MIcrobial Airborne Simulation and Measurements for MArs (MIASMMA): constraining planetary protection risk for crewed exploration

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The problem

Humans will bring our microbes to every planet we visit

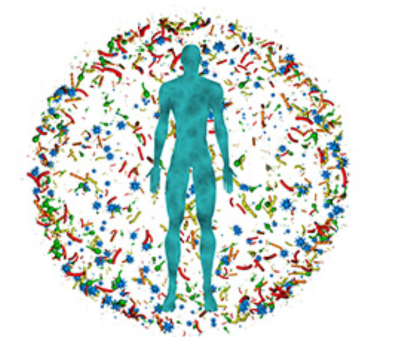


Image: NIH

Every human carries ~3.8x10^{13} microbial cells [1], with ~10^4-10^6 microbes / cm^2 on the skin [2].
It's not just microbes, and they don't stay put. Humans emit ~10^6 particles / hr (1-10 μm size range), including microbes, skin cells, and other biogenic particles [3-7]. Physical activity may increase emission rates for larger particles [8].
Of these, ~56% are likely biological (fluoresce under UV) [5] and <1% of this bioburden is typically viable [9].

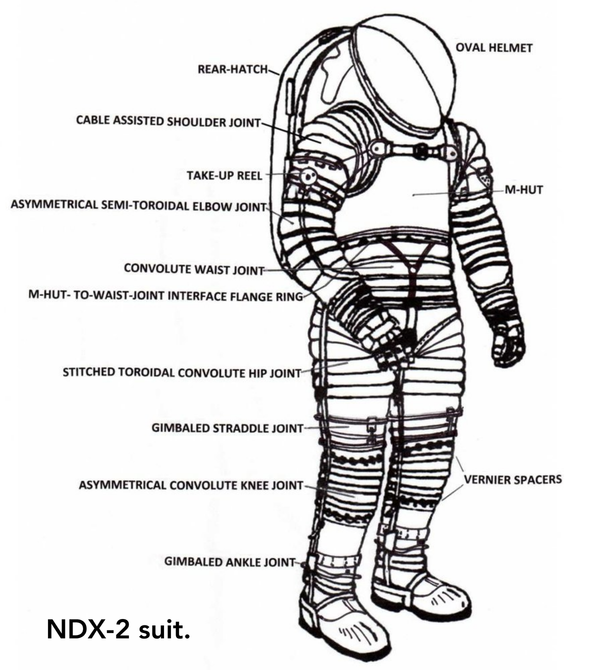
Space suits and habitats leak

No designs currently exist for Mars habitats or suits.

The **ISS Extravehicular Mobility Unit (EMU)** is the suit used on the International Space Station (ISS) for extravehicular activity (EVAs).
A normally functioning suit may leak up to ~100 cm^3 /min on Earth and up to ~16,000 cm^3 /min in space [10].
With a free volume of 0.42 - 0.56 m^3, 10-15% of the suit volume leaks every hour on Earth.
In space, the suit may leak 17-23x its free volume every hour.
Current studies on the ISS are using a specialized EVA swab kit to detect microbial leakage outside the station [11].

FIGURE 1.9 EMU LEAK CHECK SUMMARY

Test Description	Ground Processing²	EMU Checkout	PreEVA Leak Check	EVA CWS Limits	SOP Make-up Capability
Where Performed	JSC	Vehicle	Airlock	Space Vacuum	Space Vacuum
Ambient Pressure, psia	14.7	10.2 or 14.7	5.0	0	0
Suit Pressure, psig	4.3	4.3	4.3 – 4.6	4.3	3.5
Temperature, °F	70	70	70	70	70
Pass/Fail Criteria	99.3 sccm O_2, full EMU	0.3 psi suit pressure drop in 2 minutes	0.3 psi suit pressure drop in 1 minute	7 to 10.2 psi/min Primary O_2 Bottle pressure	No Test Performed
Equivalent Leakage Area, in^2	1.85x10^{-5}	2.11x10^{-4} to 3.52x10^{-4}	1.39x10^{-4} to 2.29x10^{-4}	2.00x10^{-3} to 2.91x10^{-3}	0.0152
Equivalent Leakage at Ground Conditions, sccm O_2	99.3	1130 to 1880	770 to 1230	10,700 to 16,200	81,500
Equivalent Leakage at Ground Conditions, sccm Air	104.1	1185 to 1980	810 to 1290	11,200 to 16,400	85,600
Equivalent Leakage at EVA Conditions, lb_m/hr O_2	0.006	0.069 to 0.116	0.046 to 0.075	0.656 to 0.957	5.0
Equivalent Leakage at EVA Conditions, sccm O_2	35	395 to 660	260 to 430	3750 to 5460	28,500



NDX-2 suit.

The **NDX-2** is a rear-entry planetary EVA suit designed by the University of North Dakota [12]. It is closer to a potential Mars suit design, and has lower leak rates: 10-15 cm^3/min when pressurized to 4 PSI above ambient on Earth.
This suit will be the focus of MIASMMA studies.

Hypothesis: NDX-2 leaks 1% of particles generated inside the suit each hour, which equates to 10^4 particles in the size range 1-10 μm.

Potential mitigating factors:
There are no filtration mechanisms at joints, but particles may interact with suit materials, or get trapped in tortuous paths through joints, or in the O_2 circulation system.
Conversely, the suit itself may contribute microbial bioburden [11, 13]
In short, empirical testing of leak rates is needed.

The **International Space Station** (ISS) is the longest continuously-inhabited space habitat.
Leakage in 2011 was ~0.227 kg/day, with cabin pressure at 96.5-102.7 kPa, 899 m^3 free air volume.
Activities such as EVAs and vehicle undocking cause operational losses of several kg/event [14].
ISS air is filtered to maintain air quality at:
- viable organisms: <1000 CFU/m^3 bacterial counts <100 CFU/m^3 fungal spores [15]
- total particulates: <1 mg/m^3 at 0.5-10 μm <3 mg/m^3 at 10-100 μm [9,16].

Airborne viable microbes have been reported as <7.1x10^2 colony-forming units (CFU)/m^3 [17].
These values will be used to estimate the leak rate of a theoretical Mars habitat for modeling purposes.

Any biogenic particles could compromise the search for extraterrestrial life

We are still looking for extant and past life on Mars.
While human-associated microbes might find it hard to colonize the Mars surface, any biogenic particles (dead microbes, human skin cells, dust from habitats) would carry biomarkers (e.g. membrane lipids) that could confound the search for life.

Current international planetary protection regulations for robotic spacecraft [18] dictate:
- for most missions, total surface bioburden ≤3 x 10^5 bacterial spores, average ≤300 spores / m^2
- search-for-life missions and/or visiting Mars Special Regions: total surface bioburden ≤30 spores

But humans cannot be sterilized: astronauts will not meet current planetary protection standards. Data on the extent of potential human-associated contamination is essential to inform new planetary protection policies compatible with crewed missions.

Knowledge gaps and how MIASMMA will address them

What is the rate of biogenic particle leakage from a space suit?

Leakage from individual suit parts

Atmospheric pressure of Earth at sea level is 14.7 PSI.
Mars pressure is ~0.095 PSI, and EVA suits are maintained at ~4 PSI.
Pressure differential between suit and atmosphere determines leak rate.
Space suits leak only at joints where two parts connect (e.g. where glove meets sleeve).

To validate methods and obtain single-component leak rates, we will test individual suit parts in a test box maintained at Mars pressure.
A source surface inside the suit part will be seeded with fluorescent tracer microspheres (0.1, 1 and 10 μm).
Open ends of the suit part will be capped, and the part pressurized to 4 PSI with ambient air.
A two-stage Andersen Cascade Impactor will be used for sampling; particles will be enumerated by microscopy.

Whole-suit leakage of tracer particles at Mars pressure

The Planetary Aeolean Lab (PAL): a NASA facility for experiments under different planetary atmospheric conditions

In continuous operation since 1977, the PAL includes one of the nation's largest pressure chambers.

Dummy inside a suit during a previous test at PAL.

For a controlled assay of particle mobility in Mars-relevant conditions, we will measure whole-suit leakage rates inside the PAL, using the same methods as for suit parts (above).
An NDX-2 suit will be fitted with a dummy source seeded with fluorescent tracer microspheres (no human occupant).
The suit will be positioned in the PAL, with particle detectors around the suit.
The chamber will be pumped down to 0.095 PSI and sampling conducted for 4 hours.
Multiple tests will be conducted with the suit in different positions.

Whole-suit leakage of human particles at Earth pressure

NDX-2 during fit test.

To assess mobility of real human-associated particles, we will measure leakage from a NDX-2 suit worn by a human subject.

Measurements will be made in a 12'x12' ISO 7 clean room.
The suit will be wiped down with a commercial stericide to mimic cleaning during a mission.
The suit will be overpressurized by 4 PSI above ambient to simulate the pressure differential on Mars.
Subjects will do activities to simulate an EVA for 60-90 minutes.

Particles will be measured using two methods:
- Cascade impactor for comparison with non-human tests (above), followed by ATP/ADP quantification, culturing, and staining + microscopy
- Commercial biofluorescent particle counter (BioVigilant IMD-A)

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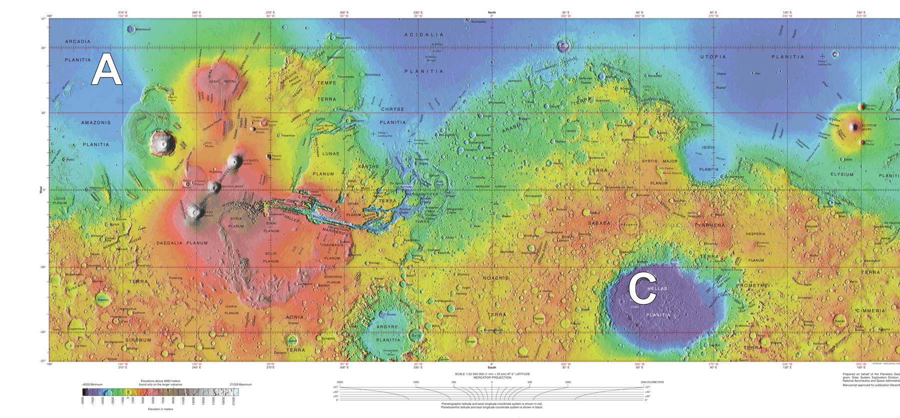
How far across Mars would leaked particles disperse?

The NASA Ames Mars Global Climate Model (MGCM): an atmospheric circulation model for Mars

The MGCM simulates the atmosphere and climate of the planet Mars using an external finite volume dynamical core to predict the global atmospheric state given various planetary parameters and physical parameters [20].



Topographical map of Mars with modeled habitat locations labeled.
A. Arcadia Planitia (39.8 °N/195.6 °E)
B. The Midlatitudes (0-5 °N - 180-185 °W)
C. Hellas basin (-35-40 °N - 60-65 °W)

To assess the extent to which leaked particles would spread and contaminate the Martian environment, will use the MGCM to simulate their atmospheric transport.

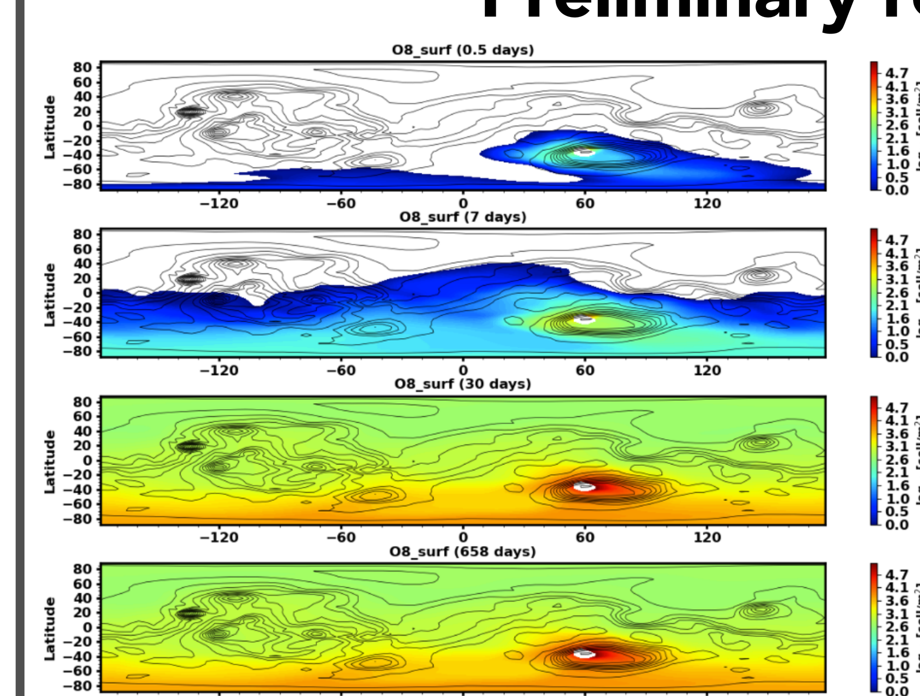
A custom submodule will allow precise control over the timing, location, and duration of leakage events.
It will simulate both viable and non-viable microbial particles (0.5–1.5 μm) and incorporate viability decay over time.
Because the spatial scale of individual EVAs is smaller than model resolution, we treat habitat and EVA activity as a single co-located source of contamination.
Leakage rates will be based on literature estimates (for habitats) and empirical measurements from this study (for EVA suits).

What mitigations would most effectively reduce contamination?

Several model runs will be conducted, to test the effects on microbial dispersal of:
- Landing site / habitat location
- Mission scenario (using published Mars mission scenarios):
  1. **DRA 5.0**: long-duration, high-resource mission, up to 4 crew [21]
  2. **SAC21**: short-duration, low-resource mission, only 2 crew [22]
- Different mitigation strategies:
  1. reduce leak rates
  2. shorten duration of human activity

Objective	Mission scenario	Location	Duration of habitation	Leak rate	Particle lifetime
2a. Best-estimate total particles; effect of location	DRA 5.0	Arcadia planitia	500 sols	Best estimates	no decay
		Midlatitudes			
		Hellas Basin			
	SAC21	1 location (TBD)	30 sols		
2b. Viable particles only	DRA 5.0	1 location (TBD)	500 sols	Best estimates	Three particle types (LD99 ~ 1 minute, 10 sols, 500 sols)
	SAC21		30 sols		Three particle types (LD99 ~ 1 minute, 10 sols, 500 sols)
2c. Mitigation strategies	DRA 5.0	1 location (TBD)	500 sols	50% of best estimates	no decay
			500 sols	10% of best estimates	
			250 sols	best estimates	
			50 sols	best estimates	
	SAC21		30 sols	50% of measured rate	
			30 sols	10% of measured rate	
			15 sols	measured rate	
			3 sols	measured rate	

Preliminary results



Results of simulation initiated in Hellas Basin, showing abundance of 1 μm particles across space at 0.5 days, 7 days, 30 days, and 658 days. Units: log_{10}(cells/m^2)

We conducted an initial simulation using a previous MGCM version with the following assumptions:
- long duration (~500 sols) stay
- habitat volume: 150 m^3
- indoor air with: 700 viable cells/m^3
- particle size range 0.5-1.5 μm
- constant leakage rate, 1.42-4 kg/s

By the end of the 658-day simulation, all regions had at least 10^2 cells/m^2. This result was similar for all three landing sites. Mitigations were not tested.

These results suggest that planet-wide particle dispersal is likely to happen on human timescales.
However, further work is needed with an updated model and parameters.

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