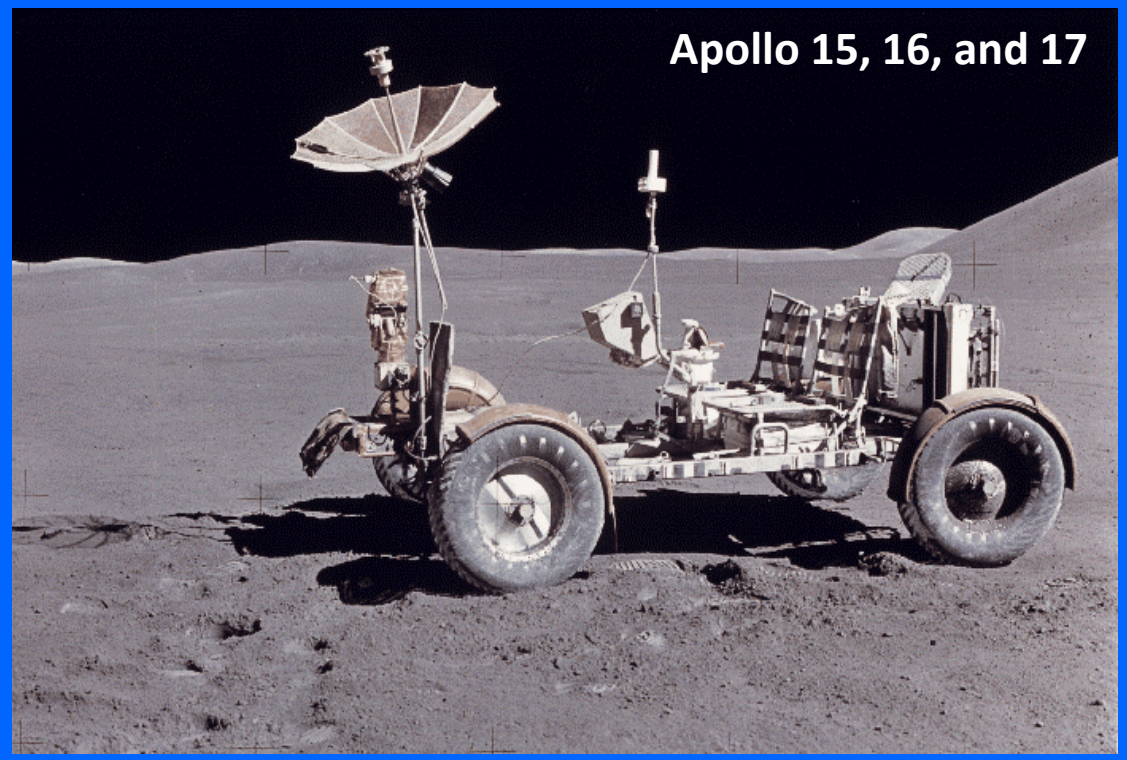
Apollo Dust Lessons Learned For Artemis



Let's Keep Lunar Dust "Outside" and Greatly Increase "Science" Time

Ron Creel - Retired Space and Thermal Systems Engineer and Apollo Lunar Roving Vehicle (LRV) Team Member

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1- Moonprint Solutions, 2- Stony Brook Univ., 3- Space Coop, 4- NASA Astronaut and Texas A&M Professor, 5- NASA Ames

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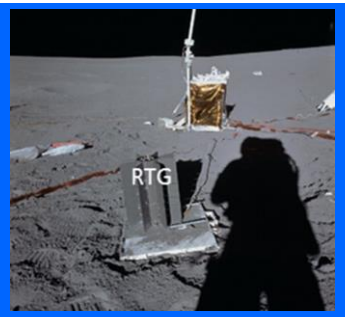
Lesson 1 - Ever Present Hazardous Dust Cannot Be Avoided On The Moon

- Lunar Dust Proved to be a Significant and Potentially Dangerous Hazard on Previous Apollo Moon Exploration Missions with Short Crew Exposure Times
- Lunar Dust Was Easily Stirred Up and Deposited on Crew Suits, Rovers, and "Science" Equipment During EVAs and Then Brought On Suits Into the Lunar Module Habitat

Driving

Walking / Falling

Sampling



Apollo Lunar Surface Experiment Package with Dust on Radioistope Thermoelectric Generator (RTG)

Fender Repair on Apollo 17

- Increased Thermal Radiator Solar Absorptance (α_s) Resulted in Reduced Battery and Communication Equipment Cooldowns/Re-planned Cover Openings, Battery Switching, and "Overtemp" On the Surface Electrical Properties (SEP) "Science" Experiment
- Lunar Dust Behavior at New Proposed Moon Exploration Sites is Unknown (Poles/PSRs)

EVA = Extra Vehicular Activity

PSR = Permanently Shadowed Region

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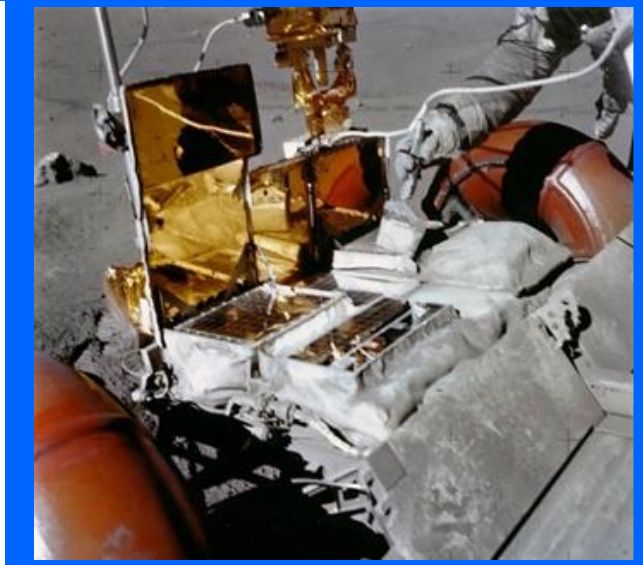
Lesson 2 - Valuable "Science Time" Was Wasted In Fruitless "Housekeeping"

- **Misleading Pre-Apollo 15 Earth Testing at the Manned Spacecraft Center, Using Apollo 12 Soil and Much Higher Pressure, Predicted That Brushing Could Be Used on the Moon to Effectively Clean Thermal Control Surfaces and Crew Suits**

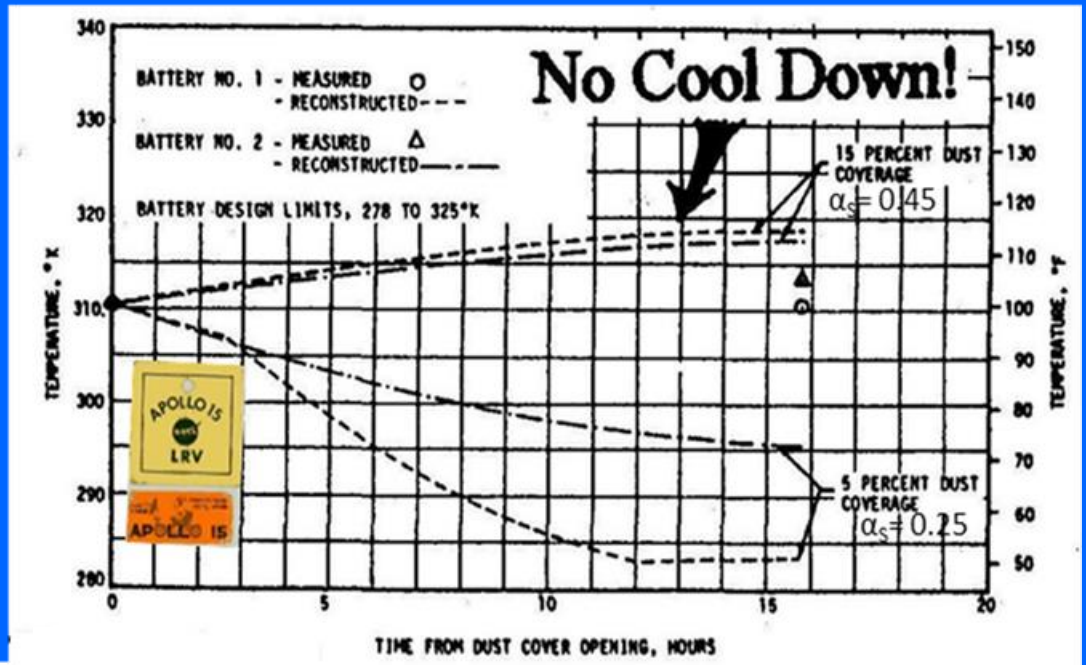
F-201 Vacuum Chamber

The dust-deposition tests used the LRL F-201 vacuum system, a vacuum chamber designed especially for use in complex vacuum operations. This chamber is a two-glove system in which glove operators perform the operations necessary to fulfill the test objectives. The test operations are described in detail in a later section of this paper. Figure 3 depicts a view, through the science observer port, showing the reflectometer head, the sample jig, the sample plates, and other supporting equipment in chamber F-201. The chamber working area measures approximately 32 inches from front to back and over 4 feet from side to side. The chamber pressure during test operations was maintained between 10^{-5} and 10^{-6} torr, which was the minimum attainable by the F-201 system. The reflectometer was outgassed under vacuum levels in the 10^{-6} torr region for several days prior to the test so that it would not introduce an unacceptable gas load into chamber F-201 during pumpdown operations.

Earth Brushing Restored Near Original Solar Absorptance



Astronaut Brushing Dust from LRV Thermal Radiators



After Brushing Radiators, LRV Battery Temperatures During Cooldown 2

Extensive Dust Cleaning Regrettably Did NOT Work On the Moon

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Misleading 1971 Pre-Apollo 15 Dust Brushing Testing at MSC (Now JSC)

Lunar Roving Vehicle Thermal Control Radiators Were Designed with the Expectation that Lunar Dust Could be Successfully Removed on the Moon - Did NOT Happen!

Bad Earth Testing Results/Conclusions

The force of adhesion may be varied by eliminating or reducing the electrostatic component (reducing the charge density). This reduction may be accomplished by modification of the surface, namely, replacing certain surface molecular groups with others. This approach was not feasible, in the study described, since thermal control coatings are involved.

Theoretical indications are that conducting particles will be discharged when they fall on a grounded surface; however, insulating or semiconducting particles tend to retain their charge. Furthermore, if the surface is nonconducting and nongrounded and if other means of charge leakage such as ionization of the air are impossible, then Coulomb forces may produce adhesion of the particles for a considerable time.

It is hoped that further tests can determine whether adhesion of lunar soil is a strong or a weak function of electrostatic charge. A proposed experiment setup will involve the sample coming into contact with a grounded metal plate and being brushed with a grounded brass-bristle brush. These data will be compared to data in which the sample or the brass-bristle brush has not been grounded.

Effect of Ultrahigh Vacuum

There are indications (ref. 4) that particles of a silicate material in an ultrahigh-vacuum environment (6.3×10^{-10} to 1.3×10^{-9} torr), with a particle size distribution nearly equivalent to that of lunar soil, exhibit adhesion to a substrate to a greater degree than at somewhat higher pressure levels (10^{-6} torr). Therefore, it is appropriate to perform additional tests with lunar soil at ultrahigh-vacuum levels to compare with those tests previously performed at vacuum levels in the 10^{-6} torr range.

AIAA Paper No. 71-459

LUNAR DUST DEPOSITION EFFECTS ON THE SOLAR ABSORPTANCE OF THERMAL CONTROL MATERIALS

by
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Recommendations for Future Tests

A literature study yielded the following two categories which are worthy of future studies:

1. Effect of static charge on adhesion of lunar dust
2. Effect of ultrahigh vacuum levels on adhesion of lunar dust

A discussion of each category is presented.

Effect of Static Charge

Reference 3 indicates that the force of adhesion and the charge value are proportional, as evidenced in the detachment of small spherical glass particles from painted surfaces. Also, the electrical charges increase as the particle size diminishes so that the electrical component of the adhesive forces also becomes greater. Although these data were obtained for small solid particles, further research into this phenomenon with lunar dust would be useful since it appears that electrostatic forces may play a major part in adhesion of dust to a painted surface.

Not True on the Moon

Concluding Remarks

Test conclusions are summarized as follows:

1. Brushing dust from the sample surface is an effective method of removing dust.
2. The nylon-bristle brush is far superior to the brass-bristle brush for removing the lunar dust from the sample surface.
3. There is apparently no significant difference between the effect of lunar dust which was stored in a vacuum and that which was stored in nitrogen when both types of dust are applied in a vacuum environment.
4. There is a wide variation in adhesion of lunar dust to various materials.

As a result of these lunar-dust-deposition tests in a vacuum environment, the following additional comments are made:

1. The nylon-bristle brush is quite efficient and should be considered for use in removing lunar dust from thermal control materials.
2. In future ground tests of this type, lunar dust which is stored in a nitrogen environment at atmospheric pressure can be used in vacuum tests without significant loss in efficiency.
3. Of the possible thermal control materials for use in lunar surface operations, quartz second-surface mirrors, which are highly efficient thermally, can apparently be cleaned easily

Much Lower Pressure Testing Recommended

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Lesson 3 - Must Listen to the Right Persons About Dust Problems and Solutions

Apollo 12 Crew Mission Report Observed "Some Type of Throwaway Overgarment for Use on the Lunar Surface May be Necessary."

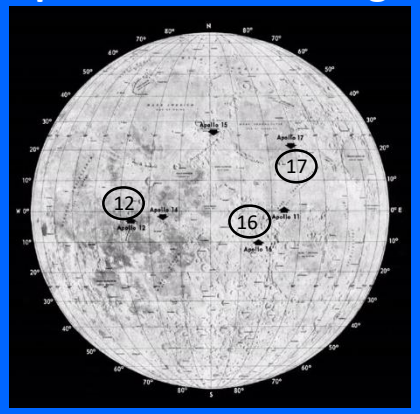
"On Apollo 16 we had brought a lot of lunar dust into the Lunar Module. When we got into orbit, all the dust floated all over the cabin. It was so bad we were concerned about our Environmental Control System, so we stayed buttoned up in our suits. After we docked, Mattingly would not let us come into the Command Module. He floated over a vacuum cleaner and closed the hatch until we got most vacuumed up. For long lunar stays with multiple EVAs, I believe an Airlock would be mandatory."

Charlie Duke - Apollo 16 Lunar Module Pilot/Rover Rider

"I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust."

Gene Cernan, Apollo 17 Technical Debrief

Apollo Moon Landings



"Due to Dust Problems, a 4th EVA Would Not Have Been Possible."

Commander Cernan

Lesson 4 - Pay Attention To Alarming Lunar Dust Toxicity Test Results

- **NASA Sponsored Research Shows Evolving Opinions About the Potential for Lung and Other Organs Damage from Ingested Lunar Dust (Apollo Astronauts Also Noted Some Irritations and Allergic Reactions):**

2015 - NASA Evidence Report - Adverse Health & Performance Effects of Celestial Dust Exposure Conclusions:

"The evidence literature provides substantial basis for concern that prolonged exposure to respirable celestial dust could be detrimental to human health. Celestial bodies where a substantial portion of the dust is in the respirable range or where the dusts have large reactive surface areas or contain transition metals or volatile organics, represent greater risks of adverse effects from exposure to the dust. It is possible that in addition to adverse effects to the respiratory system, inhalation and ingestion of celestial dusts could pose risks to other systems".

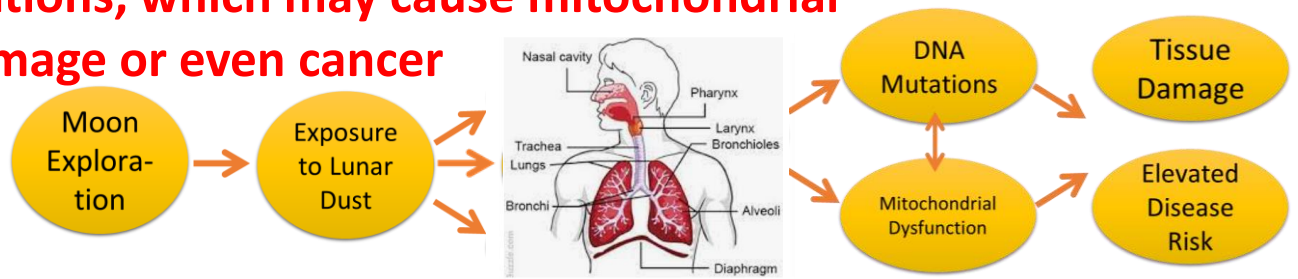
July 2021 - New Lunar Dust Toxicity/Reactivity Testing Results Presented at NASA Exploration Science Forum and European Lunar Symposium (NESF/ELS):

Alarming Toxic Effects Shown with Significant Potential for Lungs and Other Organ Damage from Ingesting Simulated Lunar Dust

Submicron Dust Can be Absorbed into the Circulatory and Nervous Systems

"There will be nuclear and mitochondrial DNA mutations, which may cause mitochondrial dysfunction. It's also inevitable to lead to tissue damage or even cancer especially in lungs when the Astronauts breathe in the dust attached to their space suits."

Caston/Chang/Hendrix, Rask et al



- **Cannot Afford to Wait for Additional Earth or Moon Dust Testing for Artemis Crews' Good Health**

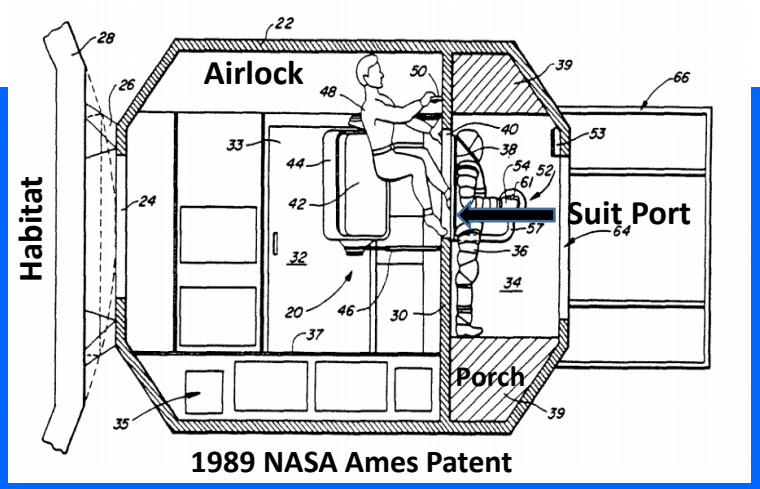
Lesson 5 - Must Do Everything Possible to Keep Dust Out of Habitats and Lungs

- **Having Crews and Suits Not Be Directly Exposed to Dust in the First Place is the Best Way to Survive Adverse and Hazardous Lunar Dust Effects - As is Done on Earth with Protective "Overgarments":**

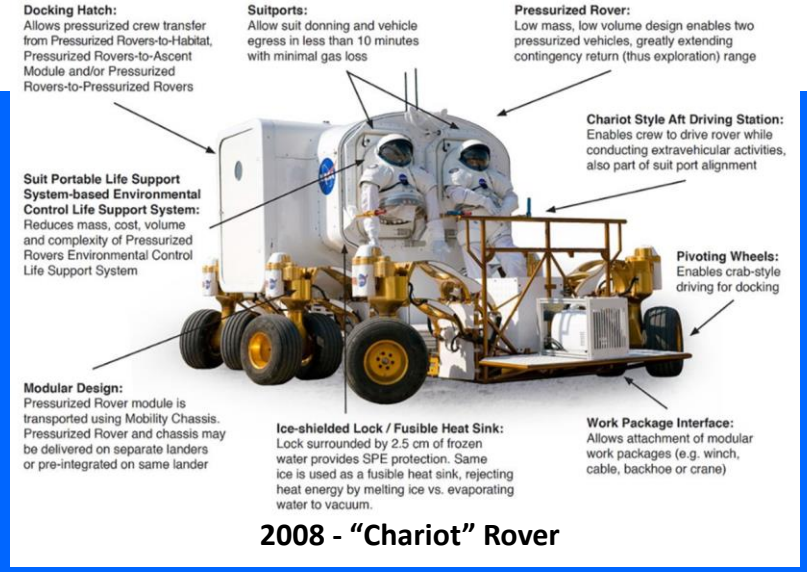
Example Suit Covers And Hang Up Area

Suit Cover Donning and Doffing

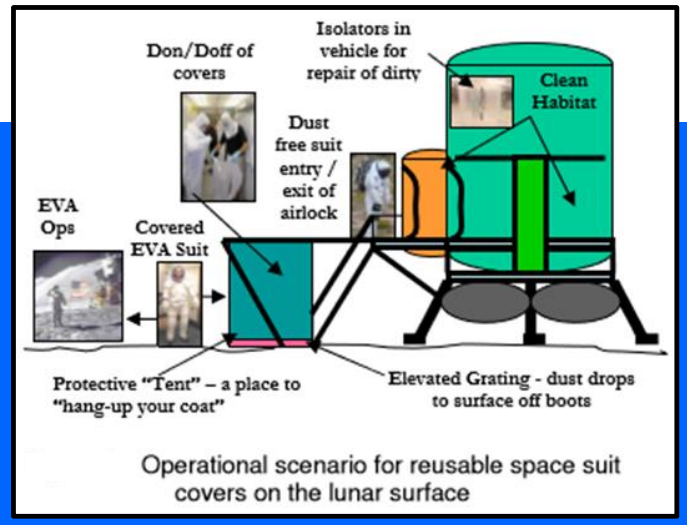
- **NASA Has Designed and Tested "Isolation Technologies" That Can Help Ensure Good Astronaut Health and Increase Artemis "Science" Time by Leaving the Dust OUTSIDE the Lunar Habitat and Explorer Lungs: Lightweight, Flexible, and Reusable Suit Covers for Astronaut Suits and Suit Joints Protection, with Airlocks and Suit Ports for Future Artemis EVAs, Rovers, and Lunar Bases**



1989 NASA Ames Patent



2008 - "Chariot" Rover

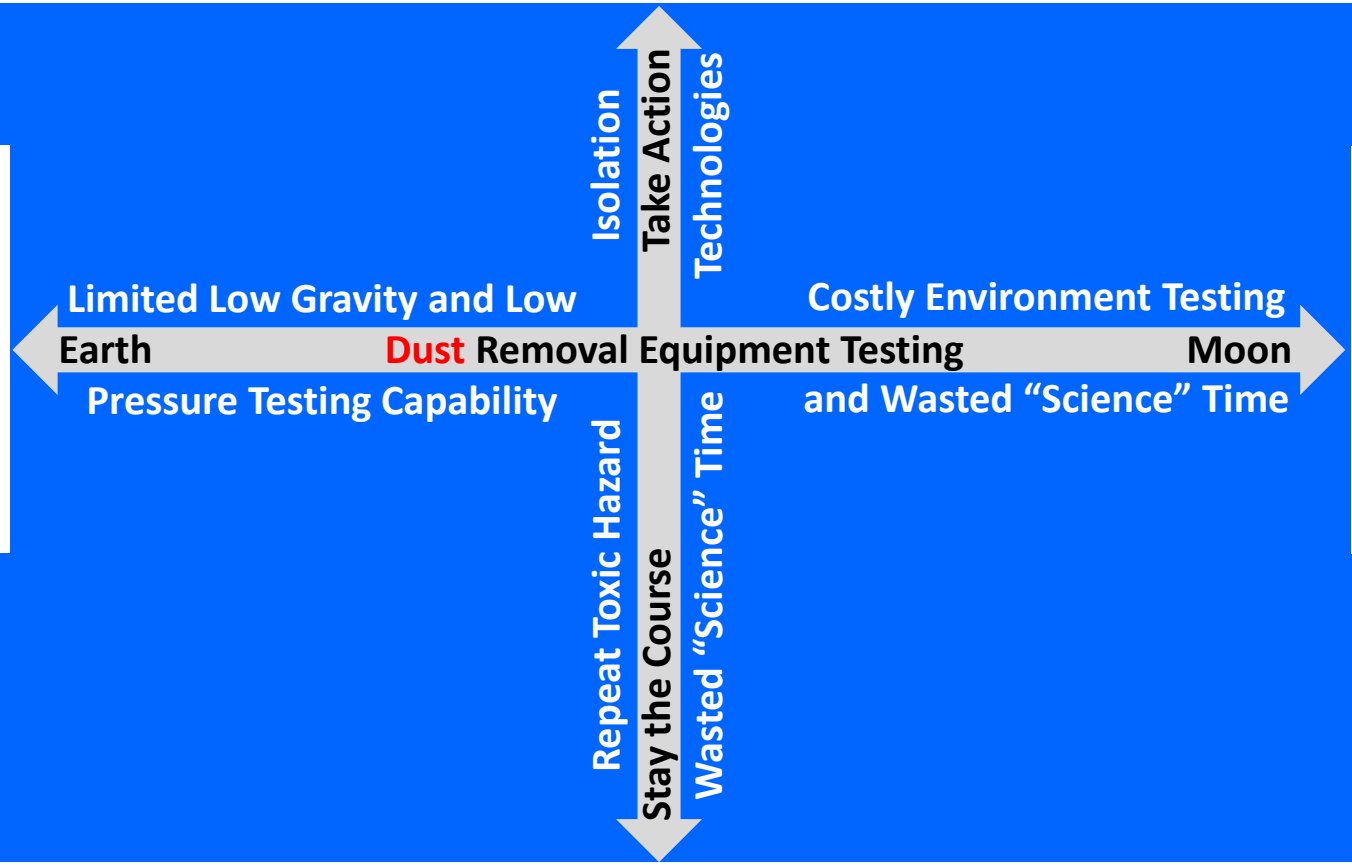


Operational scenario for reusable space suit covers on the lunar surface

We Are At a Dust "Crossroads" for Artemis - Let's Not Repeat Apollo Lessons

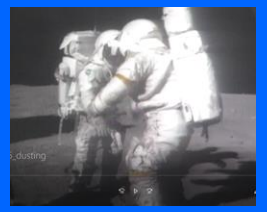
Implement Suit Covers, Airlocks, and Suit Ports to Ensure Good Astronaut Health and Maximize "Science" Time, While Minimizing Wasteful "Housekeeping" Time. (Multi-step Process That May Also Include Masks with Filters for Use Inside Habitat)

Earth-based Moon Dust Environment Simulation and Testing is Very Difficult and Not Reliable



Endanger Early Exploration Crews by Waiting for Moon Dust Environment Testing

Example Apollo 16 Frustrating 2 Minute ($82 Million) Video of Suit "Housekeeping" with Lunar Dust Brought Into the Habitat and Lungs:



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