MICROBIOLOGICAL CLEANLINESS OF THE MARS EXPLORATION ROVER SPACECRAFT

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The soon to launch Mars Exploration Rover twin spacecraft, each involving a lander and a rover scheduled to land on Mars in January and February of 2004, are required to comply with the National Aeronautics and Space Administration planetary protection regulations for such space missions. The microbial cleanliness requirements are driving a major effort to assemble clean spacecraft and to verify and maintain their cleanliness.

Planetary protection for Mars missions is described, and the approach being taken by the Mars Exploration Rover Project is discussed. Specific topics include alcohol wiping, dry heat microbial reduction, microbiological assays, and the Kennedy Space center’s PHSF clean room. Current best estimate for the number of aerobic spores to be found on the spacecraft at launch are presented and compared to the Viking 1975 and Mars Pathfinder 1996 values.
Microbiological Cleanliness of the Mars Exploration Rover (MER) Spacecraft*

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Mission Overview

Launch/Cruise

EDL

Surface

Images From Mission Animation by Dan Maas
Courtesy of JPL/Caltech
Spacecraft Configuration

Cruise Stage

Backshell

Heat Shield

Rover

Lander

1.7 m

2.65 m

Courtesy of JPL/Caltech
Entry, Descent & Landing (EDL) Scenario

- Entry Turn & HRS Freon Venting: E-70m
- Cruise Stage Separation: E-15m
- Entry: E-0s, 125 km, 5.7 km/s, γ = -11.5 deg.
- Parachute Deployment: E+295s, 11.8 km, 430 m/s
- Heatshield Separation: E+315s
- Lander Separation: E+325s
- Bridle Deployed: E+335s
- Radar Ground Acquisition: L-18s
- Airbag Inflation: 355 m, L-10.1s
- Rocket Firing: L-7s, ~150 m, 90 m/s
- Bridle Cut: L-3s, ~20m
- Bounces
- Deflation: L+20min
- Roll-Stop: L+2min
- Airbags Retracted: L+74min

Landing Times (Mars local solar time)
- MER-A: ~2:30 PM
- MER-B: ~1:00 PM
- Earthset: ~3:30 PM

TCM-5: E-12 hrs.
Concurrent with EDL, but commanded from ground.

Courtesy of JPL/Caltech
Rover Configuration

Navcams
Pancams
Pancam Mast Assembly (PMA)
Rover Equipment Deck (RED)
Front HAZCAMS
Warm Electronics Box (WEB)
Instrument Deployment Device (IDD)

UHF Monopole Antenna
Low gain Antenna (LGA)
High Gain Antenna (HGA)
Solar Arrays
Mobility System

Courtesy of JPL/Caltech
• PP Category IV-A (MER Planetary Protection Plan, JPL D-19534):
  - Documentation
  - Probability of impact of Mars by the launch vehicle (or any stage thereof) shall not exceed $10^{-4}$
  - Probability of accidental impact of Mars due to failure during cruise phase shall not exceed $10^{-2}$
  - Spacecraft assembled in Class 100,000 clean facilities or better, with appropriate controls and procedures
  - Bioburden:
    - Total exposed surface bioburden of the landed hardware shall not exceed $3 \times 10^5$ viable spores at launch
    - Total (all surfaces, including mated, and in the bulk of non-metals) bioburden at launch of hardware for which a hard impact is planned shall not exceed $5 \times 10^5$ viable spores minus bioburden allocated to landed hardware (negotiated resolution, MPF precedent)
    - Average exposed surface bioburden of the landed hardware shall not exceed 300 viable spores/m$^2$ at launch
  - Organic materials:
    - List of organic materials and masses
    - 50 g sample of any organic material of 25 kg or more is used
Comparison of PP Implementation
MER vs. MPF

Changes Necessitated by Differences in the Missions

- MER backshell exterior surface temperature < 500°C during Mars atmospheric entry (MPF was hot enough)
  - MER backshell exterior surface accountable for spore count
  - MER cruise stage has to be clean (even though will be hot enough during entry to be sterilized) because source of recontamination for backshell (i.e., during launch)
  - MER fairing and 3rd stage also source of recontamination for backshell (i.e., during launch)
Comparison of PP Implementation
MER vs. MPF

Improvements in PP implementation

- More use of dry heat microbial reduction, enabled by earlier planning
- More use of High Efficiency Particle Arrestor (HEPA) filter isolation, enabled by earlier planning
- Better “sealing” of Rover Warm Electronics Box (WEB) behind its HEPA filter than the MPF Integrated Support Assembly (ISA)
- Accounting of total spore burden in backshell thermal protection system (TPS) and in structure - honeycomb composite substrate
  - TPS volume and internal surfaces of substrate “trim pieces” assayed directly
  - MER backshells underwent dry heat microbial reduction
  - in MPF and MPL analyses, these materials were thought to have been heated to very high temperatures for a long durations during cures in manufacturing - only true for heat shield. Error corrected for M’01.
- Use of biological indicators in Engineering Model (EM) parachute processing (non-standard heat process) and for flight backshells
- Advisory use of Limulus Amoebocyte Lysate (LAL) assay for rapid screening of surface cleanliness (separately funded research)
- Real measurements of spores in filtered purge gas
MPF on Mars
Showing HEPA Filter on IPA

photo credit Sojourner

Courtesy of JPL/Caltech
Comparison of PP Implementation
MER vs. MPF

Challenges in PP Implementation

- Two spacecraft (two landers and two rovers) plus two cruise stages and two launch vehicles (with biological cleanliness measured) vs. one spacecraft (one lander and one rover)
- Tight schedule - 34 months from mission selection to launch
- Greater use of composites and honeycomb structures
- More electronics, batteries, and solid motors on MER backshell
- Increased accountable areas - larger parachute, airbags with twice as many layers
- Greater use of engineering models mounted to flight hardware during system tests
Planetary Protection
Status of Implementation

- Implementation Plan (as of 01/28/02)
  
  Hardware By Approach          Fraction of Total Items*(No. of Items)
  Dry Heat Microbial Reduction** 59% (254)
  IPA Wipe / Rinse Only          26% (113)
  WEB Exempt/ HEPA Isolation     13% (55)
  Other                          1% (5)

- Best Estimate(9/13/02)*** versus the Spore Burden Requirements
  - Landed Hardware - Lander, rover, and parts of aeroshell and of EDL subsystem that are exposed even without impacting Mars
    $1.7 \times 10^5$ spores vs. $3 \times 10^5$ spores  (76 spores/m² vs. 300 spores/m²)
  - Impacting Hardware - Most of aeroshell, BIP, and backshell-mounted equipment (includes an allowance for part of cruise stage)
    $1.2 \times 10^5$ spores vs. $2 \times 10^5$ spores
  - Cruise stage (no requirement, values for source to backshell only)
    590 spores/m²

* Percentages based on number of line items, not surface area or bioburden allocation
** Includes Non-standard DHMR & entry sterilization
*** 3 sigma worst case