



National Aeronautics and Space Administration



Contamination Mitigation Strategies for Long Duration Human Spaceflight Missions

Contamination, Coatings, Materials, and Planetary Protection Workshop

NASA Goddard Space Flight Center
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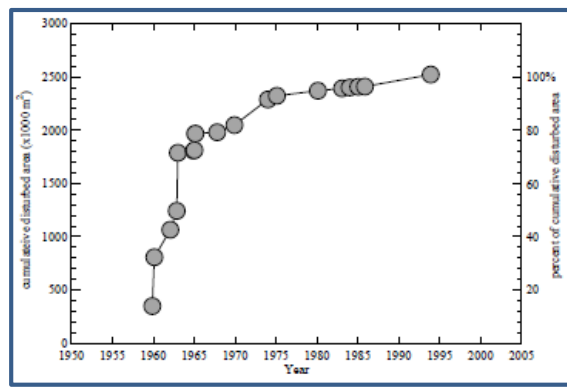
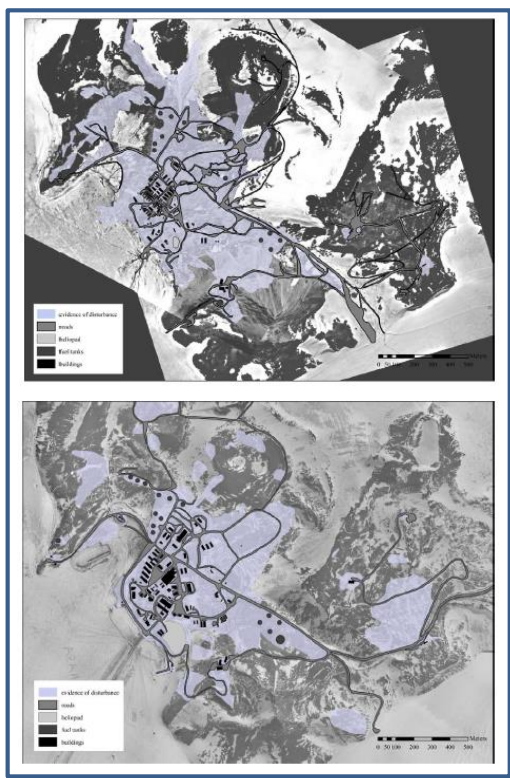
- With Earth's ecosystems, the introduction of an anomalous stimulus can deleteriously alter the balance and health of the system
- Without management protocols in place, we could expect a similar result if another planetary surface' "ecosystem" is confronted with non-naturally occurring stimuli
- Scientific observations, data, and assessments may be confounded and indeterminate, due to mixing of sources
- Contamination and environmental impacts, more generally, may occur on, to, and from planetary surfaces via unintended human-created transport

What are these stimuli and their individual and combined effects?

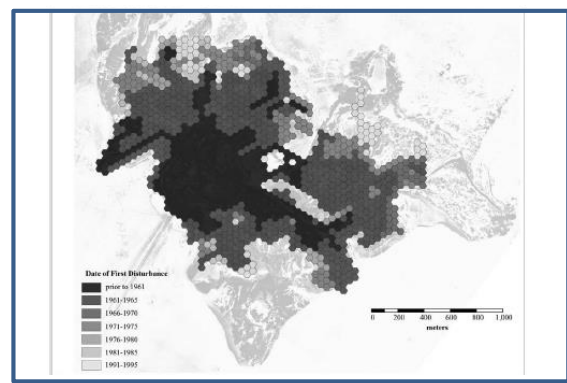
What management techniques may be used to mitigate risks?

- Antarctica's McMurdo Station is an analog for planetary human exploration
- Lack of initial infrastructure and exploration planning with haphazard region protection, habitation area buildup, and transportation corridors contributed to extensive environment and science data risk and disturbance
- Remediation is costly

Areas of surface disturbance



Cumulative area impacted by disturbance



Expanding physical disturbance



“Ecosystem”: Environment-Surface-Object Interaction



◎ Free flowing space environment

- Radiation
- Charged particles
- Micro-meteors
- Dust

◎ Surface and ground

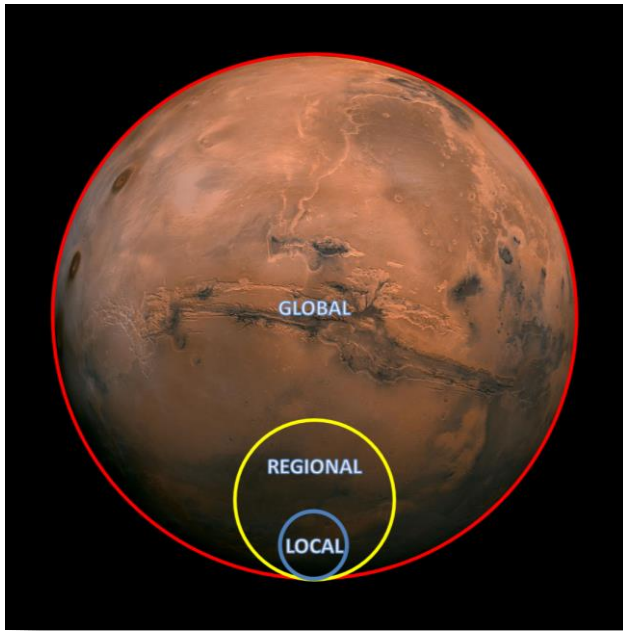
- Charges with incident plasma

◎ Humans and human-made objects

- Charges relative to surface and plasma
- Mobility across surface, cross-contamination

• “Humans leak” – documented examples

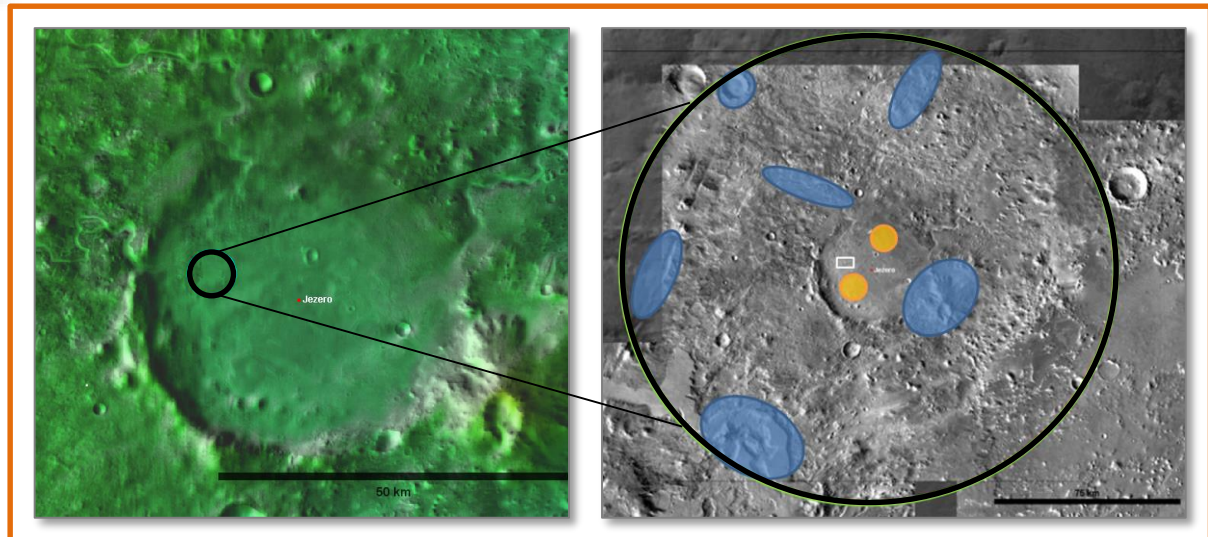
- Apollo Cold Cathode Gauge Experiment showed elevated gas concentrations
- Apollo 17 Lunar Excursion Module saturated atmosphere composition experiment via outgassing
- Current ISS tests characterizing gas and microbe leaks from Station and suits during EVA
- Orion spacecraft has dominant “exosphere” from outgassing; will adsorb to airless body



- Interactions may occur on a local, regional, and global level
- Example: human mission contamination footprint
 - Biological
 - Non-biological: fuel, landing plumes/ejecta, etc.

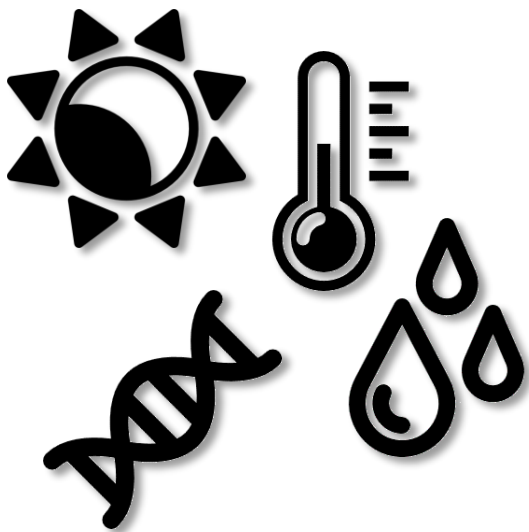
Exploration Zone and Regions

- Landing
- Habitation
- Resources
- Science
- Special regions
- Interconnecting corridors





Characterization and Measurements



- Chemical and physical environmental dynamics
 - Atmosphere
 - Wind: direction and speed variations
 - Sun angles and path, degree days/BTUs, etc.
 - Temperature cycles, flux
 - Humidity
 - Dust storms, “seasons”
 - Baseline geochemistry and mineralogy
 - Liquid and gas “runoff”
 - Combined surface and atmospheric effects

- Space weather and radiation

- Toxicity

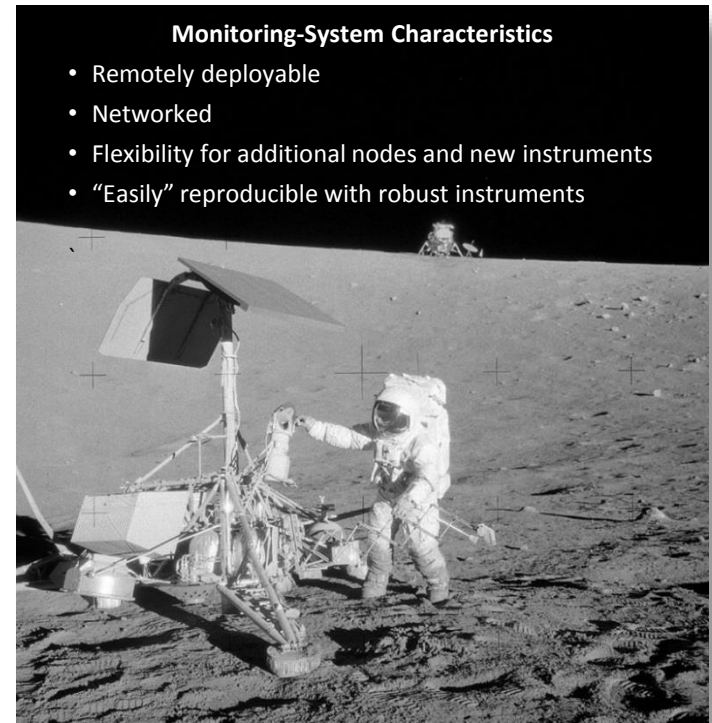
- Ground
- Dust
- Atmosphere

- Microbial and biological activity

- Geophysical response to removal or relocation of mass

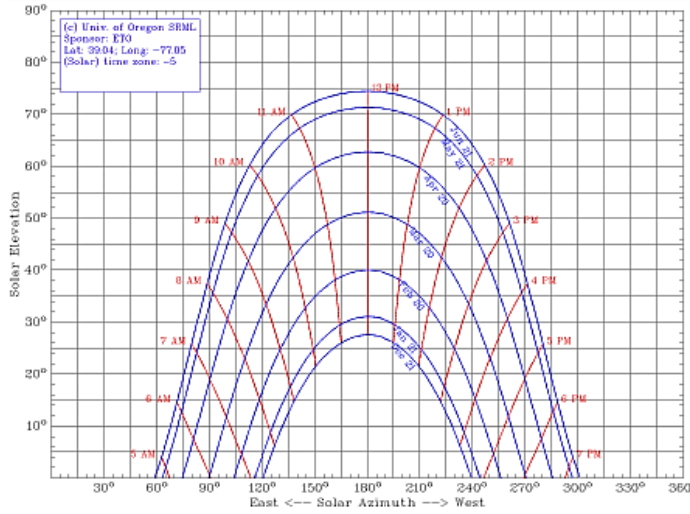
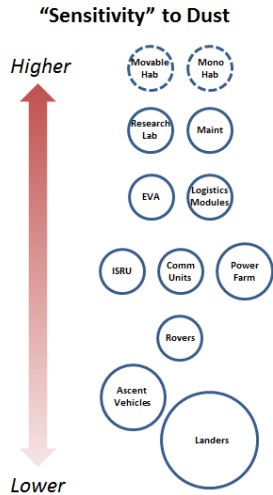


- Leverage Earth-based environmental management
- Determine required precision and accuracy of measurements
- Determine quantity and placement of monitoring “stations” – local, regional, global
- Consider using lunar environment as a testbed
- Collect baseline data and characterize the planetary environment prior to human and in-situ-resource utilization (ISRU) presence (aside from rovers)
- Perform site analysis and infrastructure operations plan prior to and during human exploration phases
- Continuously monitor and assess environment through all mission phases
- Generate environmental interaction use and operations guidelines and standards including entry/exit protocols for special exploration regions
- Derive remediation options and contingencies
- Determine success criteria for adequate measurement and management

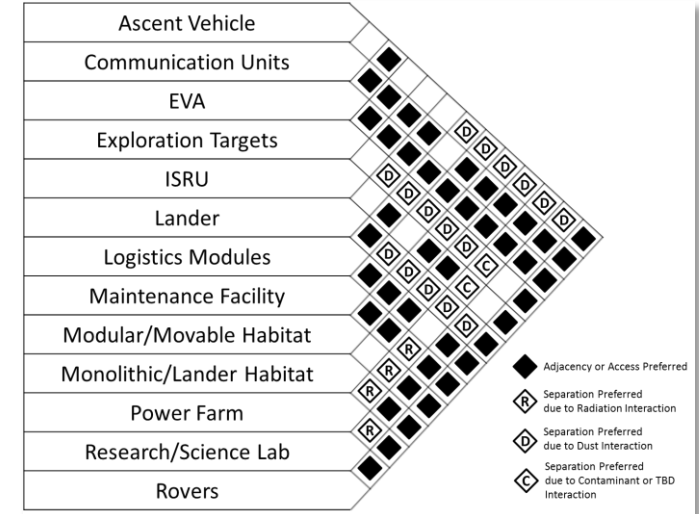


NASA Habitation Site Analysis and Tools: Research, Analysis, Synthesis

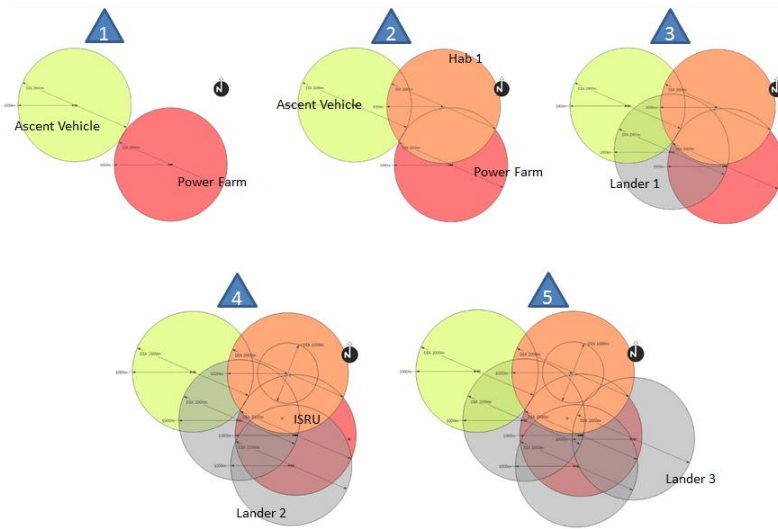
Environment (examples)



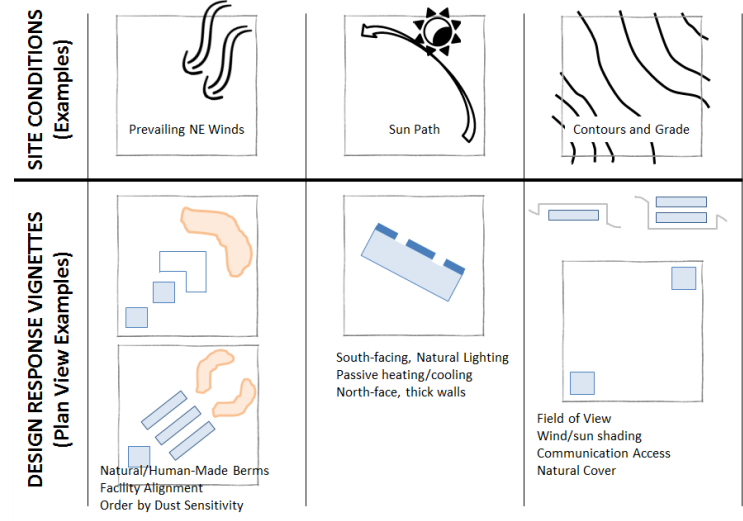
Adjacencies



Habitation Buildup Sequence

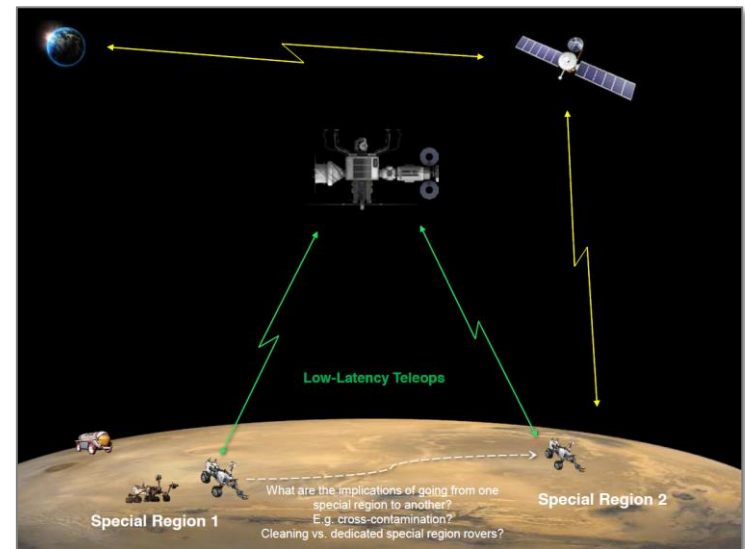


Conditions and Design Responses



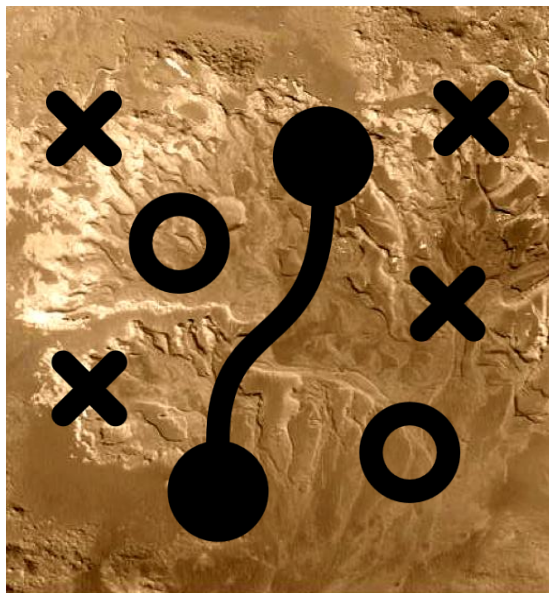
NASA Low Latency Telerobotics

- Conducting LLT from orbit, allows for multiple missions to safely explore the planetary surface in advance of crew landing
- Allows for real-time exploration of areas that may otherwise not be conducive to direct human contact
- Find and explore Special Regions -- areas of interest that might be adversely affected by forward contamination from humans or spacecraft contaminants
- Clean assets if they move between Special Regions or other areas of science interest
- Addresses the potential for cross-contamination between surface locations





Operational Implications



- Networked monitoring systems
 - Potentially shifting boundaries of special and protected regions
 - Real-time hazard assessments and response
 - Equipment cleaning and sterilization prior to and during surface mission
 - Standard and traceable handling and transfer protocols for preservation of biological and geological sample integrity
 - Toxic substance exposure mitigation; quarantine protocols
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- Pressurized crew cabin operations and venting
 - Crew waste management: storage, transfer, and disposal
 - Extravehicular activity: operations, suit design (e.g. suit leakage and dust accumulation)
 - Rover and human contamination transfer through direct and indirect contact
 - Science gathering and habitation facility development strategies
 - Planetary protection “Breaking the Chain” protocols

- Human operations and environment management are inextricably linked in in-situ exploration of a planetary surface
- How do we live and conduct operations on a planetary surface with the least risk of negative interaction?
 - Determine acceptable contamination limits and viability
 - Provide continuous, long term environmental monitoring (locally, regionally, globally) to inform potential shifts required in site placement or other management techniques
 - Effectively plan and locate human habitation area(s) and special science regions
 - Evaluate a variety of infrastructure and operations scenarios
 - Employ effective operational techniques: low latency telerobotics, sample handling and return, extravehicular and robotic exploration zoning, etc.
- Ongoing efforts
 - International Space Station vent sampling
 - Hi-SEAS analog surface instrumentation extravehicular activity protocols
 - Extravehicular suit design
 - Site design and analysis
 - Sample handling, storage, and transfer concept studies



Understand and manage the environmental interactions of the planetary “ecosystem”

Responsibly explore and utilize resources with proper management to ensure that interactions of the planetary “ecosystem” will not impede exploration and science goals