Lunar Dust Characterization Activity at GRC

Kenneth W. Street

Lunar Dust Filtration and Separations Workshop
Ohio Aerospace Institute
November 18 – 20, 2008

Abstract

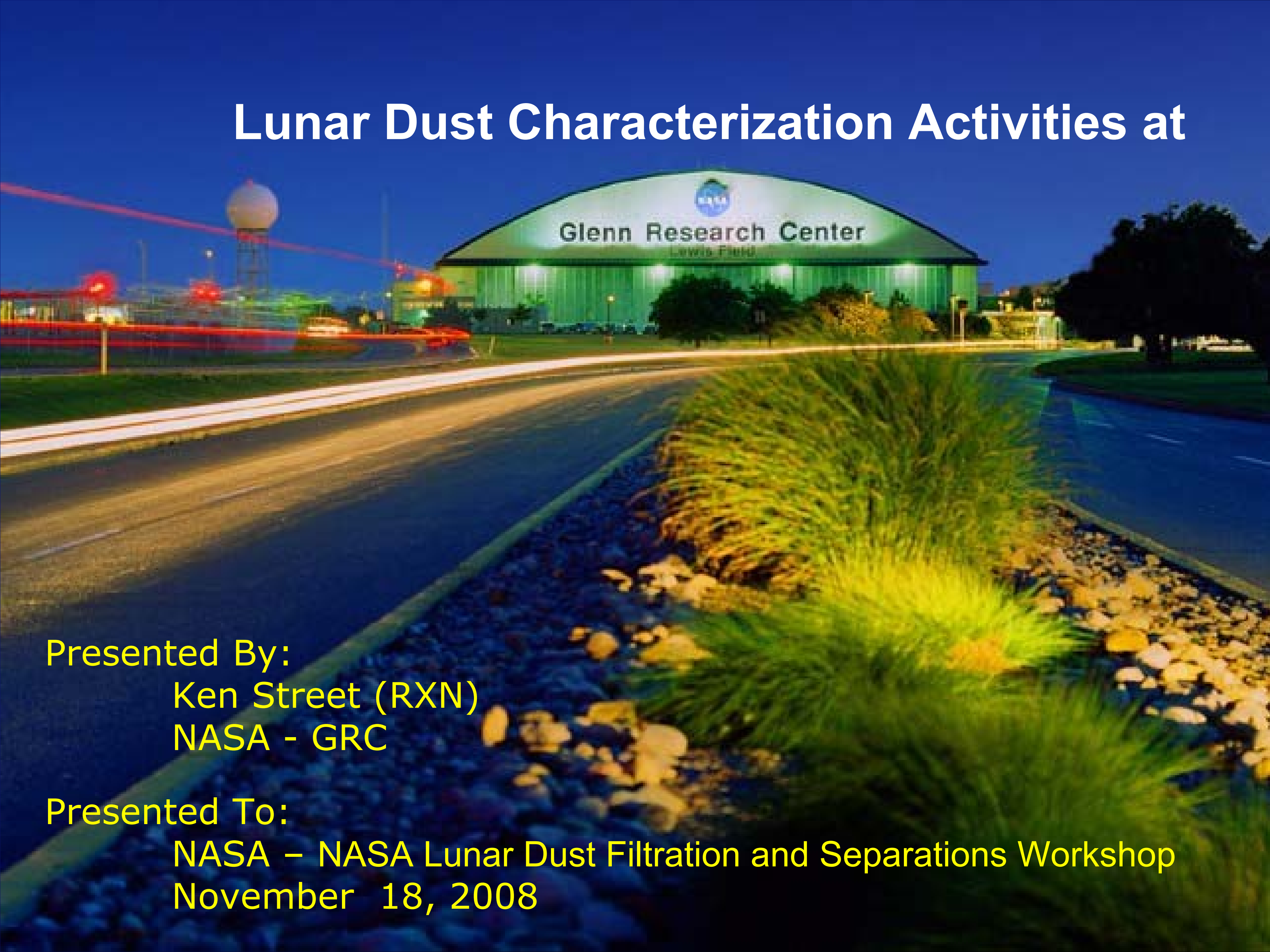
The fidelity of lunar simulants as compared to actual regolith is evaluated using Figures of Merit (FOM which are based on four criteria: Particle Size, Particle Shape, Composition, and Density of the bulk material. In practice, equipment testing will require other information about both the physical propertie (mainly of the dust fraction) and composition as a function of particle size. At Glenn Research Center (GRC) we are involved in evaluating a number of simulant properties of consequence to testing of lun equipment in a relevant environment, in order to meet "Technology Readiness Level (TRL) 6" criteria. k regolith has been characterized for many decades, but surprisingly little work has been done on the d fraction (particles <20 micrometers in diameter). GRC is currently addressing the information shortfal characterizing the following physical properties: Particle Size Distribution, Adhesion, Abrasivity, Surfa Energy, Magnetic Susceptibility, Tribocharging and Surface Chemistry/Reactivity. Since some of thes properties are also dependent on the size of the particles we have undertaken the construction of a si stage axial cyclone particle separator to fractionate dust into discrete particle size distributions for subsequent evaluation of these properties. An introduction to this work and progress to date will be presented.

Kenneth W. Street
Biography

Dr. Street, a Senior Research Scientist, joined the staff of the NASA Glenn Research Center in February 1991 in the Environmental Programs office where he ran a chemistry laboratory analyzing a variety of samples such as water, paint, fuels, etc mainly looking for hazardous components. During that time, he did research on materials to remove toxic metals from water and was awarded a patent for invention of a novel ion exchange material. Presently, he is involved in research on friction and lubrication in the space environment, development of new classes of liquid space lubricants and employs optical spectroscopy to analyze the lubricants and wear materials. Concurrent with this effort is the characterization of physical properties of lunar regolith (dust) and simulant materials. He was also the lead investigator on the development of nano-carbon materials (nanotubes and nanoonions) as advanced lubricants. He has participated in many programs throughout the center and has analyzed a wide variety of materials including Teflon from the Hubble space telescope and Egyptian antiquities from the Cleveland Museum of Art. Dr. Street earned his Bachelor's degree in chemistry from the University of Connecticut in 1970; and a Master's degree in chemistry from Cleveland State University in 1973. He received his Doctorate in 1977 from Wayne State University. Dr. Street is the author or co-author of approximately 80 papers in the areas of tribology, chemical analysis, pharmaceutical analysis, and instrumentation evaluation and in 1996 and 1997, was nominated for the NASA Inventor of the Year Award.

He is a member and officer of several professional societies: American Chemical Society, Society for Applied Spectroscopy, and Sigma Xi (research society).

Lunar Dust Characterization Activities at



Presented By:
Ken Street (RXN)
NASA - GRC

Presented To:
NASA – NASA Lunar Dust Filtration and Separations Workshop
November 18, 2008

Agenda

ETDP – Dust Management Project (WBS 1.4.1 & 1.4.3)

IR&D – High Fidelity Lunar Simulants for Exploration Risk Reduction

ETDP – HRS Surface Mobility (Running gear & Terramechanics)

NESC – "Proactive Dust Risk Mitigation"

NESC – Tribocharging

LASER/ROSES – Various Proposals

ETDP – Dust Management
WBS 1.4.1 & 1.4.3

1.4.1 – Regolith Characterization
(a.k.a Putting cart prior to horse)

1.4.3 – Simulant Development
Simulant Development (MSFC)
Simulant Characterization (GRC)

MSFC Efforts:
FOMs - **particle size and shape distribution, composition & Density**

GRC Efforts:
- **particle size** and shape **distribution**
- **adhesion**
- friability and elasticity
- **magnetic susceptibility (WU in St. Louis)**
- **tribocharging**
- **surface chemistry and reactivity (ARC & GRC)**
- surface area
- **abrasion (UC-Boulder)**
- **surface energy**
- dielectric function & conductance
- charge capacity and electrostatics

ETDP – Dust Management
WBS 1.4.1 & 1.4.3

- **particle size distribution (PSD) –** Paul Greenberg, numerous GRC sizing instruments
- **particle shape distribution –** KSC may have equipment (Lack of funding)
- **surface area –** GRC on new IGC (Lack of funding)
- **adhesion –** James Gaier's LDAB & Miyoshi pin-on-plate Rig
- **abrasion –** Ryan Kobrick, UC-Boulder Scratch Tester (2 body); Polishing Experiment (3-body like MSFC)
- **friability and elasticity –** (Lack of funding)
- **surface energy –** Allen Wilkinson IGC
- **magnetic susceptibility –** Da-Ren Chen, Washington University in St. Louis
- **dielectric function and conductance –** (Lack of funding)
- **tribocharging –** Barry Hillard (Mars Tribocharging facility)
- **charge capacity and electrostatics –** (Lack of funding)
- **surface chemistry and reactivity:**
  - GRC had capabilities through IR&D (Randy Vander Wal)
  - ARC building capabilities (Farid Salama)

Original list of most important - Top 5:
1. Particle size distribution
2. Adhesion
3. Abrasion
4. Tribocharging & electrostatics
5. Surface chemistry & reactivity (especially corrosion)

The Elusive Cyclone Separator

Currently working at GRC in pre-production mode!

It should be able to process pounds per day

It is spec'd to give fractions:

11 – 20 micrometer (u) [Assumes feed sieved to 20 um]

1 – 11 u

500 – 1000 nanometer (nm)

284 – 500 nm

100 – 284 nm

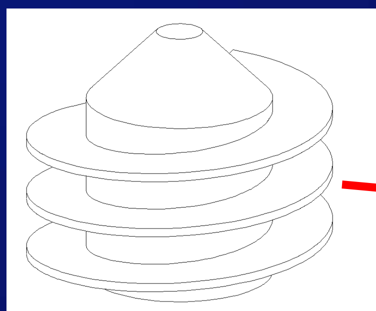
40-100 nm

Production of fine materials with narrow PSDs

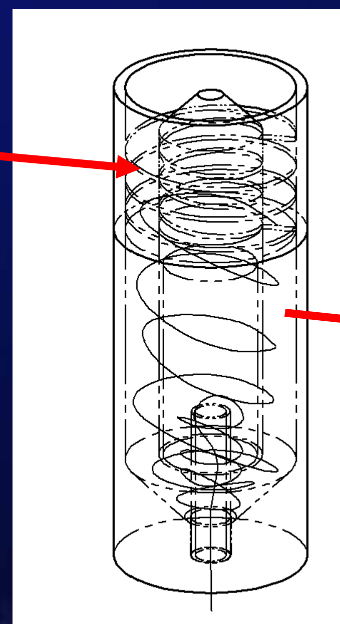
Characterization of property as a function of PSD

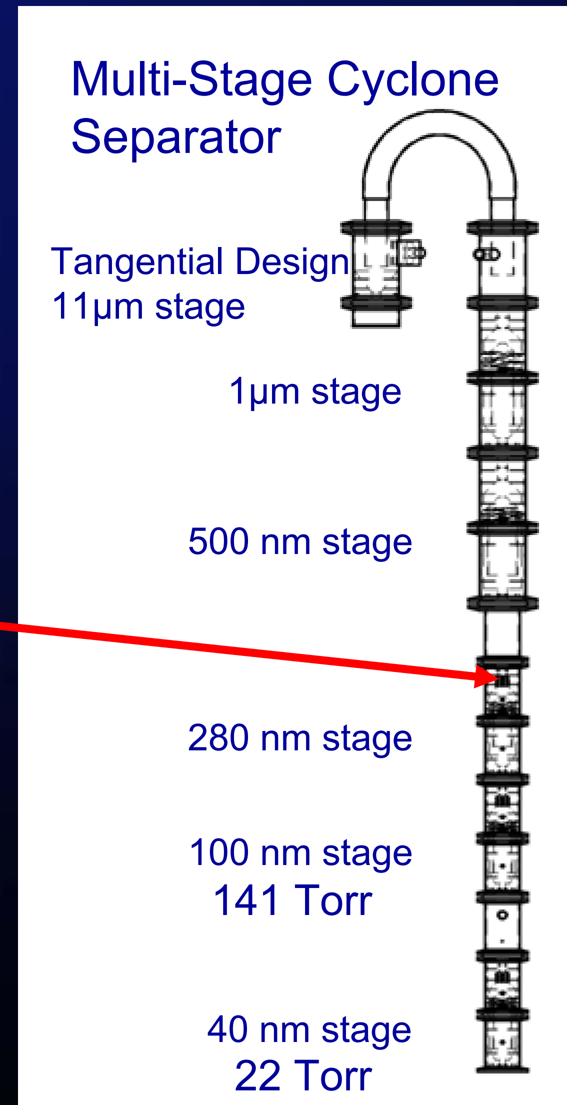
Multistage Axial Flow Cyclone Separator

Cyclone Generator



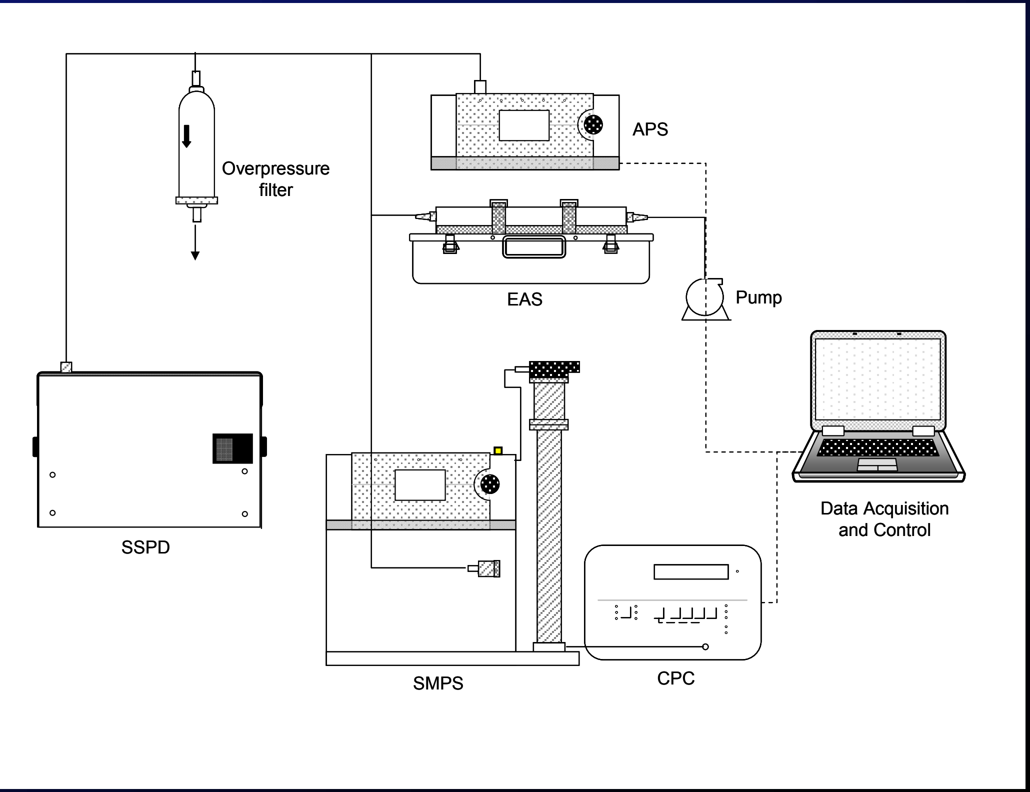
Complete Stage



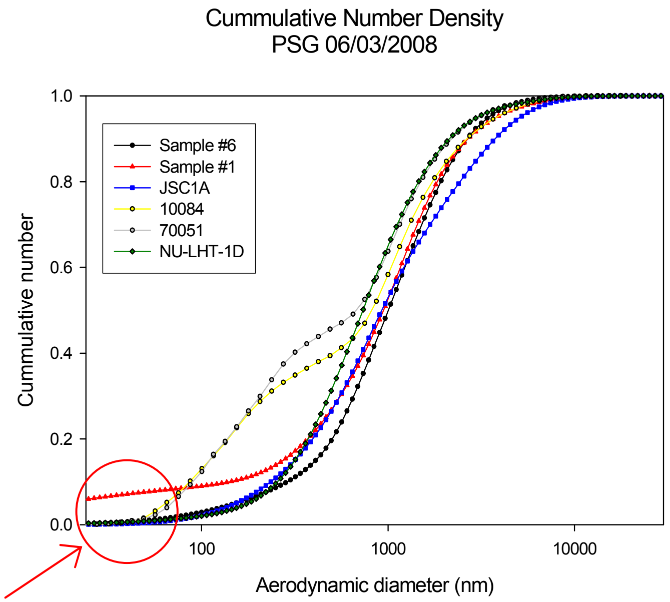


Determining Particle Size Distributions

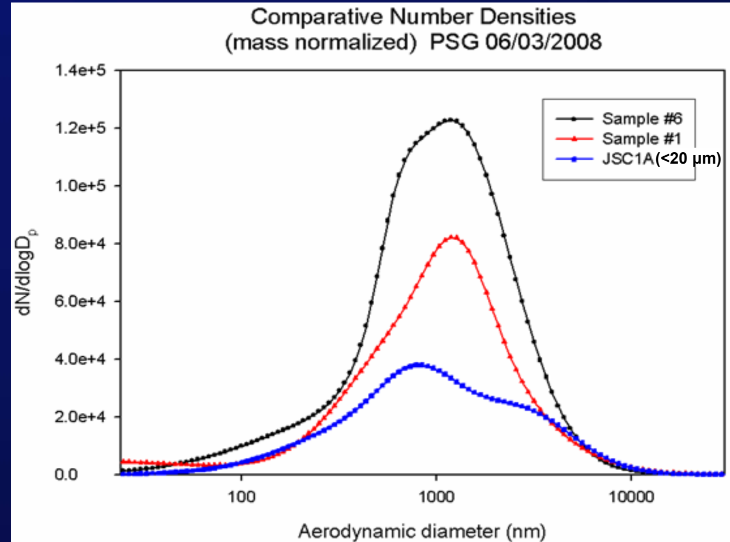
- **Basic approach: determination of *aerodynamic transport diameters.***
- **2.5 – 700 nm range characterized by Differential Mobility Analysis.**
- **- Scanning Mobility Particle Sizer (SMPS) with Condensate Particle Counter (CPC) detector.**
- **700 nm – 20 µm range characterized by Aerodynamic Particle Sizing (APS).**
- **Both techniques are sequential, and require no *a priori* assumptions about the expected particle size distribution function.**
- **Direct dry-phase aerosolization accomplished through the use of a Small Sample Particle Disperser (SSPD).**

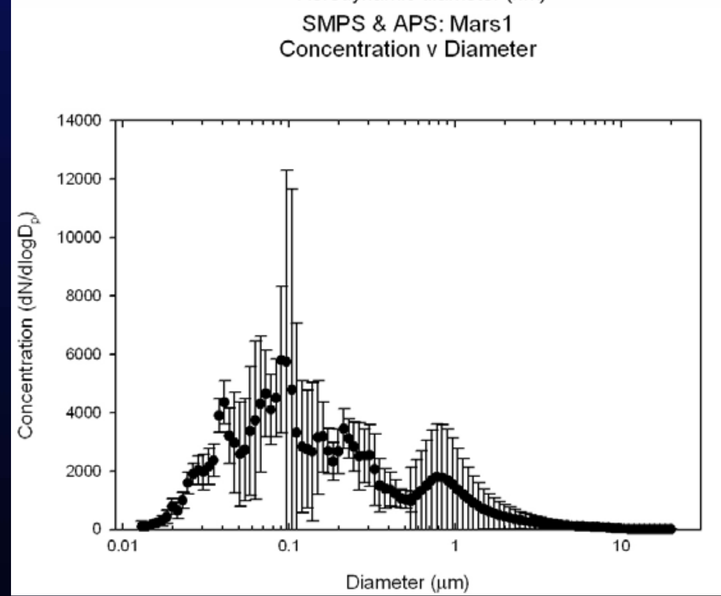


Determining Particle Size Distributions



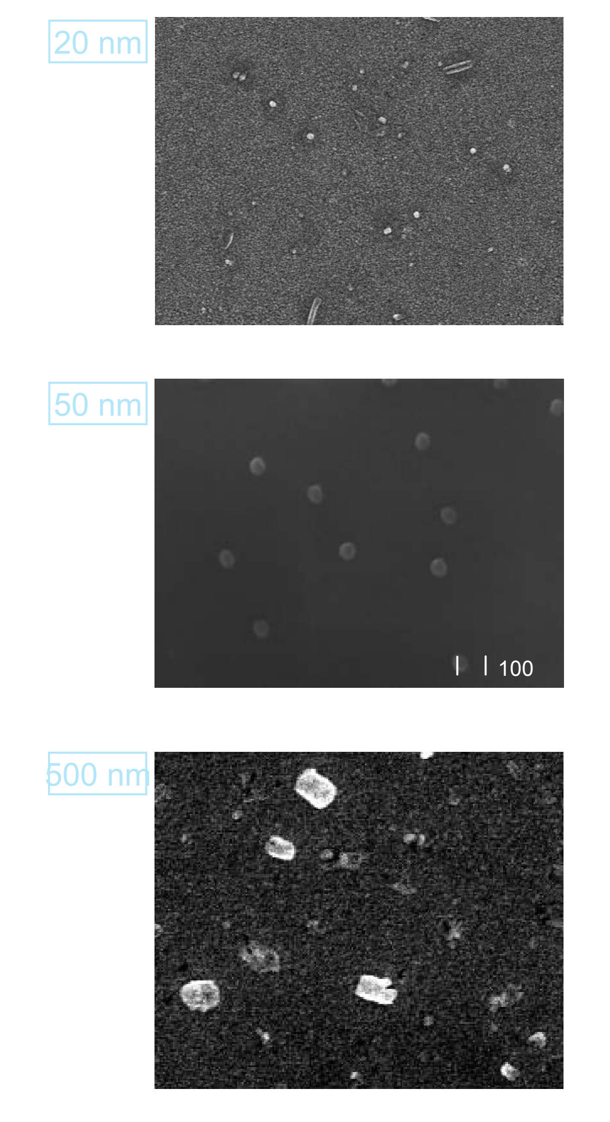
Simulants capable of replicating nanoscale particles present in regolith samples.



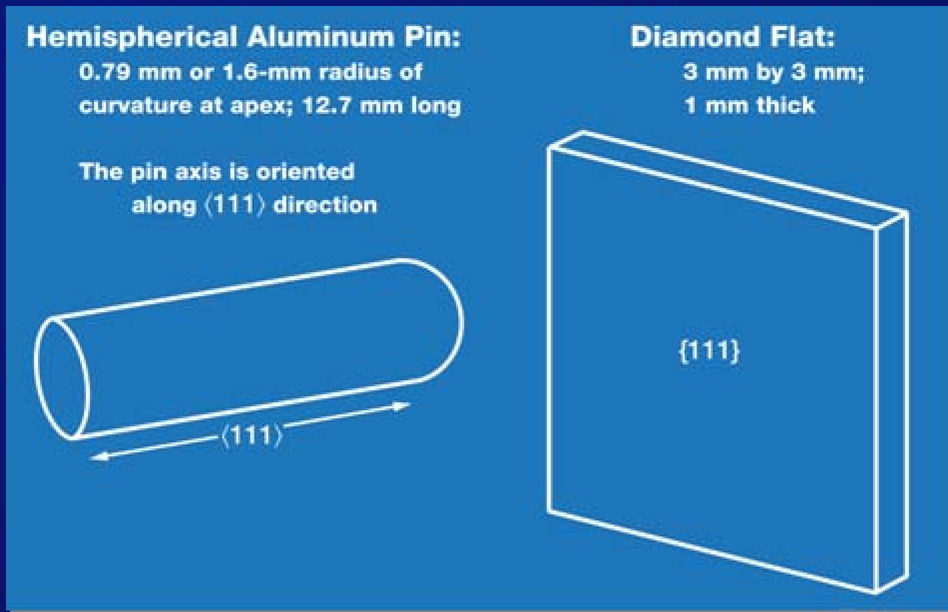


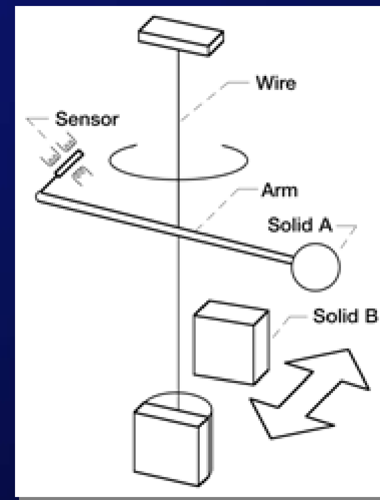
Collection of nm Sized Particles

- **DMA classification column tuned to fixed size passband.**
- **Emerging particles have a defined charge state, allowing collection by electrostatic focusing.**

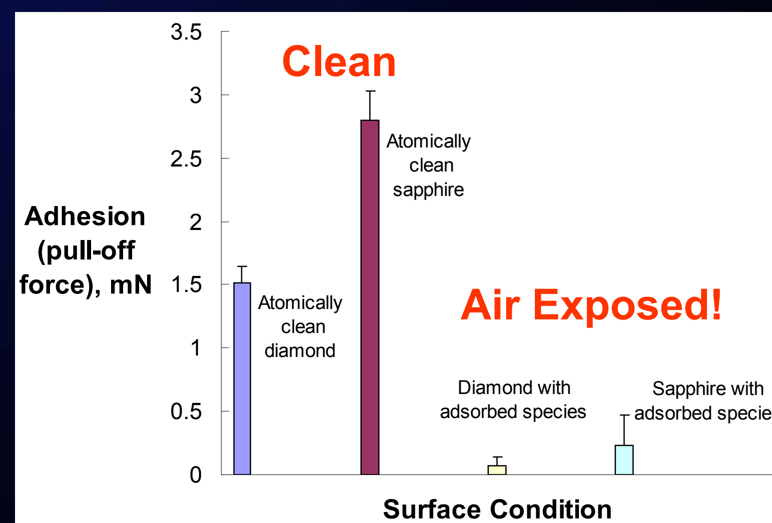


Adhesion





Miyoshi's Rig
~10^{-14} Torr

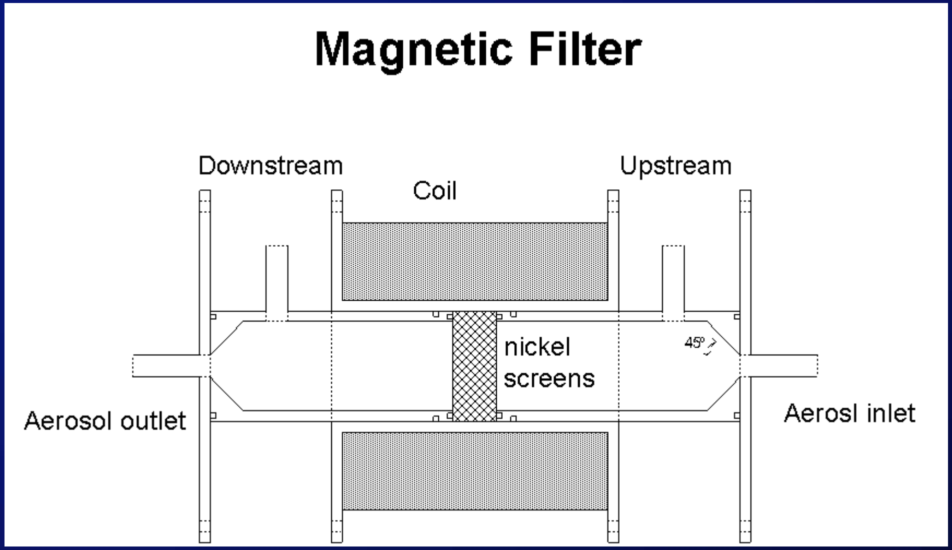


Adhesion Testing

Lunar Dust Adhesion Bell-jar (LDAB)

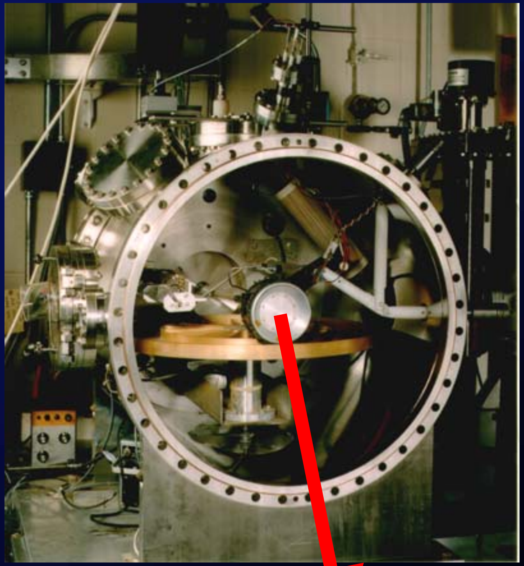
Testing the adhesion of dust on thermal radiators in a relevant environment

Magnetic Susceptibility of Individual Grains (Washington University in St. Louis)



- Method A: Size of particles pre-screened using differential mobility separator, and field sequentially increased until particles are trapped within the device.
- Method B: Disperse sample is introduced, and exiting size distribution determined while sequentially increasing field strength.

Tribocharging

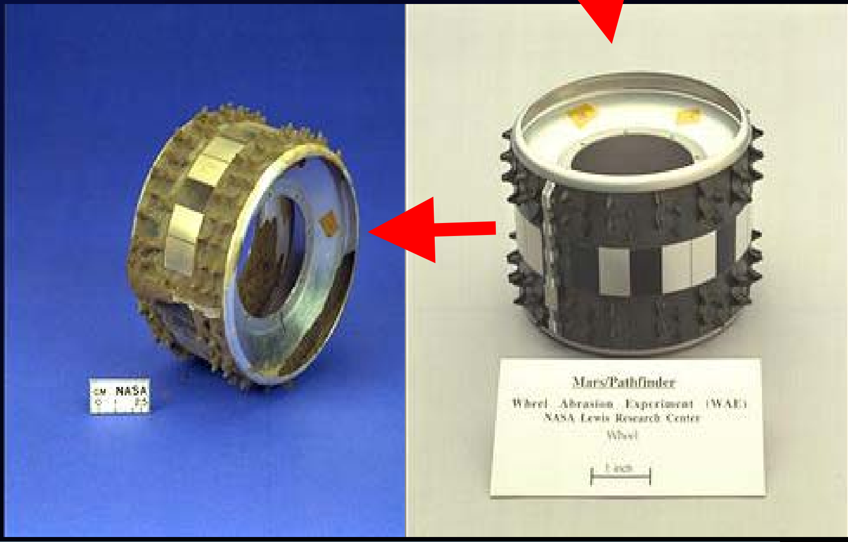


Abrasion testing for Mars Pathfinder

Wheel from Marie Curie in Mars environment

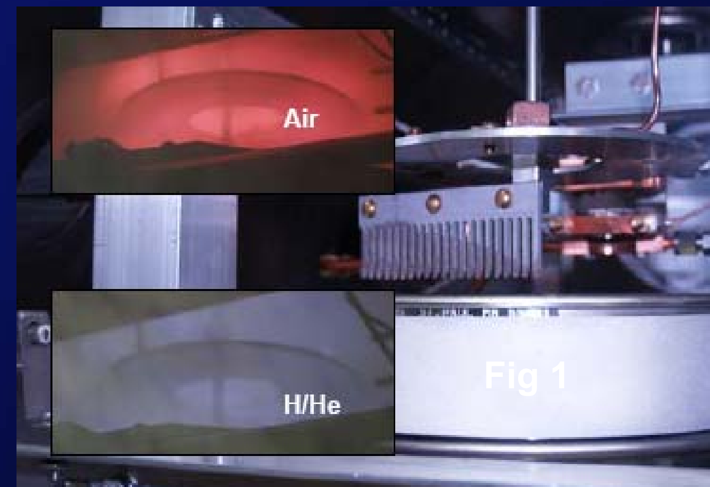
Wheel charged readily
- **Potential spiked > 300 volts positive**
  - **Tray charged negative**
    - **Wheel coated and caked with simulant**
- **Data return for abrasion was very poor**
  - **Tribo-charging resulted in heavy dust adhesion**

With Lunar simulants and hard vacuum
- **Expect wheel to be covered with dust**
  - **Charge to TBD levels**



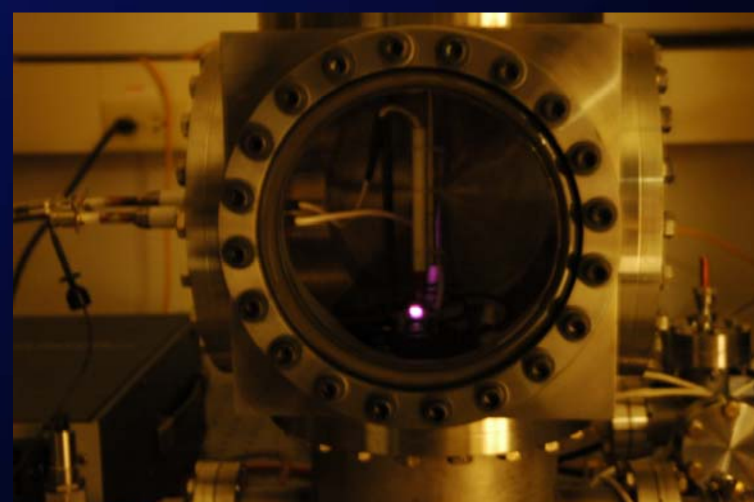
Surface Chemistry and Reactivity (GRC)

Done with IR&D Funding



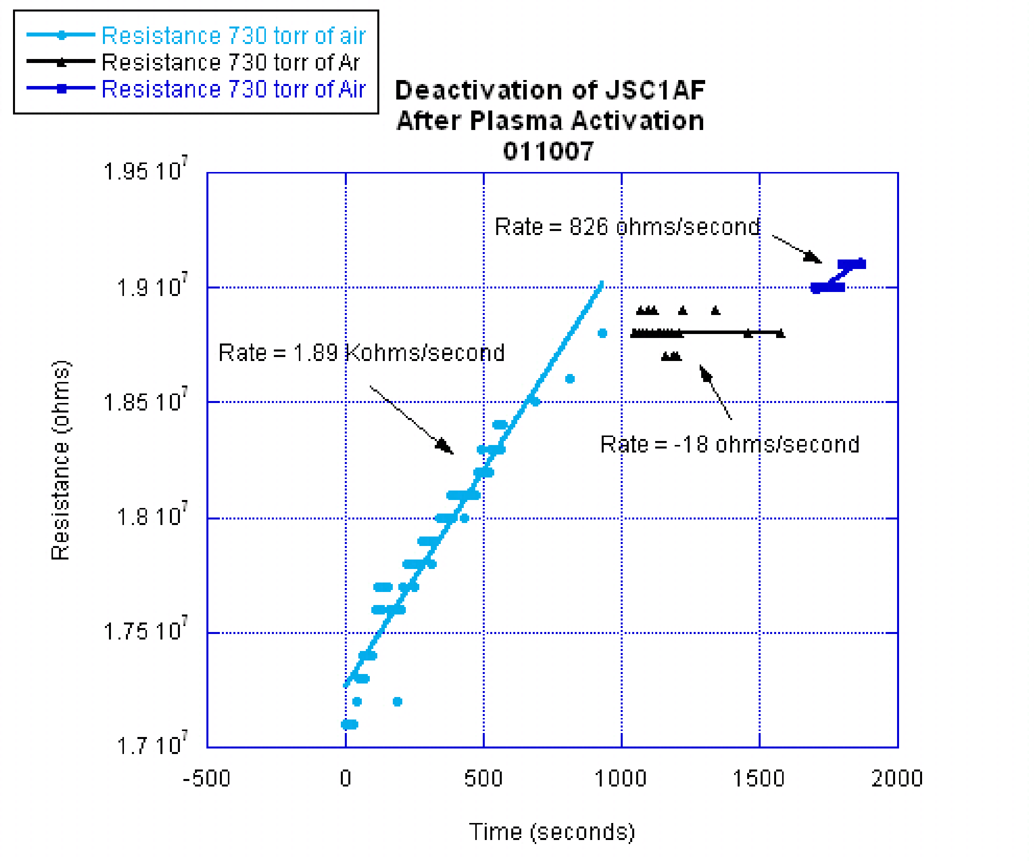
Four Activation Types:

- Plasma
- Chemical
- Thermal
- Mechanical

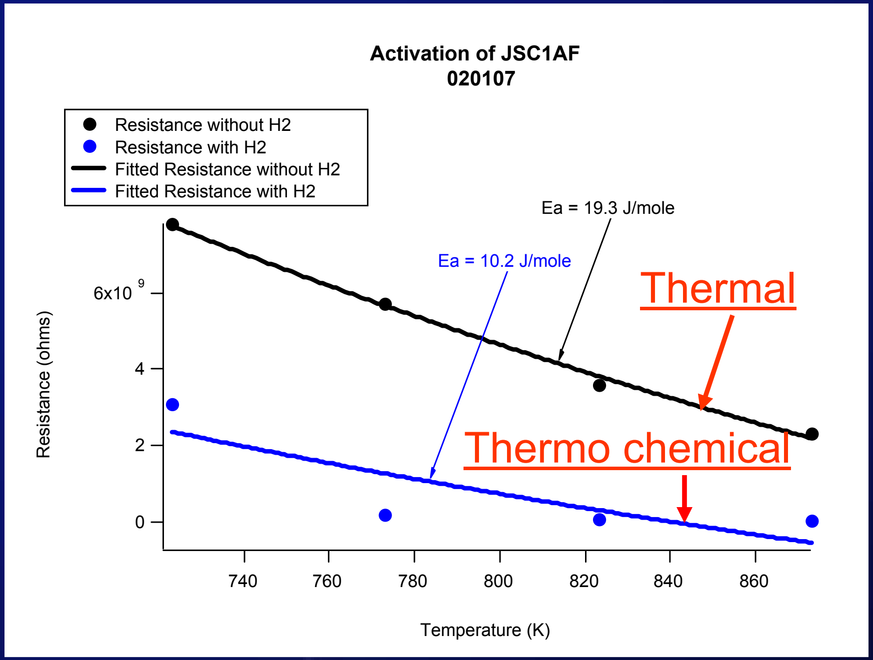


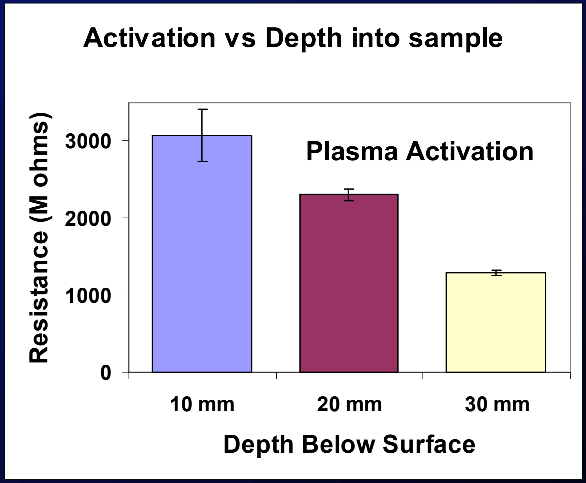
Surface Chemistry and Reactivity (GRC)

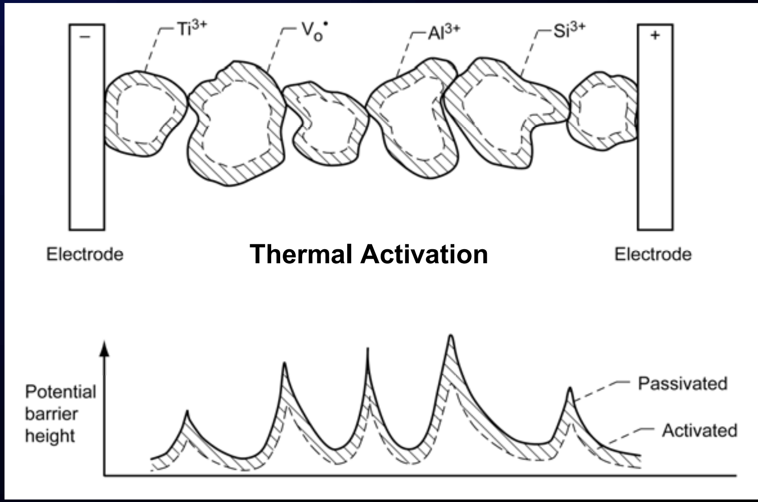
Activation as monitored by deactivation



Surface Chemistry and Reactivity (GRC)







Surface Chemistry and Reactivity (GRC)

What we do know:

We are doing something to the samples

What we don't know:

Pretty much the rest!

For a given material, a given method has reproducible deactivation.

For a given activation method, different materials have different deactivation profiles.

Between activation methods, same material gives different deactivation profiles.

- What does change in conductivity relate to chemically?
- How do we account for surface area?
- How do we account for electrode contact?
- How do we quantify % of surface modified?
- How do we tell what kind of modification occurred?

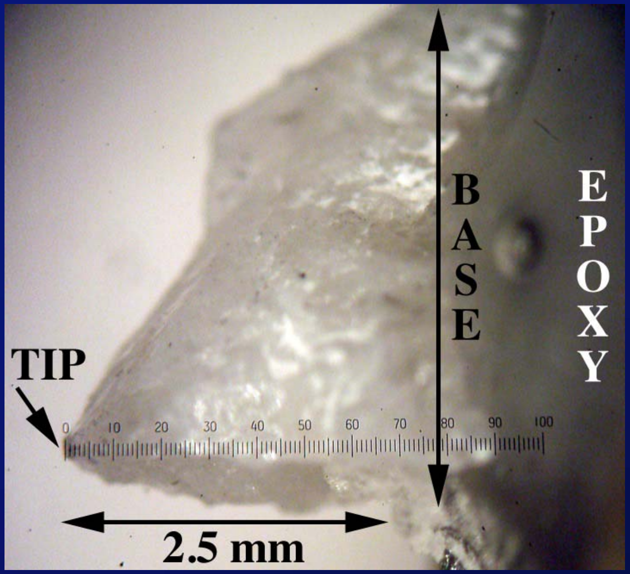
Surface Chemistry and Reactivity (ARC)

Activate particles in chamber

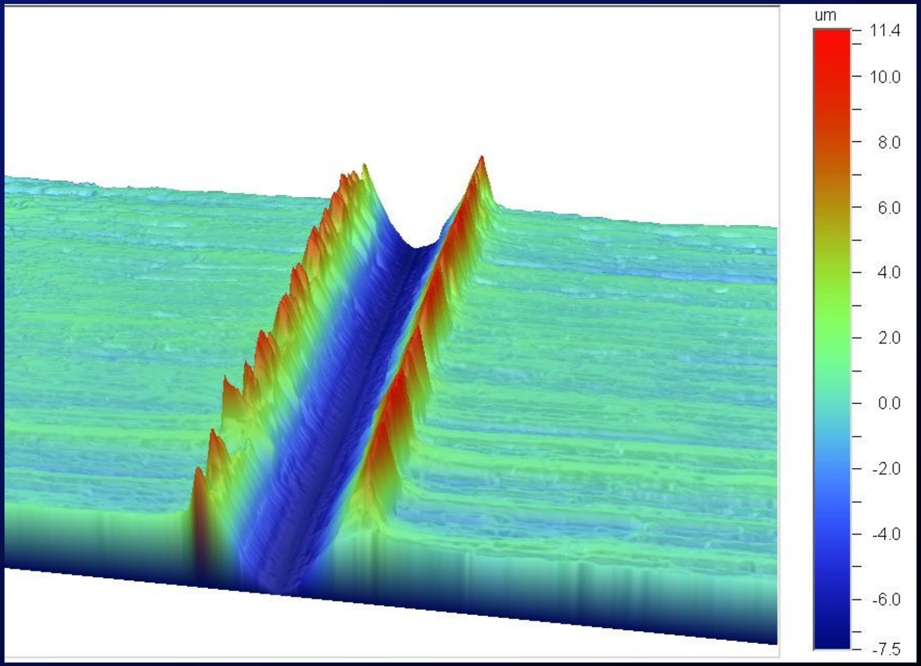
Probe surface spectroscopically

Gives chemical change information about surface

Abrasion – 2 Body (CU-Boulder)

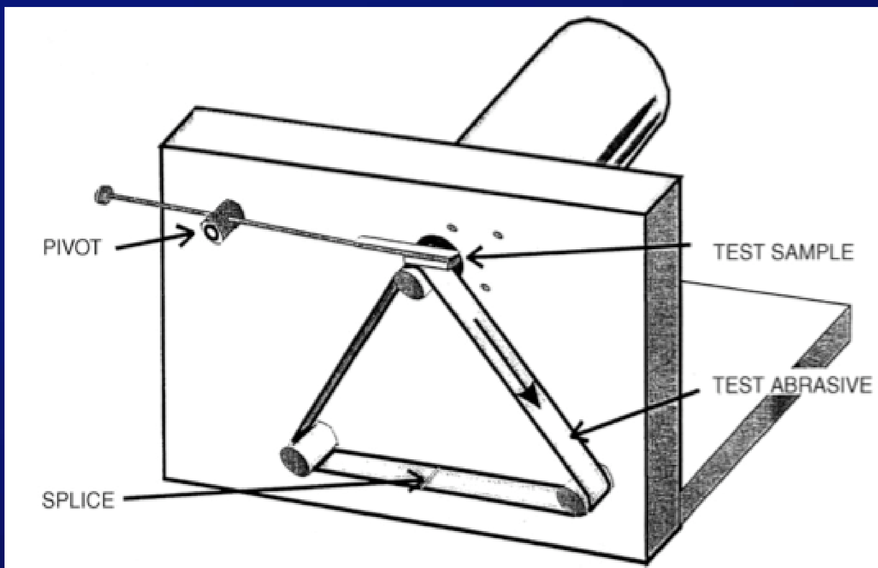


Anorthositic Tip

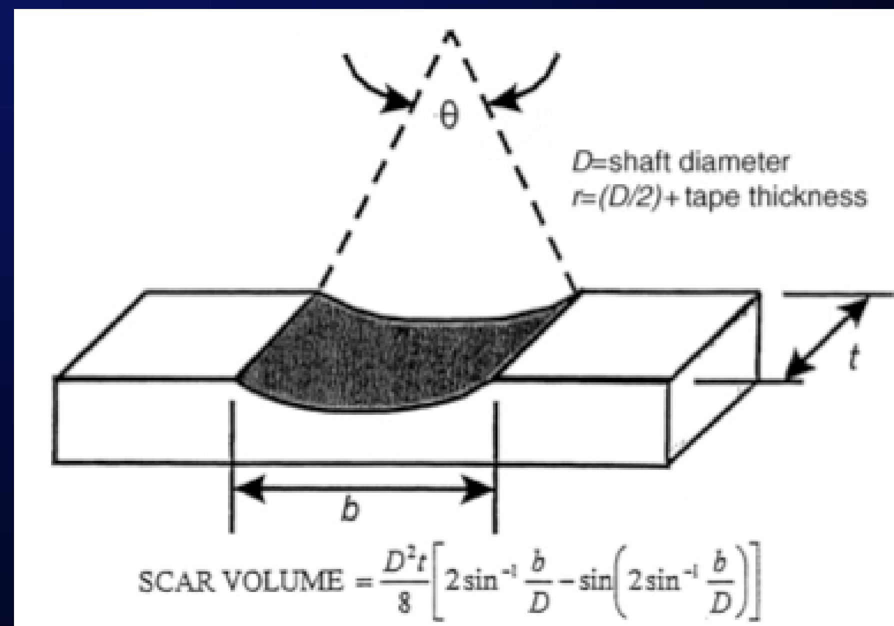


Diamond tip across Al 6061-T6

Abrasion – 3 Body (CU-Boulder)



ASTM G-174



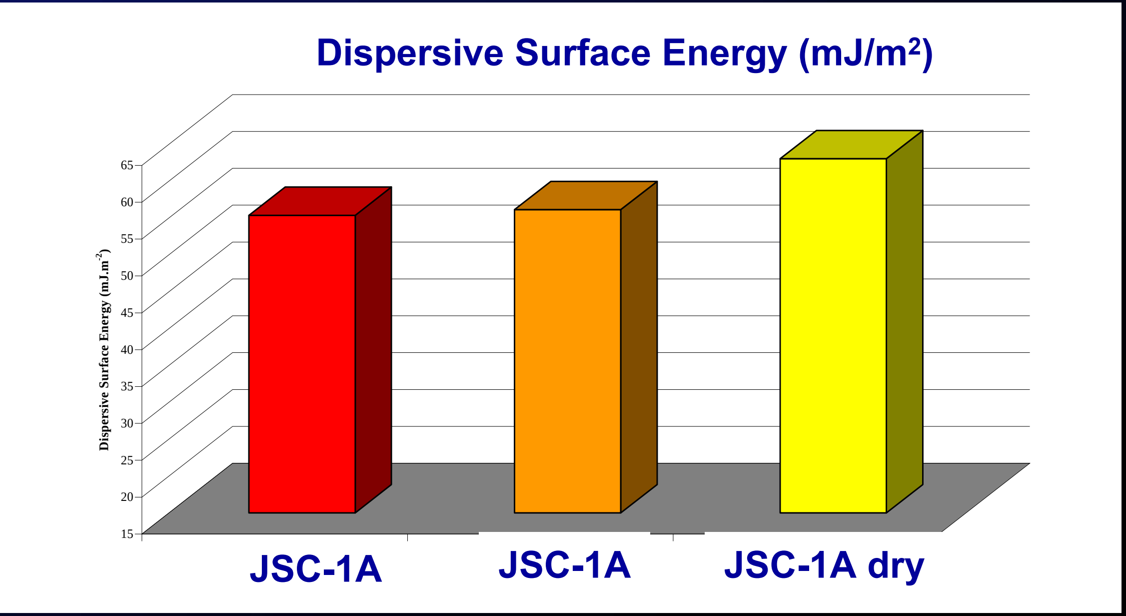
An alternative is the MSFC developed “Polishing Wheel” experiment

Surface Energy

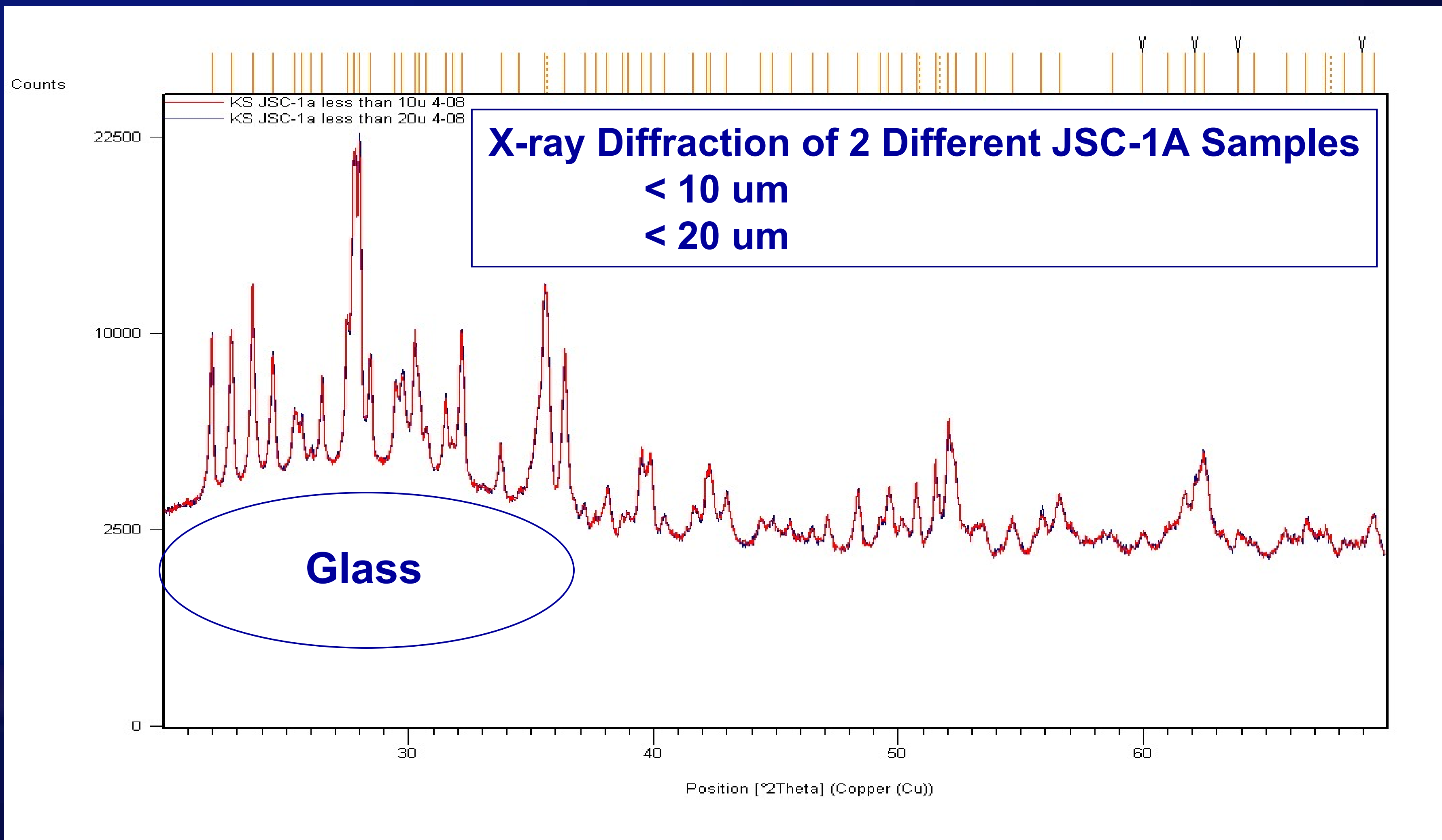
- Inverse Gas Chromatography
  - Unknown Stationary Phase
  - Known Eluents (Probes)
    - Hydrocarbon series
    - Dichloromethane
    - Acetone
    - Ethyl Acetate
    - Acetonitrile
    - Ethanol

Assumes ΔG = ΔH

Probes measure Dispersive (HCs and Polar (H bonding, Acid/Base) Forces



Composition (GRC)



Composition (GRC)

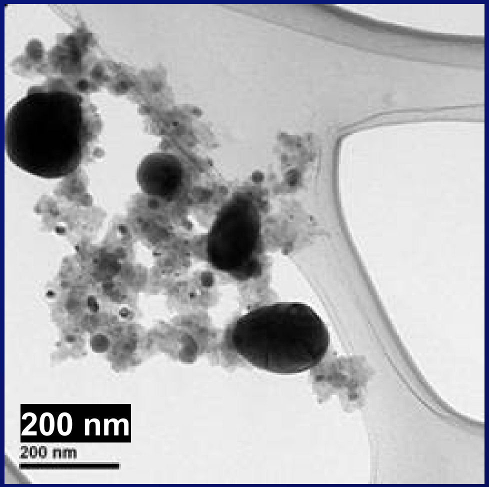
Element	JSC-1A Feedstock	Dust Simulant #1	Dust Simulant #6
W	0 ppm	30 ppm	170 ppm
Ni	110 ppm	120 ppm	120 ppm
Co	60 ppm	100 ppm	100 ppm

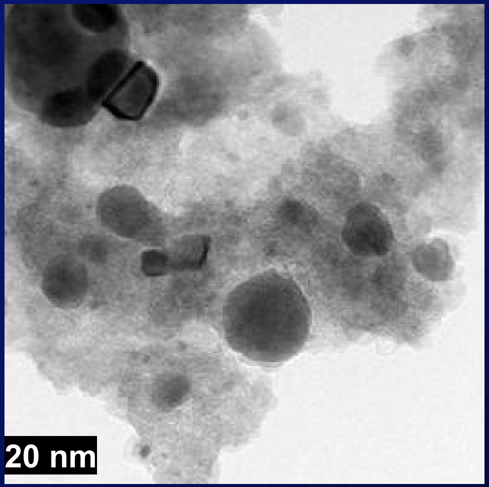
ICP Data for Trace Element Contamination

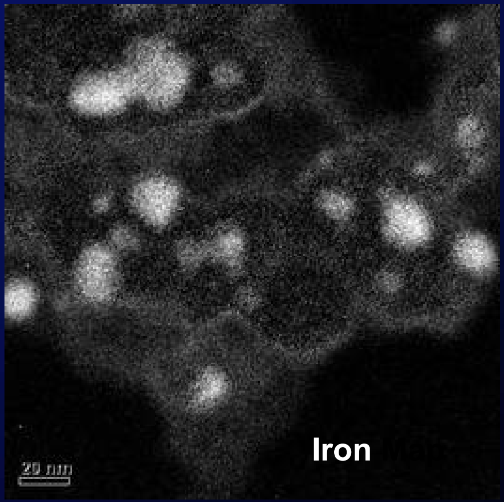
- An Inductively Coupled Plasma (ICP) analysis was performed on the feedstock material and the dust simulants to quantify the amount of contamination introduced during grinding
- Mill had a tungsten carbide liner, so the expected contaminants are tungsten (W), nickel (NI), and cobalt (Co)
- All of the expected contaminants were measured in the prototype lunar dust simulants
  - The amount of contaminant increased with grinding time
  - Although observable, the overall level of contamination does not appear to be a significant problem.

<u>Contamination from Grinding</u>

Composition (GRC)







Gatan image filter (GIF) maps using electron energy loss spectroscopy.

TEM Images of a Simulated Agglutinate: embedding of nanophase Fe^0 globules

oxygen map

Silicon Map

Concluding Remarks

Dust Management Project team is charged by NASA to be the “go-to” place for definitive answers on how physical properties of simulants relate to lunar regolith properties for verification of material and component performance of lunar equipment, habitat, seal behavior, etc. in order to reduce risk to safety, mission, cost, etc.

Having this information centered in the government reduces the risk of proprietary restrictions fogging the fundamental understanding of simulant behavior in lunar simulation projects.

Thanks for your attention.

Any Questions?