SURVEY OF DUST ISSUES FOR LUNAR SEALS AND THE RESOLVE PROJECT

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Challenges of Future Lunar Exploration

"Dust represents the single largest technical challenge to prolonged human presence on the Moon."

Harrison Schmidtt, Apollo 17 Astronaut March 2005

- The extent and duration of planned lunar surface activities is much higher than prior Apollo experiences.
- Systems and components will be exposed to environmental factors for periods of time orders of magnitude longer than those previously addressed.

Dust mitigation strategies:

1. Design systems tolerant of dust properties
2. Develop techniques to clean or remove dust from surfaces
3. Active abatement methods to minimize or eliminate deposition and/or adhesion of dust

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Apollo Lunar Sample Return Containers a.k.a. "Rock Boxes"

- Used to return lunar regolith samples to earth
- Triple seals designed to provide a vacuum seal of 10^{-6} torr
- Aluminum box (7075 AA) with Knife edge seal in soft indium alloy (90% indium, 10% silver), 150 cm long

•Teflon spacer prevents contact prior to use.
•Single use and pressure required to maintain sealing.
•Double O-rings (L608-6 fluorosilicone) for add'l sealing.

Of the 12 Rock Boxes, 4 had substantial leaks due to bag material or dust on sealing surface[1]

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The Apollo Lunar Sample Return Container (ALSRC) maintained a lunar-like vacuum around the samples until they were opened in the Lunar Receiving Laboratory. In practice, substantial leakage was detected in 4 of the **12** ALSRC's returned from the moon due to pieces of equipment or dust interfering with the seals.

[1] Stansbery, E.K., Kaplan, D.I., Allton, J.H. and Allen, C.C.(1997) Planetary Protection Issues for a Mars Sample Return Mission. Report to the NASA Planetary Protection Officer. October 1997

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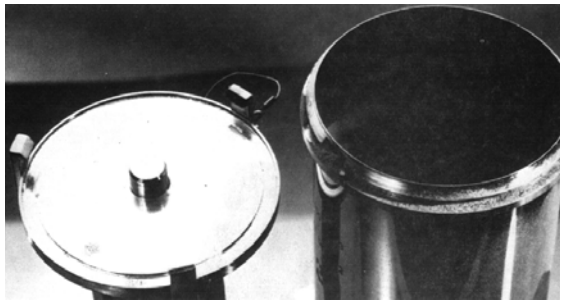
Apollo
Special Environmental Sample Containers



- 340L S.S. with knife edge seal into indium alloy
- 18 cm long
- At end of Apollo missions, no reports of leakage

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Apollo Space Suits

Space Suits

- Designed to operating pressure: 3.75psig (25.8 KPa),
  temperature: $\pm$ 250 ^{o}F ($\pm$ 394 ^{o}K),
  maximum leak rate: 0.0315 lb/hr (180 scc/min)
- Leakage increased with use.

Apollo Helmet Attaching Neck Ring

- Manufactured by Air-lock Inc.
- Aluminum alloy 7070-T6 treated with an anodized coating.
- Helmet disconnects have interior stainless steel bearings
- Seals in the Extravehicular Mobility Suits (EMS) were used to attach the space helmets to the spacesuit by a pressure-sealing neck ring.
- Between Extra-Vehicular Activities (EVAs) the helmet disconnect seals were cleaned and re-lubricated with Krytox oil and grease to reduce leakage.

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1. Carson, M.A., Rouen, M.N., Lutz, C.C. and McBarron, J.W.(1975) Biomedical Results of Apollo. Chapter 6 Extravehicular Mobility Unit. NASA SP-368
2. Young, L.A. and Young, A.J. The Preservation, Storage, and Display of Spacesuits. Smithsonian National Air and Space Museum Collection Care, Reprot Number 5, December 2001.
3. Apollo Operations Handbook (1971) Extravehicular Mobility Unit. Volume I. System Description. CSD-A-789-(1). Revision V, March 1971.
4. Gaier, J.R. (2005) The Effects Of Lunar Dust On Eva Systems During The Apollo Missions. NASA TM 2005-213610, March 2005.

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Apollo Helmet Attaching Neck Ring

- Attached to suit by a self-latching self-sealing quick disconnect coupling

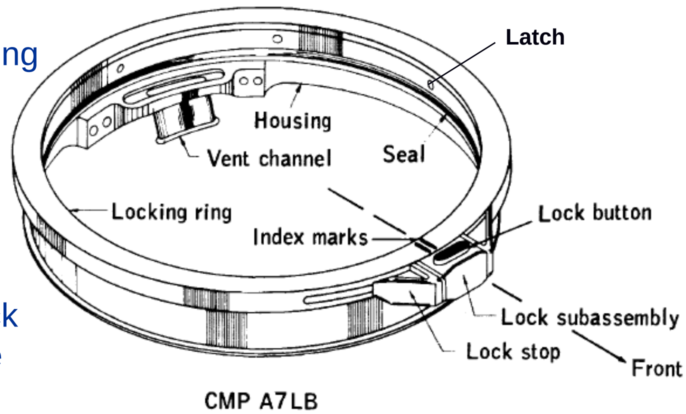
It has….

•Neck ring housing

•8 latch assemblies

•A rotating lock ring

•Push button lock assembly on the locking ring.



Command Module Pilot (CMP) Helmet

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Apollo Space Suits

Glove Disconnect Assembly

- Manufactured by Air-lock Inc.
- Aluminum alloy 2024-T4.
- Have interior stainless steel bearings.
- Pressure-sealing disconnects attached gloves to spacesuit
- arms
- Wrist bearings and rotational hardware connectors had fabric coverings to keep out the dust.
- Between EVAs glove disconnect seals were cleaned and re-lubricated with Krytox oil and grease to reduce leakage.
- Air-lock has a patent (4596054) on the synthetic resin lip seal used in the bearing assembly of the space suit at the rotary motion locations, such as at the glove connection.
- The suit side has a manually actuated lock/unlock mechanism.
- The glove has a sealed bearing that permits 360^o glove rotation.

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1. Young, L.A. and Young, A.J. The Preservation, Storage, and Display of Spacesuits. Smithsonian National Air and Space Museum Collection Care, Reprot Number 5, December 2001.
2. Apollo Operations Handbook (1971) Extravehicular Mobility Unit. Volume I. System Description. CSD-A-789-(1). Revision V, March 1971.
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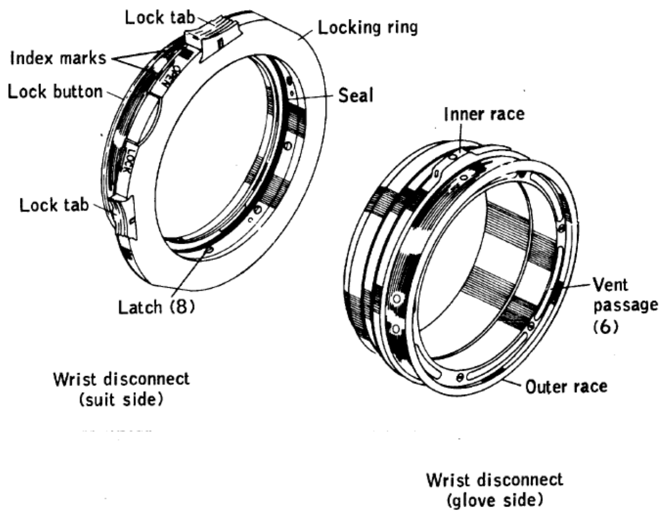
Apollo Space Suits-Glove Disconnect Assembly



Reference: Apollo Operations Handbook (1971) Extravehicular Mobility Unit. Volume I. CSD-A-789-(1)

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Lunar Soil Characteristics

Characteristic	Description
Size	90% < 1000 µm, 70% < 100 µm
Shape	Angular/subangular sharp
Bulk Density (0-30 cm)	1.58 ± g/cm^3
Hardness	5-7 (Mohs scale)
Porosity (0-15 cm)	52% ± 2%
Cohesion (0-15 cm)	0.52 KPa (.0053 kg/cm^2; .0754 psi)
Toxicity	Primarily non-toxic
Corrosiveness	Not active in vacuum
Electrostatic	Highly charged
Magnetic	<20 µm high ferromagnetic susceptibility
Thermal Conductivity	1.72-2.95 x 10^{-4} W/cm °K (Apollo 17)
Compressibility (loose)	0.3 (compression index)

Reference: Fuhs, S., Harris, J.(1992) Dust Protection for Environmental Control and Life Support Systems in the Lunar Environment. Proceedings of the Lunar Materials Technology Symposium.

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Size 1000 µm=1 mm=.04”

Bulk density - property of particulate materials. mass particles divided by the volume they occupy. The volume includes the space between particles as well as the space inside the pores of individual particles.

Hardness - resistance to permanent deformation (Diamond=10, Quartz=7, Gypsum=2)

Porosity of a porous medium (such as rock or sediment) describes how densely the material is packed. It is the proportion of the non-solid volume to the total volume of material. 15 cm depth measurement?

Cohesion-particles stick together

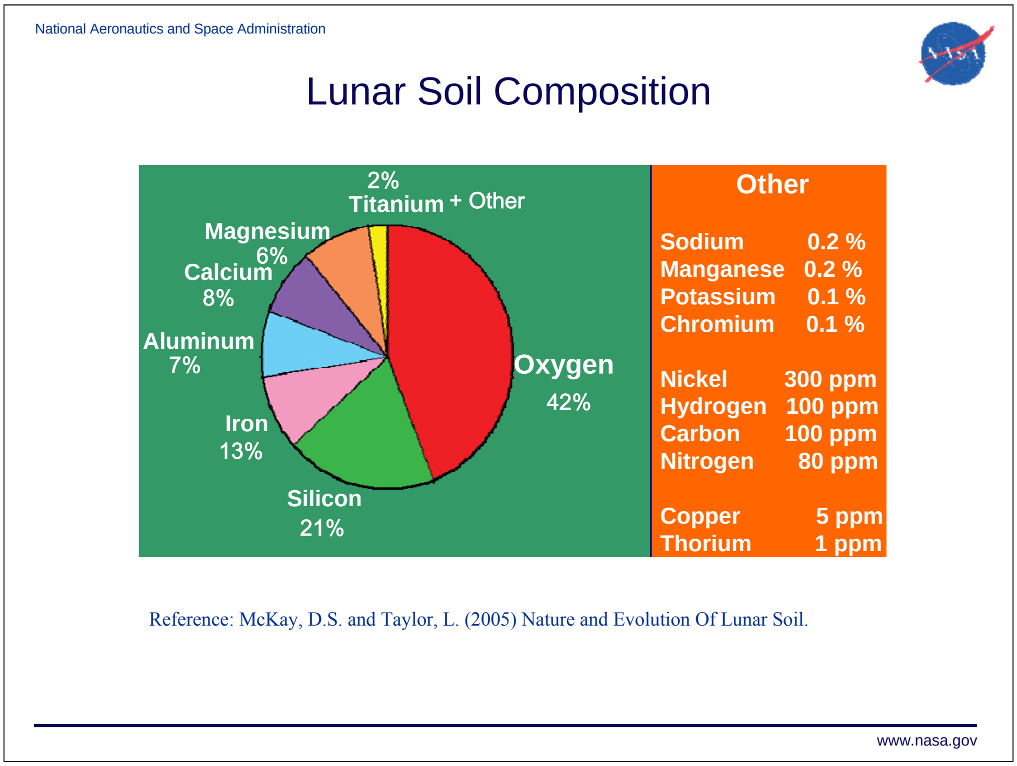
Electrostatic- forces exerted by a static (i.e. unchanging) electric field upon charged objects

Magnetic- Susceptibility of Soil Particles Increases as Grain Size Decreases; Effects of Vapor-Deposited Nanophase Feo are a Direct Function of Surface Area and Most Pronounced in the Finest Grain Sizes; Virtually All <10 µm Particles are Easily Attracted by a Simple Hand-held Magnet

Thermal Conductivity- ability to conduct heat. Apollo 17 heat flow probes 2.36 m

Copper is 385 W/m-K, 3.85 W/cm-K

Compressibility is a geological term used to quantify the ability of a soil to reduce in volume with applied pressure



Composition from Apollo mission samples at specific sites

Other

Titanium 2%????

Sodium 0.2 %

Manganese 0.2 %

Potassium 0.1 %

Chromium 0.1 %

Nickel 300 ppm

Hydrogen 100 ppm

Carbon 100 ppm

Nitrogen 80 ppm

Copper 5 ppm

Thorium 1 ppm

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Lunar Environment

Equatorial radius	1738.1 km
Surface area	37.8 x 10^6 km^2
Mass	7.35 x $10E^{22}$ kg
Density	3.34 g/cm^3
Surface gravity	1.63 m/sec^2
Orbital Period around earth	27.32 Earth days
Atmospheric Pressure	3 x 10^{-13} KPa (2 x 10^{-12} torr)
Measured Surface Temps. (Apollo)	Min -181 C (92 K) Max 111 C (384 K)
Atmosphere (%)	Helium (25);Neon (25);Hydrogen(23);Argon(20); Trace: Methane; Ammonia; Carbon Dioxide
Lunar Radiation Sources	Galactic cosmic rays (GCR) Solar particle events (SPE) wind, cosmic rays

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Summary of radiation found on page 48 of:

Heiken, G.H., Vaniman, D.T. And French, B.M., "LUNAR SOURCEBOOK, A User's Guide to the Moon," Cambridge University Press 1991.

Estimated lunar surface temperature of 40K from Lunar Study Group in 1972 based on Earth-based observations and need to be updated with actual measurements on the Lunar surface.

Dalton, C. and Hoffman, E. (1972) "Conceptual Design of a Lunar Colony" NASA Grant Rpt. NGT 44-005-114, NASA, Washington, D.C.

Shakleton Crater

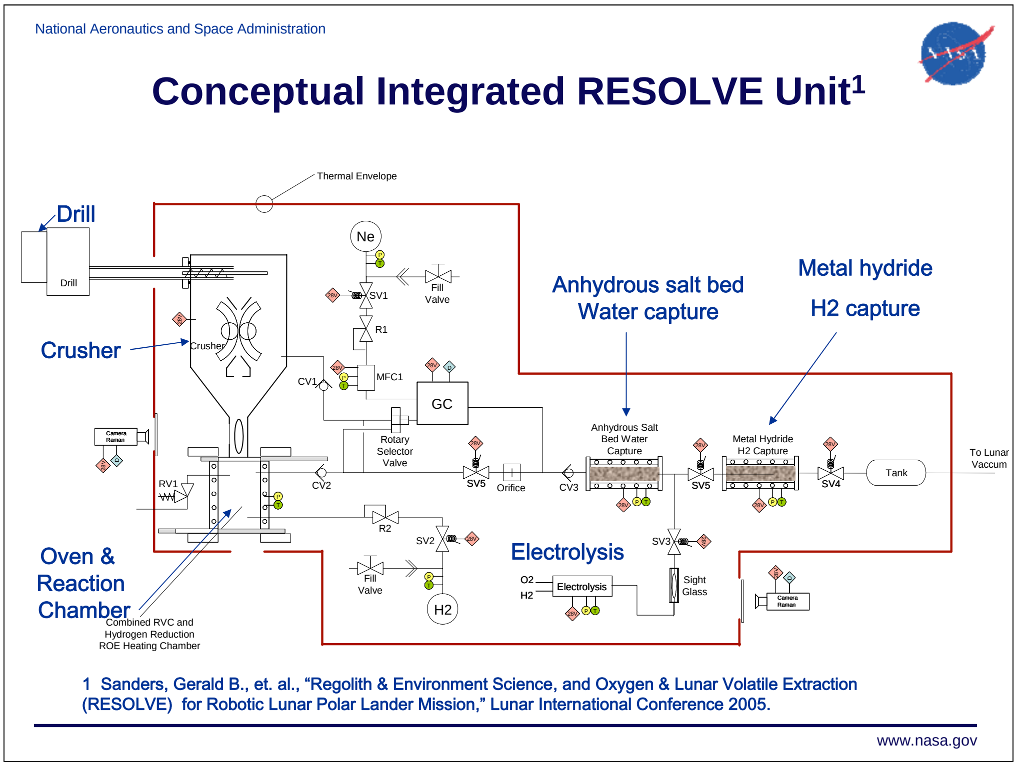
Due to this almost constant illumination, the crater rim is considered a preferable location for a future lunar outpost.[9] The light could be converted into electricity using solar panels. The temperature at the location is also more favorable than on most of the surface, and does not experience the extremes along the lunar equator where it rises to 100 °C when the Sun is overhead, to as low as −150 °C during the lunar night. The continuous shadows in the south polar craters cause the floors of these formations to maintain a temperature that never exceeds about −173 °C, or 100 **K**.

http://www.answers.com/topic/shackleton

The RESOLVE project

- **Purpose:**
  - find water or ice in lunar soil
  - demonstrate the ability to produce water and hence oxygen and hydrogen for life support and propellants from lunar regolith.
- **How will this be done?**
  - Core samples of lunar regolith heated in a Volatiles Characterization Oven to 150 ºC to look for water vapor or other volatiles.
  - Hydrogen reduction process reacts hydrogen to the oxides in the lunar regolith to form water, which can then be split into H_2 & O_2 using electrolysis. Process requires heating to ~900 ºC.

Self-explanatory



[1] Sanders, Gerald B., et. al., "Regolith & Environment Science, and Oxygen & Lunar Volatile Extraction (RESOLVE) for Robotic Lunar Polar Lander Mission**,"** Lunar Interanational Conference 2005.

Lunar regolith is loaded into the crusher, goes to heating chamber for volatiles characterization, and hydrogen reduction process. Off-gases from the oven pass through anhydrous salt bed for water capture. Water then goes through electrolysis to produce oxygen and hydrogen. For hydrogen reduction process, hydrogen is supplied to the reaction chamber (oven). Again the off-gases pass through the anhydrous salt bed for water capture. Remaining gases pass through a metal hydride bed for hydrogen capture.

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Seal Requirements for Volatiles Characterization Oven (VCO)

- Capable of -233 to 150 ºC
- Effective for 0-75 psi differentials (may be revised to 150 psid)
- Low or no out-gassing in a vacuum (lunar 10^{-14} atm or 7.6×10^{-12} torr)
- Leakage rate less than 0.5 cm^3/min during 20 minutes processing time at 5 atm differential assuming H_2
- Compatible with hydrogen, oxygen, water, water vapor, other volatiles
- Tolerant of vibrations up to 10g at 80-100 Hz
- Reusable up to 40 open/close cycles
  – Resistant to lunar radiation environment
  – Resistant to damage from lunar dust
  – Material repels lunar dust or has means to remove dust from seal*
  – Material flows around lunar dust trapped at seal interface*
- Light weight → Small load to achieve a seal
- Inexpensive
- High reliability → Low number of components
- Geometrically compatible with interface requirements

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Challenges of Sealing Hydrogen Reduction Reaction Chamber

- Same requirements as the volatiles characterization oven except:
  - 900 ºC
  - 3 batches processed at 900 ºC
- Initial bench testing allows the volatiles characterization oven to be separate from the hydrogen reduction chamber.
- Want the same chamber for both processes to reduce weight .

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Some Options for Sealing VCO

- O-Rings
  - Metal
  - Viton A -
  - Teflon – cold flows around single layer of dust particle
- Tungsten Carbide Knife edge on Tungsten Carbide
  - Knife is very hard and very sharp for cutting any particles between it and the hard flat sealing surface
- Knife edge into Indium or other soft metal that could be re-melted after each use to restore the “gasket” material.

Key: Protect sealing surface from dust !

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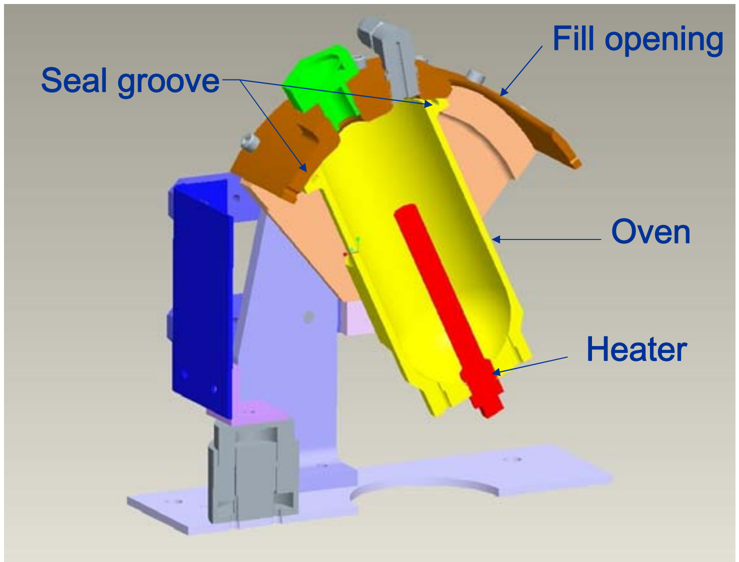
A Volatiles Characterization Oven Concept



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This is a cross sectioned view of a concept design being considered for the Volatiles Characterization Oven. The yellow oven rotates relative to the brown lid to the fill opening for loading regolith into the oven. Heating of the regolith occurs in the position shown in this chart. To dump the regolith the yellow oven and brown lid rotate ~180 degrees to the right and the yellow container rotates to align with the fill opening. Some type of o-ring would ride in the seal groove. The o-ring would be subject to sliding motion. The lid would shield the o-ring during the fill operation. However, it may still be necessary to provide a means to provide a wiper to clear any dust that may fall onto the o-ring as it slides past the fill opening.

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Summary

- Lunar dust poses a challenge to long term missions on the moon.
- Assessment of material capabilities in the lunar environment is needed.
- Protecting and/or cleaning sealing surfaces of lunar dust must be addressed for re-usable seals.
- The RESOLVE project poses a challenging seal problem.

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