Test Before You Fly - High Fidelity Planetary Environment Simulation

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Introduction

- Global Space Exploration
  - Planetary
  - Near Earth Asteroids
- Specific destination
  - Designating achievable intermediate milestones for extended duration space exploration with which to quantify progress in this arena is not only prudent but a requirement of sound engineering practice.
  - Returning to the moon offers the most logical way to move this quest forward.
  - Moon-Base 2025 should be an engineering test bed for technologies applicable to long-term exploration missions.
  - Without these technologies, long-term exploration goals will be elusive.
- Irrespective of the destination, there is a critical need for rigorous testing of components, sub-systems, and systems in a realistic environment.

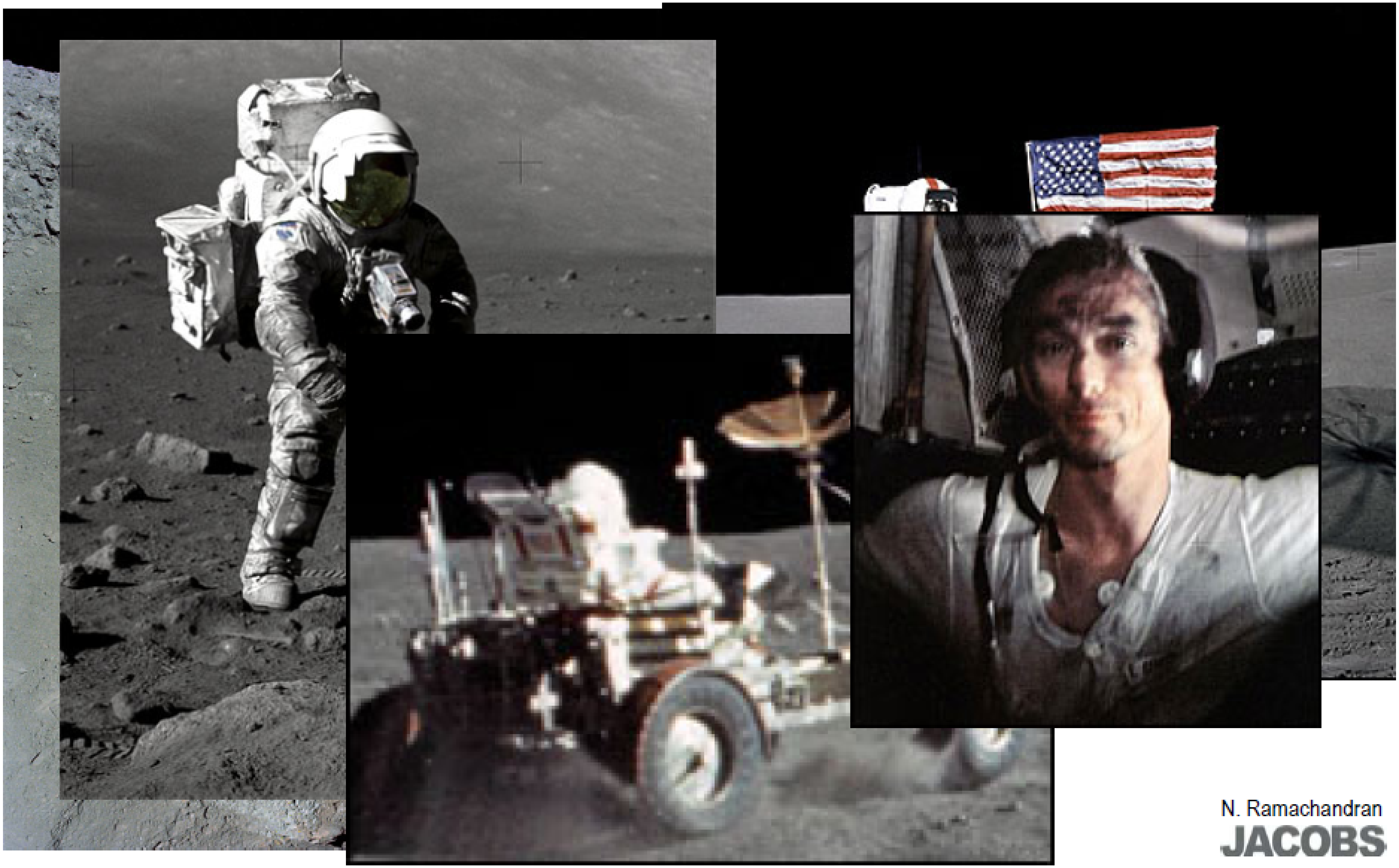
Environment at the Moon

- Equator and mid-latitude
- Environment
  - 14 Earth day diurnal period
  - Surface temperatures ~150°C local noon to -150°C before sunrise
  - Hard vacuum 10^{-12} – 10^{-10} Torr
  - Hard radiation environment
    - Electrons / Ions / Cosmic Rays
    - UV/VUV
  - One sixth Earth Gravity
  - Dust / Small regolith particles
  - Each has its own mitigation strategy
  - Specific focus on combinatorial effects due to dust, thermal conditions, radiation, and vacuum – high fidelity testing.

What are we trying to Solve ?

- What is known about the moon?
  - Regolith
  - Environment
- Apollo experience - What worked and what did not? Need to develop an acute understanding.
- What potential challenges do we face as we go back?
  - Short terms stays – Apollo model
  - Long term stays on surface
    - Habitat – human survival needs, power, transport, storage, equipment, etc.
- Can we solve them? List of issues and potential solutions. Develop an evolving strategy – ground testing to lunar experiments.
- NASA Approach – Project Dust, NASA Engineering Safety Center studies – lack of concerted, funded approach.

Moon is a dusty place - quite unique



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Specific effects of Lunar dust

- Crew life critical, mission critical, short term and long term requirements.
- Life support systems (habitat, EVA, safe havens).
- Mechanical systems – Components (bearings, bushings, gears, ball-screws, elastomeric and metallic seals, lubricants, other rotating surfaces, fasteners: latches, clamps, bolts, etc.), and Subsystems.
- Electrical systems: Electrostatics, thermal cycling.
- Fundamental studies (additional property measurements, size distributions, characterization by location, etc.)

Lunar Dust Effects And Removal Techniques Were Studied In 1967

- Dust Significantly Increases Amount Of Solar Heat Absorbed By Space Radiators

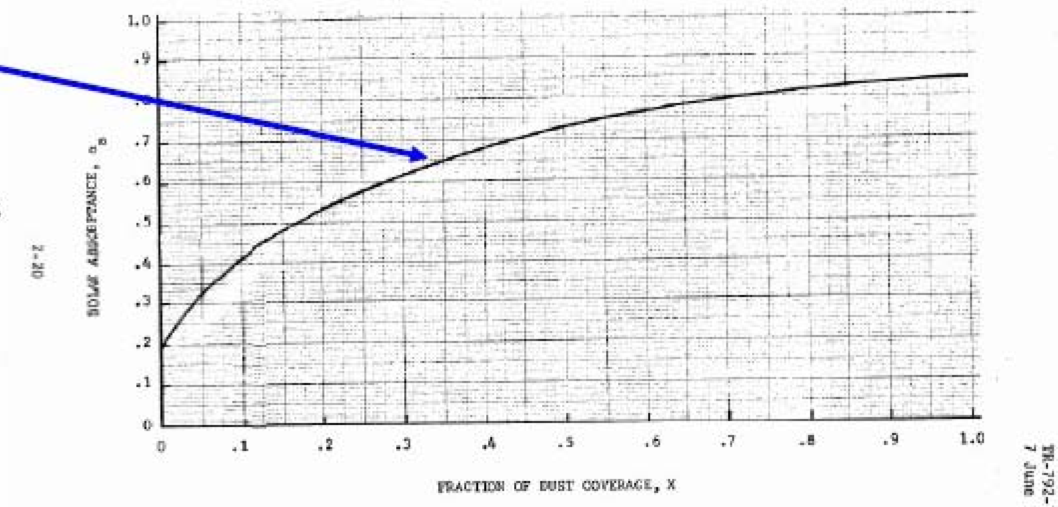


Figure 2-4. VARIATION OF TOTAL SOLAR ABSORPTANCE WITH DUST COVERAGE OF S-13 PLATE

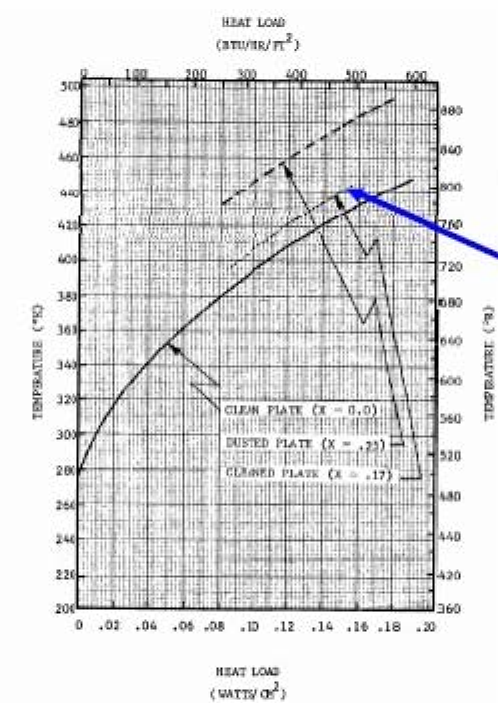
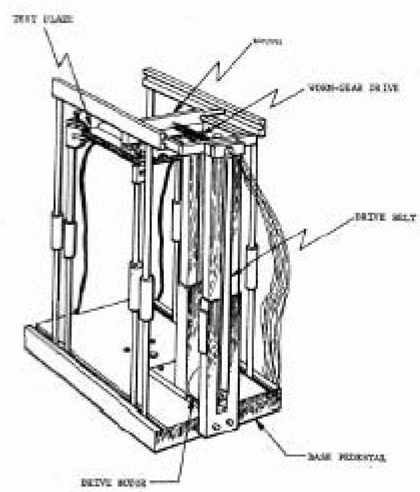


Figure 3-30b. TEMPERATURE VARIATION WITH HEAT LOAD (SOLAR SIMULATOR ON) FOR MECHANICAL BRUSH TEST RUN

Chart courtesy R. Creel, SAIC

Misleading Earth-Based Test Results

- Brushing Restored Near-Original Solar Absorptance
- Fluid Jet Was Superior, But Had Weight And Safety issues



Brush Test Apparatus

Specific example*

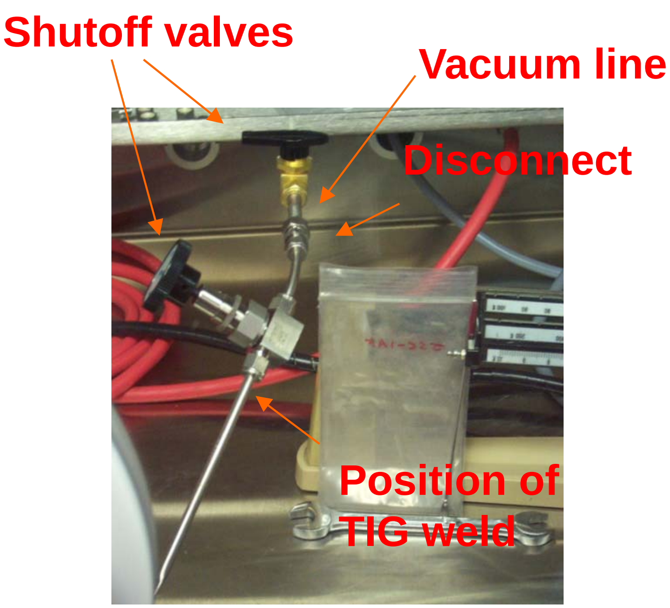
• High temperature alloys are vital for power plants and energy conversion devices, and the dissipation of excess heat; e.g. Heat pipes
• Continuous operation for 10 or more years in a hostile environment is needed with little maintenance possible
• Must be chemical and creep resistant in the high vacuum of space (lunar), or Martian atmosphere (7 mb CO_2).
• Must operate reliably in low gravity conditions. Probable exposure to penetrating dust, which could react with heat pipe materials at the high temperatures anticipated, and in the predicted environment.
• Design and carry out tests to evaluate reactivity of Inconel 625 to withstand the lunar environment, with simulant regolith, JSC-1A.
• Recommend alternative materials, and design tests for future programs.

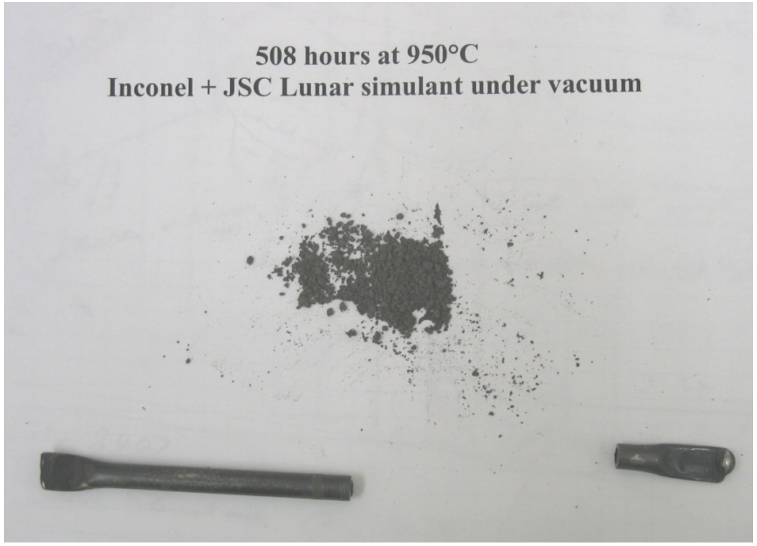
Test Specifications:
• Inconel 625 – frequently used for high temperature heat pipes. Composition: ~58% Ni, ~21.5% Cr, ~9% Mo, ~5% Fe, ~3.5% Nb/Ta, ~1% Co, ~2% Others.
• Tubes of ¼" OD, 3/64" wall thickness and 5" long were TIG welded closed at one end.

*Compatibility Studies of Inconel 625 with Lunar Regolith Simulant – D. Gillies et al., Space Tech. App. Intl. Forum, 2007

Specific example

• After loading the tubes with JSC-1A simulant, they were evacuated within the glovebox, disconnected and then TIG welded.
• Tubes were then heated for periods of time from 1 week (168 hrs) to 3 weeks (508 hrs). Furnace operated in air. Temperatures of 750°C, 875°C, 950°C, and 1000°C were used.
• Post heat treatment, the tubes were opened with a tube cutter, and the powder removed for analysis.
• The tubes were then cut lengthwise to reveal and extract material from the inner surface.





Specific example

- X-Ray Diffraction of processed simulant shows formation of a new Cr-containing spinel (mineral) phase. Cr must have originated in the Inconel.
- Much less glass phase in the simulant after 750°C (and possibly lower).
- Chemistry shows increase in Cr in simulant at 950°C.
- Chemistry shows an increase of iron in the metal at 950°C.
- Chemistry shows a decrease of iron in the simulant at 950°C.
- First conclusion is that Cr from the metal has reacted with the simulant.
- Also iron from the simulant has reacted with the metal.
- Cr-containing materials are susceptible to loss by evaporation under vacuum at elevated temperatures.
- Reaction has taken place between the Cr vapor and the simulant resulting in new phases.

Specific example

- Alloys containing “high” vapor pressure elements are likely to degrade at high temperatures (over 750°C) over long durations.
- Stainless Steels, Inconels are used in high temperature applications on Earth, but in oxidizing atmospheres, and not in vacuum.
- Major issue is on the outside, particularly on the moon, where a hard vacuum exist and the regolith is present.
- Results apply to any system operating at high temperature.
- Refractory metals with lower vapor pressures, such as Re, Mo, and W should be tested for application for long duration, high temperature service in Lunar applications.
- Coatings should be examined as alternatives.
- Comprehensive testing on Earth should be done to examine compatibility issues.
- Perform experiments on the moon and learn from inferences drawn.

Mitigation Strategies

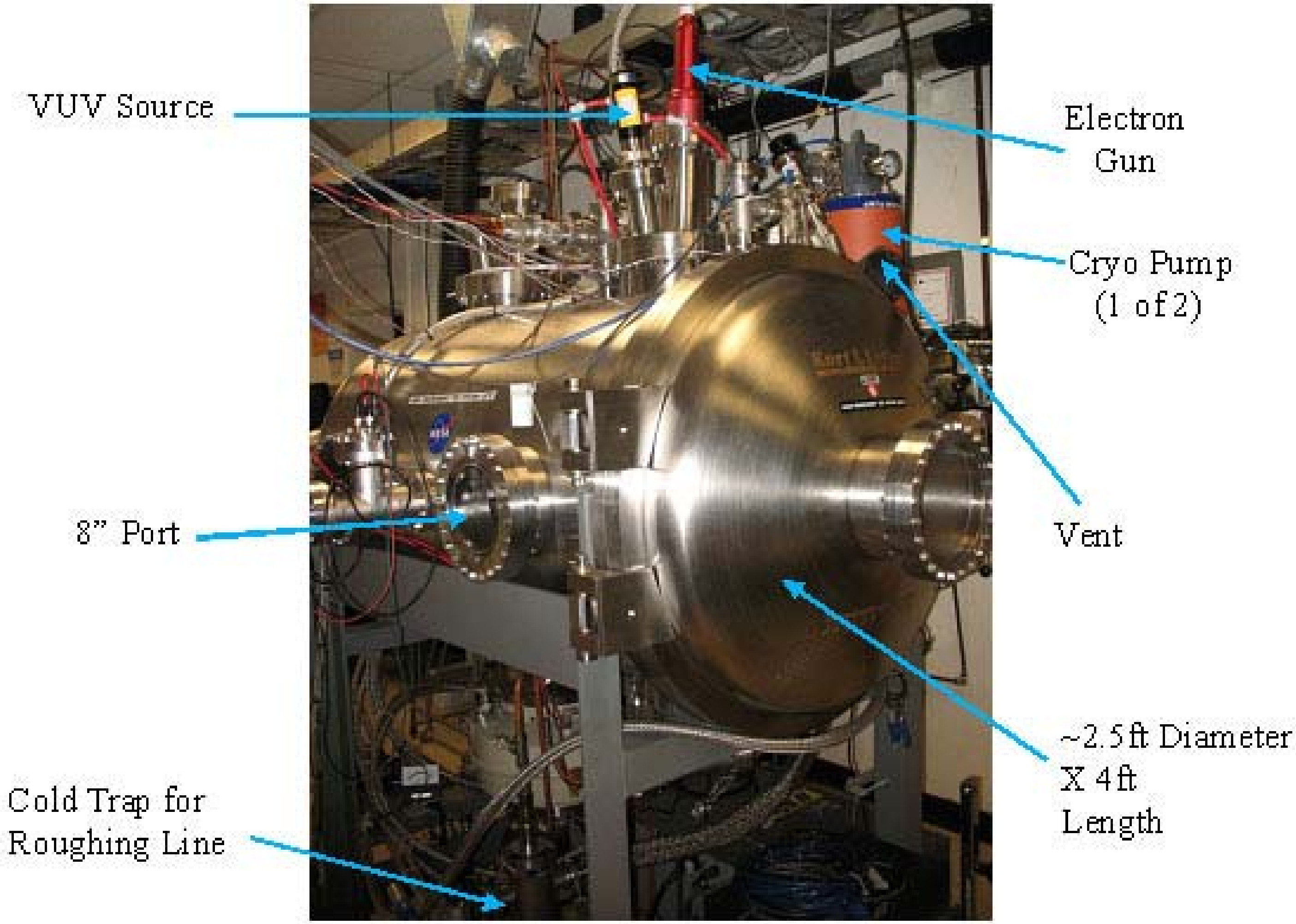
- Surviving in the lunar environment - NESC Lunar Dust Workshop, Jan. 2007
  - Avoid
    - Design and test
  - Remove
    - Active systems
      - Electrodynamic
      - Electrostatic shield
      - Magnetic
      - Plasma
    - Passive methods
      - coatings
      - Fibers, textiles non-woven technologies,
      - Filters
  - Tolerate
    - Design to avoid problem. Verify and Validate by testing.
  - Other(?)

Need for High Fidelity Tests

- Long term manned stays (Lunar Surface) and short term, large distance targets (asteroids) demand that systems be reliable and robust.
- Testing in the environment is ideal
- Testing on Earth with simulated environment is practical and cost effective
- High Fidelity systems and organizations exist that can do such testing
- Approach
  - Identify possible risks. Minimize risk by developing tolerance.
  - Adopt sound engineering design and practice.
  - Develop robust qualification program.
  - Perform tests in high fidelity simulated environment using standardized simulant/s.
  - Incorporate mitigation strategies.
  - Iterate on design and engineering as more is known.
  - Obtain specific in-situ measurements for design validation and ground-based verification testing.

Planetary Environment Test System (PETS) - MSFC

PETS Chamber

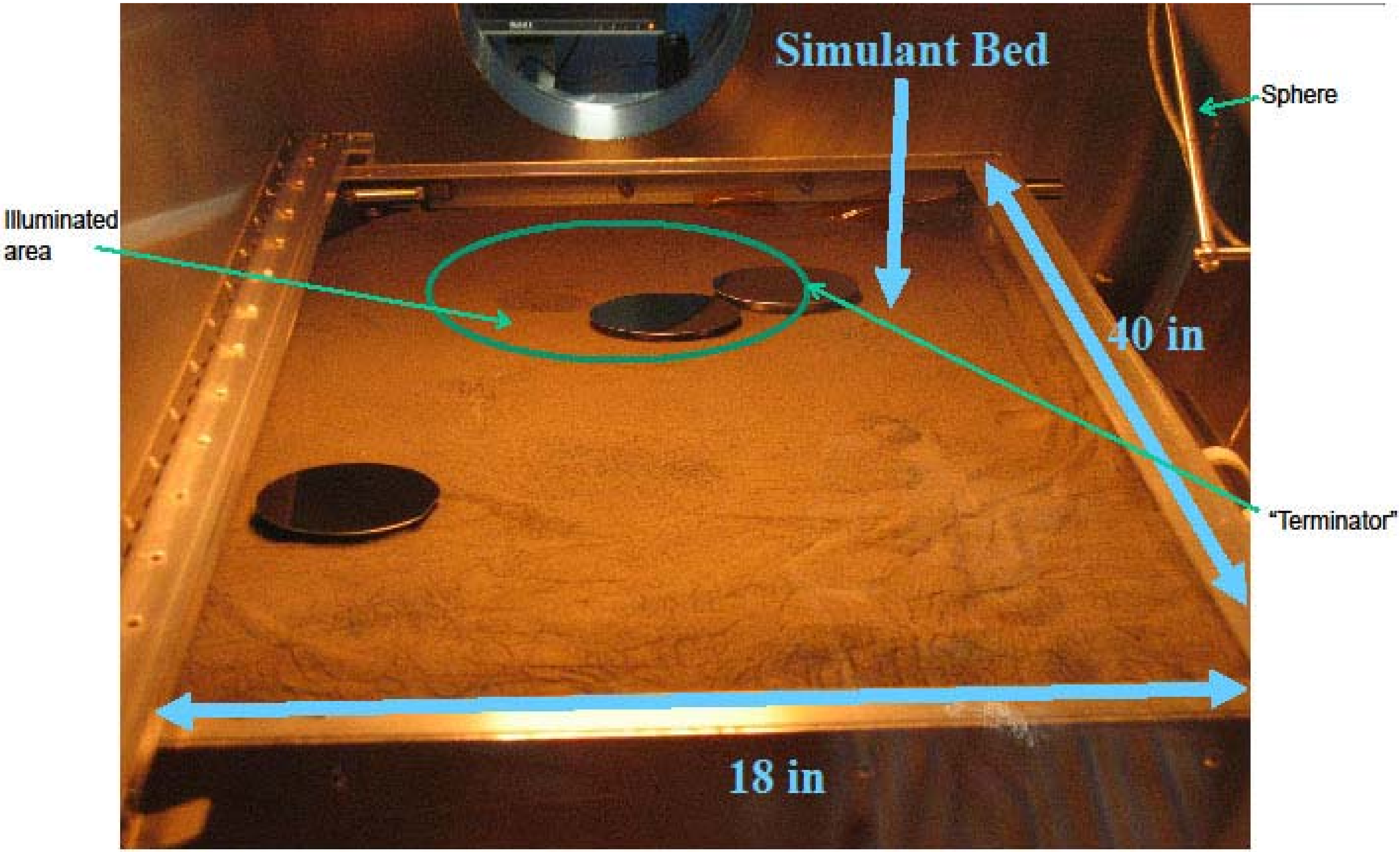


PETS Environment Simulation Capabilities

Environment	Capability
High Vacuum	Cryo-or turbo-pumped vacuum chamber with base pressure of 1 x 10^{-7} Torr
Temperature Range -150°C to +130°C	Liquid Nitrogen (LN_2) Cold Shroud (-190 °C) or Cold plate, Quartz Lamp Array (+150 C)
Solar Radiation	UV and Vacuum Ultraviolet Lamps
Charged Particle Radiation (Solar Wind)	Electron Flood Gun and low energy proton source
Regolith Simulant	Containment system to hold 100 kg. 75 kg (JSC-1A) in vacuum chamber at 1 x 10^{-7} Torr.
Volume	$0.45m^3$ or ~$16ft^3$

PETS Chamber Internal View with Rake

PETS Chamber Internal View with 75kg Simulant



Recommendations

- Develop a good understanding from past manned and unmanned lunar missions of what worked and what did not work.
- Adopt a "holistic" approach to design, analyses and testing – a challenge.
  - Radiation environment, Hard Vacuum, Thermal cycling, Fractional gravity, Unique dust environment, process parameters (pressure, temperature, fluids, etc.)
  - Interactions may produce unexpected results.

Recommendations

- Develop high fidelity terrestrial test facilities to understand
  - Fundamental effects (dust behavior in plasma)
  - Mechanical systems (component, subsystem, system level)
  - Electrical systems
  - Life support and surface mobility
  - Crew health

- The lunar environment cannot be sufficiently emulated on Earth, therefore system verification testing will rely to some extent on extension by analysis and ultimate testing in the field (lunar operations).

Recommendations

- Smart design (avoidance), inclusion of mitigation strategies (removal), and robust design (redundancy and tolerance) should be the philosophy followed in every aspect of system design.

- Include the development and testing of passive and active technologies in dust mitigation strategies.

- The entire process should be dynamic and iterative as we learn and adapt from initial remote sensing, to robotic, to ultimately manned missions.

- MSFC facility is open to collaborations. Please contact the authors.