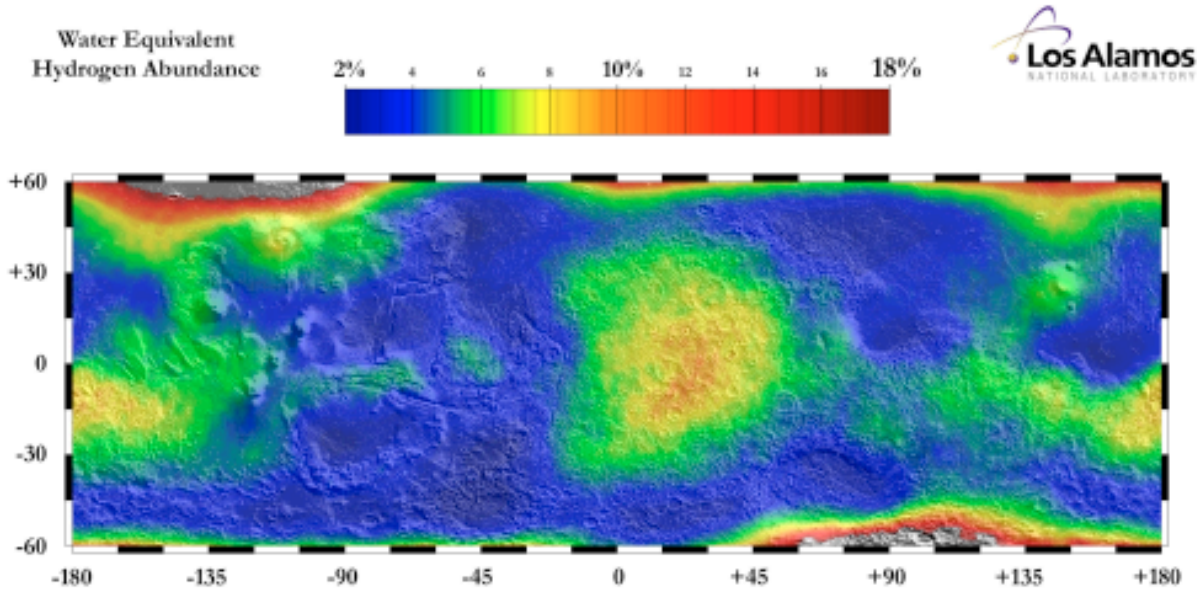


MSL – July 2005

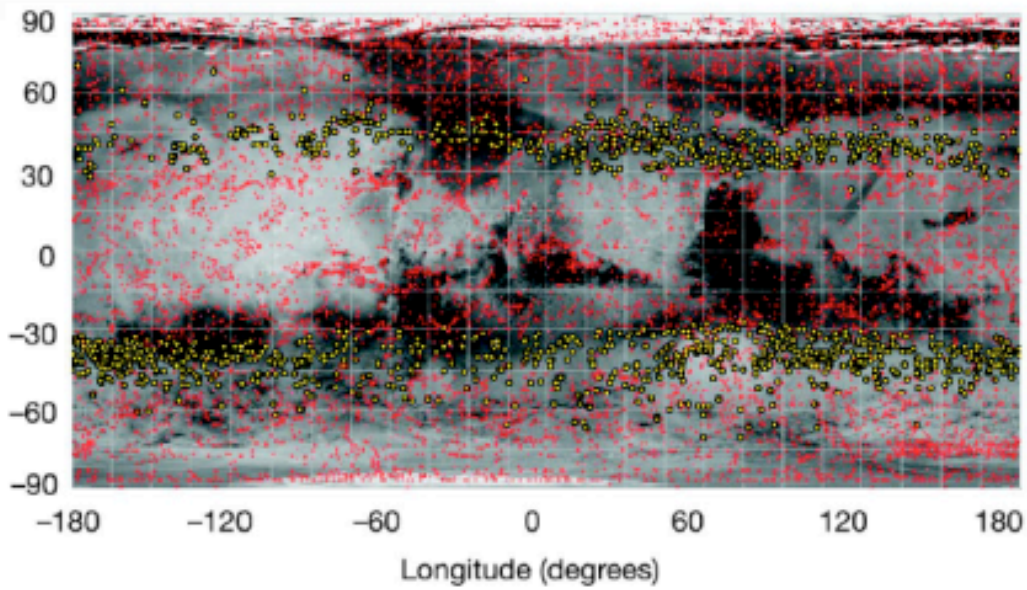
Evolution of MSL (?) *Evidence for Humans and Robots, Together*



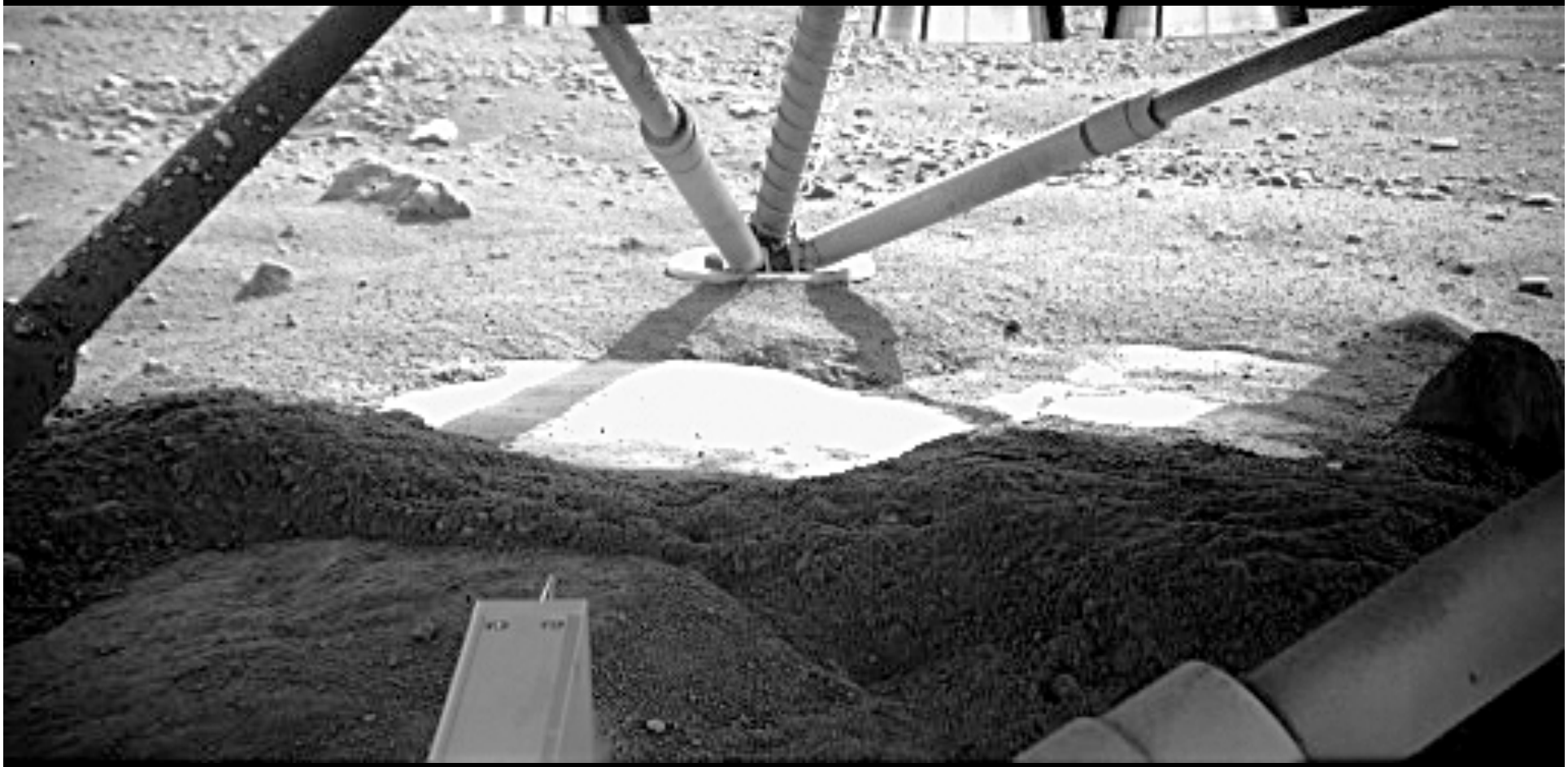
The Evolving Story Of Martian Water



Head et al. Nature Dec'03

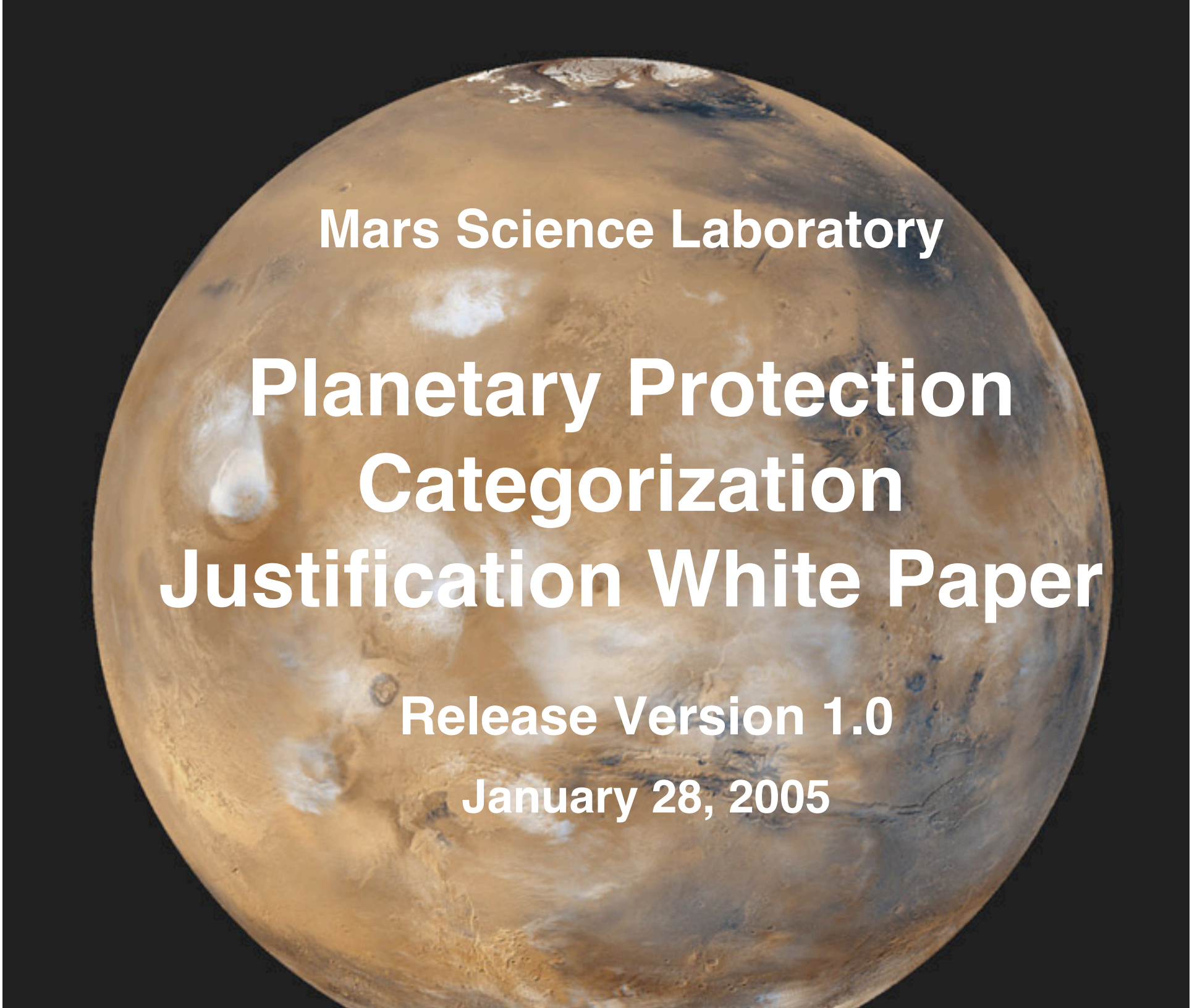


Mars Phoenix Landing Image (2008)



Overview of MSL Planetary Protection Approach

- **Factors considered**
  - COSPAR guidelines, including Category IVc and the concept of “special regions”
  - Possible presence of a radioisotope power source (RPS) on board the rover
  - PP implementation options
    - Viking approach
    - Restricted landing site and Phoenix-type PP approach
    - Probabilistic and deterministic design approach similar to that used at beginning of Viking
- **Overall approach taken by the Project**
  - Developed a PP strategy and proposed a categorization that meets NASA requirements, is consistent with the mission’s science objectives, and is technically and programmatically feasible
  - Used a probabilistic approach to the potential to inadvertently biologically contaminate Mars in the event of an off-nominal landing
- **PP category requested**
  - Category IVc implemented as Category IVa for the spacecraft with the additional provision that the sample-contact hardware, the corer (that could contact martian subsurface ice, if present) should meet the equivalent of Category IVb
- **Open issues and challenges**
  - Integration of advice from the NRC and the PPAC
  - Integration of White Paper reviewer comments and specific instructions from the PPO



Mars Science Laboratory

Planetary Protection Categorization Justification White Paper

Release Version 1.0

January 28, 2005

Introduction to the Executive Summary

This is the Executive Summary for Release Version 1.0 of the Mars Science Laboratory (MSL) Planetary Protection (PP) Categorization Justification White Paper. It provides a very abbreviated introduction, structure, examples and conclusions of the work associated with the off-nominal landing of the MSL spacecraft carrying a radioisotope power source. This significant body of work has been developed and reviewed over more than a year by a team of experts in many fields.

- The MSL Project is working to develop a planetary protection strategy and proposing a categorization that meets NASA requirements, is consistent with the mission's science objectives and is technically and programmatically feasible.
  - The MSL project is using the COSPAR 2002 policy to help define the PP approach.
  - The presence of a radioisotope power source (RPS) is assumed (but will not be official until the Record of Decision is formally announced by NASA, expected early in 2006).
  - The MSL Planetary Protection Categorization Justification White Paper provides the analysis that supports the Project's PP categorization request
  - Early and often interaction with the Planetary Protection Officer on our plans and strategy
- The following are initial conditions for the mission with respect to Planetary Protection:
  - MSL is not carrying instruments for the investigation of extant life
  - MSL is not targeting a "special region" (per COSPAR, 10/20/02 policy definition)
  - MSL expected science objectives will require a biologically and organically clean sample handling and analysis chain

What Makes MSL Different from Missions Since Viking

- From the Planetary Protection point-of-view a number of things are very different and much more challenging for MSL compared to past Mars lander/rover missions
  - Identification of a special region concept and the need to deal with “off-nominal” landings (elements of category IVc, COSPAR, 10/20/02 policy)
  - Orbiter measurements, the scientific interpretations of those measurements and new theories point to the possibility of water ice being present over a large portion of the Martian surface “relatively close” to the surface
  - Proposed use of a radioisotope power source (RPS)
- It is the presence of a “perennial heat source,” the RPS, coupled with the possibility of an off-nominal landing in an area where water ice may be relatively near the surface that requires a careful and thorough assessment of the project’s options for meeting planetary protection requirements and objectives.

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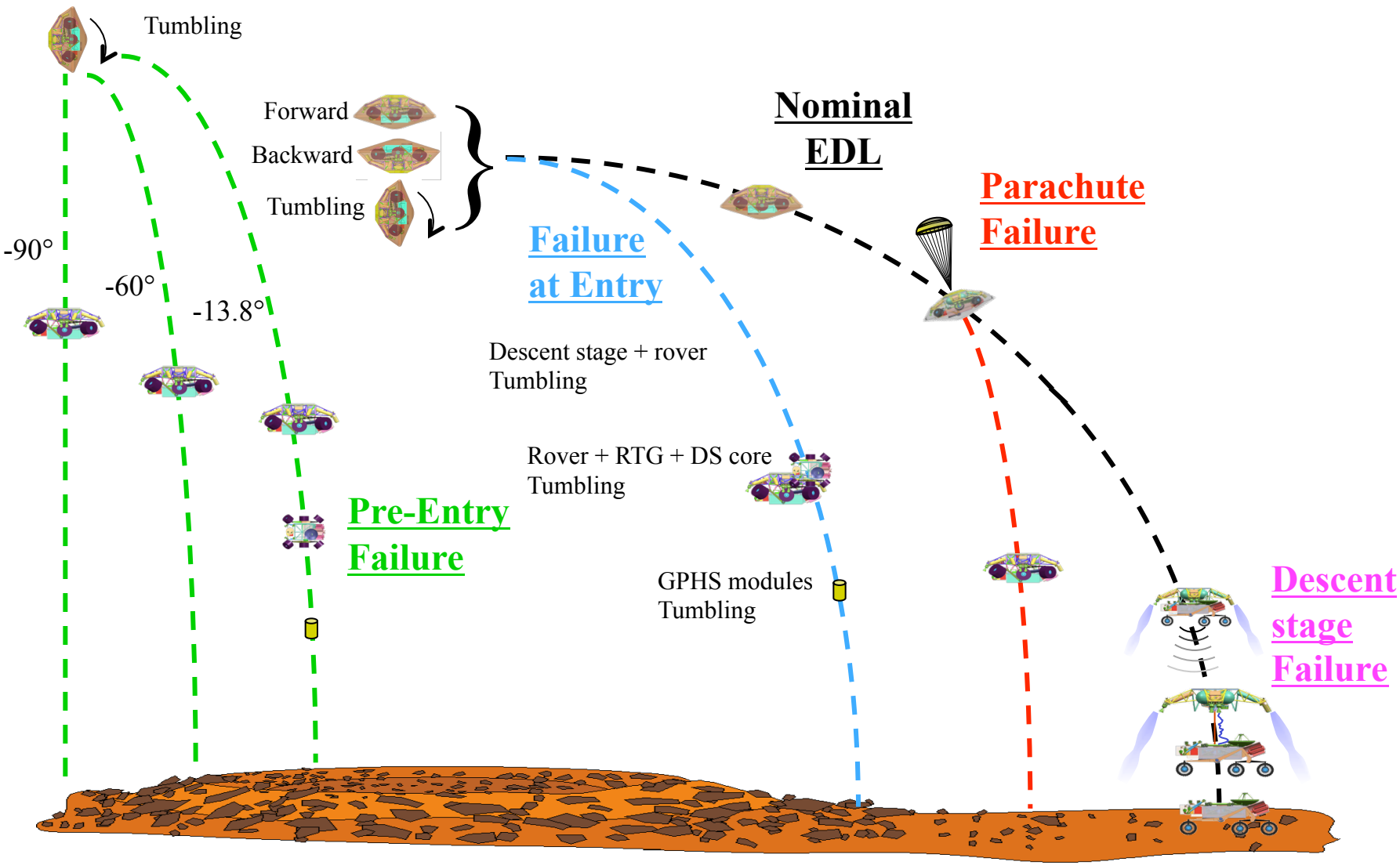
Failure Scenarios and Breakup Sequence During Entry Descent and Landing (EDL)



Basis for Surface Ice Distribution Assumptions

What We Know

- The Mars Odyssey Gamma Ray Spectrometer (GRS) Suite has detected large amounts of hydrogen within the top meter of the Martian surface layer poleward of 60° latitude in each hemisphere (and at certain longitudes poleward of 45° latitude), and smaller amounts of hydrogen at lower latitudes (Boynton *et al.*, 2002; Mitrofanov *et al.*, 2002; Feldman *et al.*, 2002).
- The interpretation is that large volume percentages of ground ice (50-75%) are present at high latitudes, covered by at least 15-30 g/cm^2 (roughly 10-20 cm) of dry regolith.
- Lower-latitude features may be due to bound water, adsorbed water, or spatially unresolved patches of ground ice. Observed water-equivalent hydrogen volume percentages are <12%.
- Morphological evidence (Head *et al.*, 2003) suggests sublimation of an icy surface may have occurred in the 30º-60º latitude band. No such evidence is present for latitudes equatorward of about 30º.

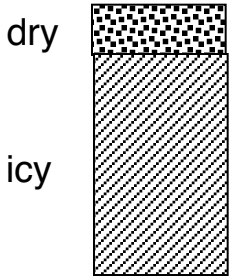
What We Don't Know

- No near-surface ground ice has been unambiguosly detected equatorward of ~45º latitude (i.e., over most of the MSL landing area). So we have to estimate from theory and observation.
- We have no ability to detect ground ice below ~1 m at the present (although orbiting radar systems may soon change that).

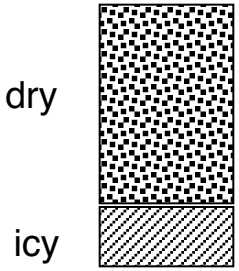
Surface Model Cases

- These models are relevant for ground ice in diffusive contact with the present atmosphere, as suggested by the GRS observations.
- Surface Model Case S (20 cm of dry regolith overlying ground ice, shallow icy layer) is representative of stable ground ice at latitudes between 45° and 60°. It also represents latitudes <45° where topographic shadowing or slopes create conditions favorable for ice stability, or where unstable ground ice persists from an earlier climatic regime. However, for the latter to be consistent with the GRS observations, such near-surface, low-latitude ground ice deposits must exist in patches that are small compared to the GRS footprint of 600 km.
- Surface Model Case D (100 cm of dry regolith overlying ground ice, deep icy layer) is representative of stable ground ice at latitudes between 0° and 45°. However, observations and models suggest that ground ice is likely to be deeper or absent at these latitudes.
- Each case above is run with ground ice at 100% saturation. The bulk ice volume, then, is equal to the porosity (nominally 50% ice by volume)
- To understand the cases where the fraction of ground ice is less than fully saturated a sensitivity analysis has been performed for impact and thermal analysis for 5%,10%, 20% ice by volume and is included in the appropriate analysis section.

Model Case S



Model Case D



Summary of Failure Conditions and Pre-Impact Initial Conditions

Failures		Nom. Impact Speed (m/sec), FPA (deg)	Comments
Pre-Entry Failure	-90° FPA (PE2)	4018, -89.8°	No atmospheric breakup.
	-60° FPA (PE3)	3774, -59.0°	No atmospheric breakup.
	-13.8° FPA (PE4)	554, -14.6°	GPHS modules released
Failure at Entry	Forward (E1)	445, -22.3°	No atmospheric breakup
	Backward (E2)	423, -23.3°	GPHS modules released
	Tumbling (E3)	470, -22.6°	GPHS modules released
Parachute Failure	Supersonic chute (P1)	298, -45.8°	Aeroshell impacts intact.
Descent Stage Failure (D1)		85, -89.7066°	Rover and descent stage impact

Impact Scenario Cases and Methods

- Large velocity range requires different prediction methods, as follows:

Scenario Case	Impacting Object	Impact Velocity m/s	Impact FPA degrees	Prediction Method
PE.2 (PE Failure, -90 deg FPA)	Spacecraft	4179	-90	Hypervelocity cratering model
PE.3 (PE Failure, -60 deg FPA)	Spacecraft	3951	-59	
PE.4 (PE Failure, low FPA)	GPHS	554	-13.8	Rigid body penetration model for low velocity GPHS
E.2 (E Failure, backward entry)	GPHS	421	-23	
E.3 (E Failure, tumbling entry)	GPHS	439	-24	
E.1 (E Failure, forward entry)	Entry Vehicle	444.8	-22.3	Crushable body penetration model for low velocity vehicle,
P.1 (Failure of supersonic chute)	Rover+DS	298	-46	
D.1 (high altitude loss of control)	Rover	85	-90	
D.3 (D failure, intermediate altitude)	Rover	5 to 132	-90	
D.2 (hard landing)	Rover	5	-90	Rigid body model for compact parts

PE=Pre-Entry, E=Entry, P=Parachute, D=Descent Stage

- Case D.3 velocity range will be illustrated with velocities 20 m/s and 132 m/s

General Thermal/Fluid/Bio Scenario

A. Thermal wave has not reached organism

B. Warming of ice and organism

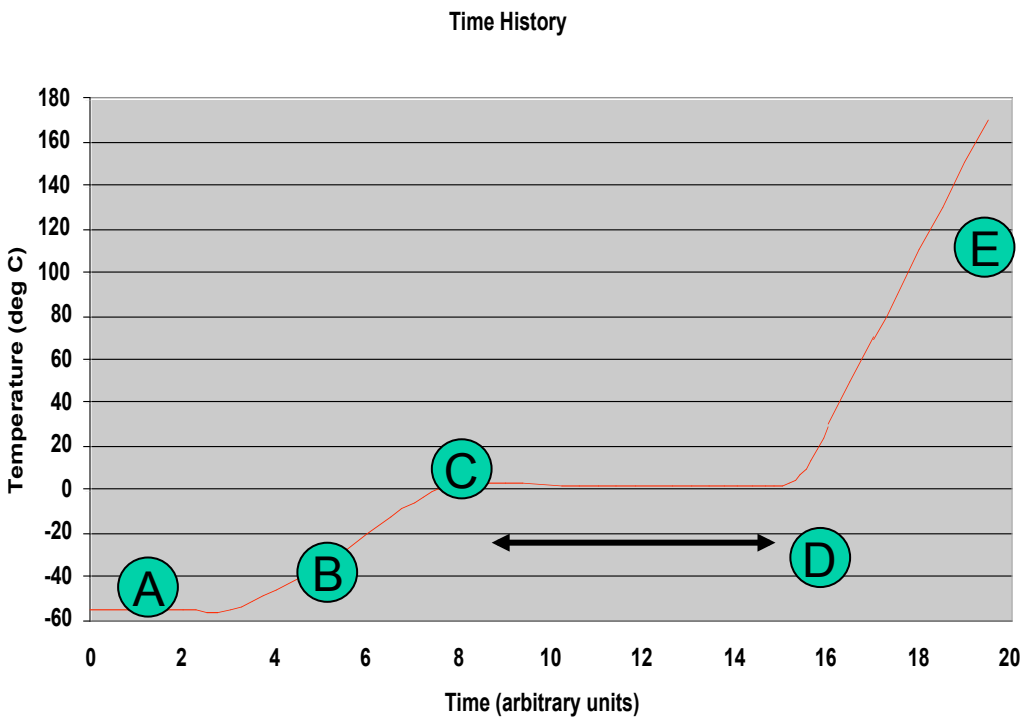
C. Liquid H_2O present

- Opportunity for microbial multiplication

D. Bioavailable H_2O has been depleted

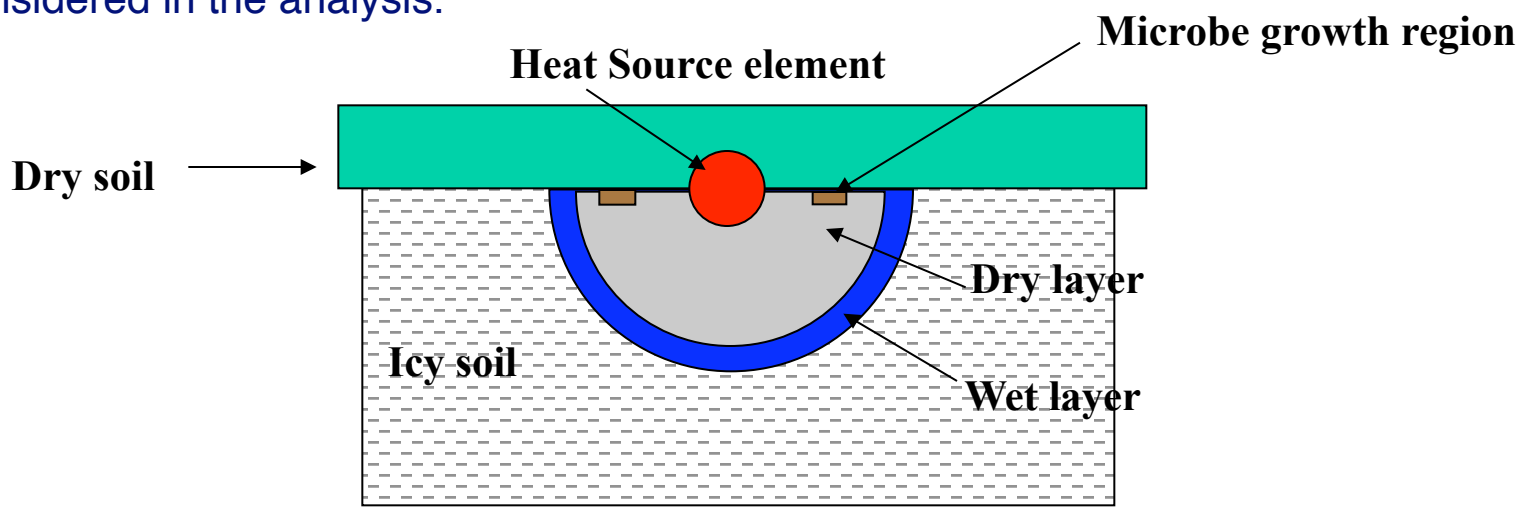
- Losses due to sublimation, chemical reaction, wicking, and boiling
- Organisms become dormant (e.g., sporulation)

E. Heating to sterilizing temperatures depending on closeness to the heat source



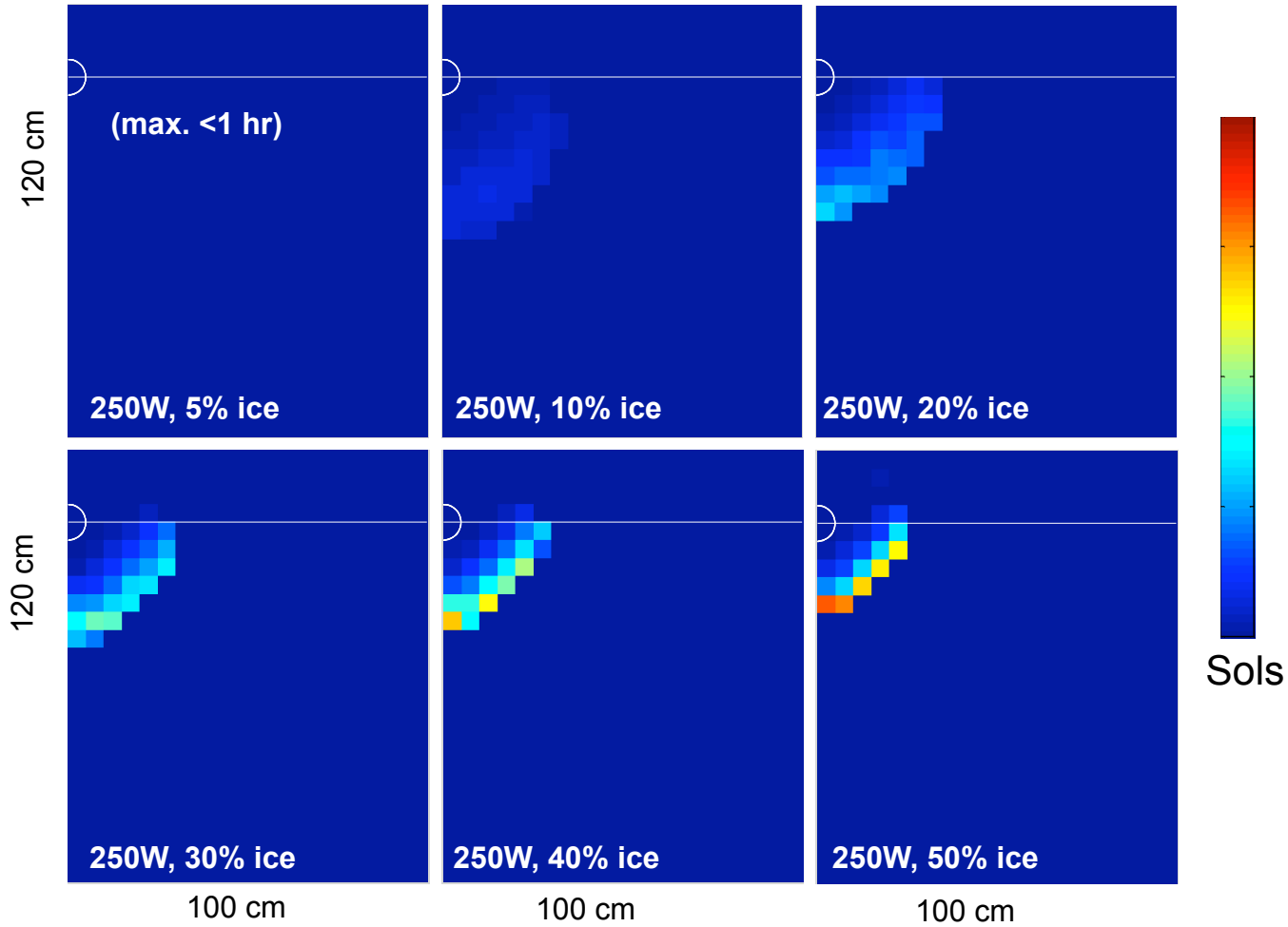
Thermo-fluid Dynamic Analysis of Heat Source at Dry/Icy Interface Summary (U)

- General results for probabilistic analysis
  - The transient thermal wave passes quickly at first then slows down approaching a critical radius beyond which no ice will melt.
  - Moisture content must be above a critical level, >4% by mass (the hygroscopic limit for a loam-like soil, very conservative), for reproduction to occur but that level of moisture is transient and a function of the initial ice content (see following page)
  - Heat source and dried area around heat source become very hot
- Net result is that there is a very restricted region near the dry/icy boundary where microbes must be initially located in order to be in liquid water and grow. That region is transient and lasts on the order of 10's of sols. Conditions where there is high ice content which produces >40 % water by mass could allow for mobility which is also considered in the analysis.



Duration of wetness

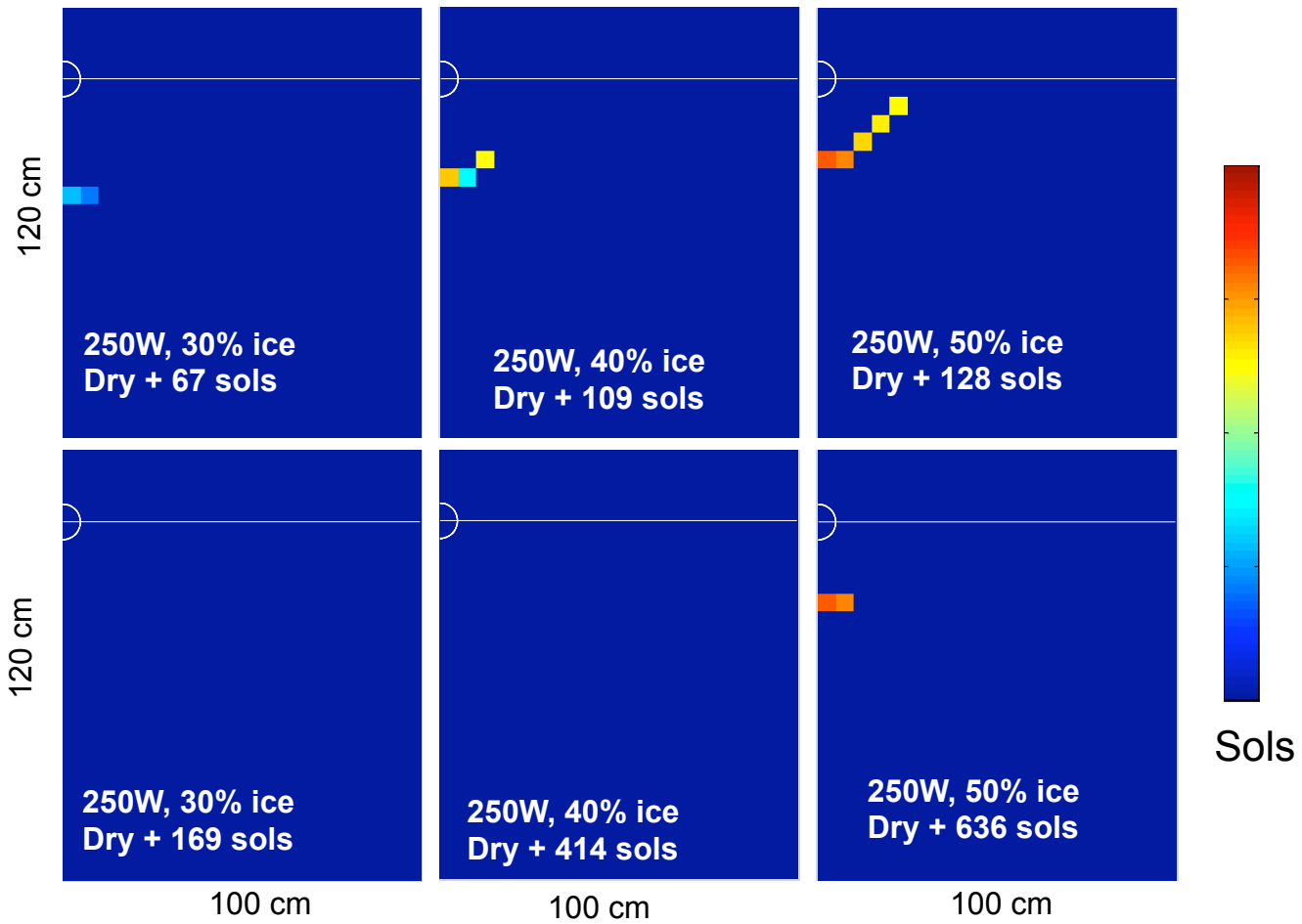
Map of elapsed time with more than 4% water by mass, a minimum value for propagation of microbes. Cells near the dry/icy boundary (20 cm line) are most likely to contain microbes. The 50% ice case is most problematical, offering a habitat for up to 25 sols near the boundary, 50 sols deeper.



Viable zones

The colored cells satisfy the criteria of (a) containing more than 4% water by mass at some time, and (b) not exceeding 383K at the indicated time after drying. The scale indicates how long the cell was wet.

No cells meet the criteria for < 30% ice. The 30% case reaches sterilization temperatures by 160 sols, the 40% case by 400 sols. Even after a Martian year, the two deepest "wet" cells remain unsterilized in the 50% case (this was still true nearly a year later).



Categorization Request

- **Based on the above results the Project proposes the following categorization for the mission:**
  - **Category IV-A for the spacecraft with the additional provision that the sample-contact hardware that could contact Martian subsurface ice, the corer, should meet the equivalent of Category IV-B.**
  - **This combination is intended to meet the provisions of the current COSPAR planetary protection policy's Category IVc.**

MSL Planetary Protection
White Paper Review Summary

Major Findings:

- For a nominal mission [not encountering "special regions" on the surface], the requested Planetary Protection Category IVa requirements for the flight system with the exception of the corer (or other sampling device) at Category IVb requirements seems appropriate.

- Selecting a landing site where near-surface ice is not present greatly reduces the potential consequences of off-nominal events during the final descent stages and is the most cost effective approach to address Planetary Protection concerns. It is recommended that this area receive further attention.

- The probabilities listed for the various events on slides 278-281 appear to neglect hardware/software failures and therefore are slightly optimistic.

PPAC Recommendations for PP Categorization

(final screen, 27 July 05; pre-edits by Chair)

One of two approaches to PP categorization are recommended by the Committee:

1. Follow the example of Viking and perform a system-level dry heat microbial reduction (DHMR) implementation in accordance with Category IVc restrictions.
   - No restriction on landing sites would be required

OR

2. The landing system and rover shall be cleaned to the Viking pre-sterilization-level bioburden (cf., Category IVa) with hardware contacting the martian subsurface cleaned to the Viking post-sterilization-level bioburden. Collectively these requirements comprise a Category IVc implementation.
   - No landing or roving into a surface "special region" is allowed; vertical access into subsurface regions are allowed by sterilized hardware only
   - At this level of cleanliness, if an RPS is incorporated into the lander, landing sites (i.e., potential off-nominal landing ellipses for failure cases where RPS and lander components are left in contact) are restricted to regions where there is no evidence of extant water/ice within 1 m of the surface
   - Landing site acceptability with respect to planetary protection criteria will be determined in view of data sets and theoretical models available upon landing site selection prior to launch

RICE UNIVERSITY

EUGENE H. LEVY, PROVOST
HOWARD R. HUGHES CHAIR
PROFESSOR OF PHYSICS AND ASTRONOMY

Dr. Mary L. Cleave, Associate Administrator
Science Mission Directorate
NASA Headquarters
Washington, DC 20546

August 15, 2005

Dear Dr. Cleave:

The Planetary Protection Advisory Committee (PPAC) met during July 26-27, the first of such meetings at which I was privileged to serve as chair. Although the committee devoted a certain amount of the meeting time to advancing its understanding of emerging issues that will occupy its attention in the future, most of the focus was on questions related to forward contamination of Mars. At this meeting, the PPAC received its first information about the just-completed report of the National Research Council Space Studies Board, *Preventing the Forward Contamination of Mars*.

Science Mission Directorate 23 August 2005

Mr. Richard A. Cook
Manager, Mars Science Laboratory Flight Project
M/S T1723-118
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109-8099

Subject: Mars Science Laboratory (MSL) Planetary Protection Categorization

Dear Mr. Cook:

I have received Pete Theisinger's letter of 2 February 2005 requesting Planetary Protection Categorization for the MSL Project's mission in accordance with NPR 8020.12B. I am also in receipt of the Project's Planetary Protection Categorization Justification White Paper, version 1.0, dated 28 January 2005.

Both documents have proposed an implementation of the mission to meet the requirements of COSPAR's Category IVc—requirements that are now incorporated by NASA in the "C" version of NPR 8020.12, issued 27 April 2005—and have provided options for mission implementation that include either restrictions on landing sites, reduction of spacecraft bioburden, or both. I very much appreciate the efforts taken by the Project to understand and characterize the planetary protection implications of taking MSL to Mars, and particularly wish to state that Project's White Paper was deemed by the peer reviewers, the Planetary Protection Advisory Committee (PPAC; see enclosure), and my office to be a thorough, impressive, and commendable analysis of the issues.

Nonetheless, the White Paper's capable analysis also demonstrated that the central issue in understanding the potential for a Radioisotope Power Supply (RPS) containing spacecraft to contaminate its landing site is one of the probability of growth (P_g) of Earth organisms in the martian subsurface. Unfortunately, neither the peer reviewers nor the PPAC agreed that the Project could make a convincing case that that P_g argument could be, within our current understanding of the parameters, persuasive in allowing the Project unrestricted access to all desirable landing sites on Mars. In the words of PPAC, "this conclusion should not be construed as a criticism of the MSL project team's analysis, but rather as an observation on the state of the art." Given the historically high incidence of Mars-lander failures, the presence of an RPS, and the increased sensitivity regarding special regions derived from the interpretation of multiple data sets from Mars, additional constraints will be necessary to achieve the goals of NASA's planetary protection policy as defined in NPD 8020.7F.

As requested, the MSL mission is hereby assigned as Category IVc in accordance with NPR 8020.12C, with the following options for implementation (assuming an RPS is incorporated into the final design for the landed portion of the mission):

2c. The mission will be limited to landing sites not known to have extant water or water-ice within 1 m of the surface. One-sigma landing ellipses that address failure modes subsequent to parachute opening at Mars need to fall outside such areas. In addition, later access to martian special regions (as defined by NPR 8020.12C) will be permitted only by vertical mobility, through the use of sterilized sampling hardware, as detailed above. No horizontal access through mobility by an unsterilized rover will be allowed:

- Proposed landing sites will be reviewed by my office for compliance with this requirement pre-launch, and prior to the preparation and presentation of landing site options to the Science Mission Directorate Associate Administrator.

Mars Science Laboratory
Planetary Protection Plan
Initial Release

JPL D-27176
MSL 216-0210

June 2006

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Requirements are then included in the mission's planetary protection plan.

4.3.5 Landing Site Selection Requirements

The project will be limited to landing sites not known to have extant water or water ice within 1 meter of the surface. One sigma (σ) landing ellipses that address failure modes subsequent to parachute opening at Mars shall fall outside such areas. Proposed landing sites will be reviewed by the NASA PPO for compliance with this requirement pre-launch and prior to presentation of landing site options to the Science Mission Directorate Associate Administrator.

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

And that is what one lives with!

Mars thanks you,
and the PPO thanks you....

Questions?

What does HITACHI stand for?

HITACHI

Hope It Takes A Curiously Happy Image...
...of Mars