Lunar Sample Management Issues

Dean Eppler
Constellation Lunar Surface Systems Office
Lunar Sample Management Issues

• Lunar samples returned from Apollo represent one of the treasure troves of human endeavor
  • Although the Apollo crews did a superb job of describing and photographing the rocks and landscapes they saw on the lunar surface, without the returned samples, much of what we now know about the Moon would remain unknown
• As we plan extended lunar surface stays with the ability to rove long distances from an Outpost location, the issues of what to do with all those rocks and dirt becomes critical, and boil down to two basic topics:
  • Having sufficient return mass from the lunar surface to the Earth, which impacts the designs of vehicles that are presently underway, such as the Orion and the lander
  • Deciding what we can do on the lunar surface in the way of preliminary sample analysis so that we bring a representative suite home for detailed analysis
• This presentation will deal with these two issues, including the status of requirements and proposed paths forward to work out the details of open questions remaining
• Before I get started, I need to acknowledge the input of the Chip Shearer and the CAPTEM group for taking the lead on definition of sample mass, and to Craig Kundrot of JSC-Life Sciences for input on life sciences sample mass
Apollo Sample Return Mass and Volume

<table>
<thead>
<tr>
<th>Mission</th>
<th>Geologic Sample Mass, kg</th>
<th>Sample Container Mass, kg</th>
<th>Total Geologic Sample Return Cargo, kg</th>
<th>Biomedical Sample Return Mass, kg</th>
<th>Biomedical Sample Container Mass, kg*</th>
<th>EVA Crew Days</th>
<th>Geologist Crewmembers</th>
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<tbody>
<tr>
<td>Apollo 11</td>
<td>21.7</td>
<td>14.7</td>
<td>36.4</td>
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<td>Apollo 12</td>
<td>32.4</td>
<td>14.9</td>
<td>47.3</td>
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<td>15.0</td>
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<td>n/a</td>
<td>3.0</td>
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<td>Apollo 15</td>
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<td>14.0</td>
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<td>Apollo 16</td>
<td>94.7</td>
<td>13.9</td>
<td>108.6</td>
<td>1.5</td>
<td>n/a</td>
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<tr>
<td><strong>Apollo 17</strong></td>
<td><strong>110.5</strong></td>
<td><strong>13.4</strong></td>
<td><strong>123.9</strong></td>
<td><strong>2.3</strong></td>
<td>n/a</td>
<td><strong>6.0</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>

*Biomedical (fecal) samples were stowed in internal CM stowage, with no thermal conditioning

- Apollo samples were returned in 2 Apollo Lunar Sample Return Containers (ALSRCs), which had a volume of 0.029 m³ each
  - Although there were other smaller containers for special samples, they had relatively insignificant volume and mass, and were returned in the ALSRCs
- Constellation missions will land 4 crew for a minimum of 7 days, with a minimum of 16 EVA crew days, implying the ability to see more terrain and to significantly increase sample return
- Apollo biomedical samples did not require thermal conditioning, which will be required on Constellation
Geologic Sample Return Mass Estimation Approach

• In order to understand the mass of geologic samples that we need to return from the Moon, the NAC asked the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) to come up with an estimate for this number

• The aggregate mass of samples needed is related, in part, to the kind of samples and the type of analysis planned for any one sample
  • Meteorite impact breccias require more mass per sample due to their inhomogeneity
    • They can contain many different samples of different rocks from the lunar surface derived, in some cases, far from the landing site
    • Consequently, large breccias that might have substantial mass can more than “pay their way” by providing us indirect access to many lunar locations in a single sample
    • The present outpost site, being located in the highlands, will abound in breccia samples, so we can expect a significant suite of breccias being collected from the seventh lunar landing onward
  • More homogeneous rocks, such as basalts, allow a somewhat smaller sample size without degrading science content
    • However, the occurrence of these kinds of samples will be limited at the outpost site, except as clasts in breccias
  • Analysis method can also drive sample size
    • The analysis quality is dependent on getting clean samples to analyze, to ensure you are not analyzing multiple rock types simultaneously
    • Different analysis methods require different sample size as well, based on the details of the particular analytical machinery
      • For example, Nd-Sm analysis of a lunar basalt (15475) required only 10 mg of sample, while the same analysis of an anorthosite (62236) required 2000 mg of sample
Geologic Sample Return Mass Estimation Approach (cont.)

• CAPTEM started with the early Apollo requirements derived by science community at the Santa Cruz Apollo science planning conference in 1967:
  • “It is recommended that the total returned payload from the Moon…increase to 400 pounds (181.6 kg) so that a minimum of 250 pounds (113.5 kg) of lunar samples can be returned. The consensus…was that a capability to return ≈50 pounds (22.7 kg) of refrigerated samples was needed as soon as possible.”

• We can initially estimate the needed sample mass by plotting EVA time as a function of mass returned
  • Apollo returned sample mass varied systematically upward as time on the surface and EVA crew hours increased
  • Using the Apollo experience, CAPTEM estimated that a 7 day sortie mission with 16 crew EVA days could collect as much as 800 kg of samples

• A different approach CAPTEM used was to consider the relationship between sample type, sample mass, and the lunar architecture science objectives
  • Each sample type has, by virtue of lithology, collection method and/or individual sample size, characteristics of mass and number of samples collected that can be used to estimate total returned sample mass
    • The samples considered are 1) large individual (“hand”) samples of breccias and homogeneous rocks; 2) samples collected by rake tools; 3) bulk regolith samples; 4) drill cores, and; 5) frozen volatile samples

• This second approach forms the basis for the estimates developed in the table on the next slide
# Geologic Sample Return Requirements

<table>
<thead>
<tr>
<th>Sample Category &amp; Lithology</th>
<th>LAT Objective Science Rationale</th>
<th>Analytical Approach</th>
<th>Estimated Average Mass, kg</th>
<th>Estimated Number of Samples per Mission</th>
<th>Estimated Total Mass per Mission, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – Large hand samples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>A1</td>
<td>Homogeneous rocks</td>
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<tr>
<td>Basalts</td>
<td>mGEOL1, 2, 3, 4, 7, 15, 16</td>
<td>Mineralogy/petrology, geochronology, spectral studies, geophysical properties</td>
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<td>20</td>
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<td>Clast-free impact melt rocks</td>
<td>mGEOL6, 7, 8, 15, 16</td>
<td>Mineralogy/petrology, geochronology, spectral studies, geophysical properties</td>
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<td>90</td>
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<td>A2</td>
<td>Breccias (monomict &amp; polymict)</td>
<td>Mineralogy/petrology, geochronology, spectral studies, geophysical properties</td>
<td>5</td>
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<td>90</td>
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<td>B – Rake samples</td>
<td>mGEOL1, 2, 3, 4, 5, 6, 15, 16</td>
<td>Mineralogy/petrology, geochronology, geophysical properties</td>
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<td>20,000</td>
<td>10</td>
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<td>C – Unseived regolith samples</td>
<td>mGEOL4, 5, 6, 9, 10, 11, 12, 13, 15, 16</td>
<td>Mineralogy/petrology, spectral studies, geophysical properties</td>
<td>2</td>
<td>5</td>
<td>10</td>
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<tr>
<td>D – Drill core</td>
<td>mGEOL4, 6, 9, 10, 11, 12, 13, 15, 16</td>
<td>Mineralogy/petrology, implanted solar wind chemistry</td>
<td>0.7/core tube</td>
<td>12 core tubes</td>
<td>8.4</td>
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<td>E – Volatile-enriched regolith cores</td>
<td>MGEOL12, 13, 14</td>
<td>Geochemistry, spectral studies, implanted solar wind chemistry</td>
<td>0.9</td>
<td>12</td>
<td>10.8</td>
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</table>

**TOTAL ESTIMATED SAMPLE MASS, kg**: 149.2 kg

Total estimated sample mass = 149.2 kg + 10% margin = 164 kg

Total estimated container mass = 3 * 6.6 kg/container based on ALSRC = 19.8 kg

\[ \sum \text{Return mass requirements for geologic samples} = 183.9 \text{ kg} \]

Volume per ALSRC = 0.029 m³

\[ \sum \text{Return volume requirements for geologic samples} = 0.09 \text{ m}³ \]
Biomedical Sample Return Requirements

<table>
<thead>
<tr>
<th>Sample Stowage Conditioning Requirement</th>
<th>LAT Objectives Addressed</th>
<th>Estimated Sample Volume, m³</th>
<th>Sample Mass per mission, kg</th>
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<tr>
<td>Ambient</td>
<td>mHH7</td>
<td>0.001</td>
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<td>+4°C</td>
<td>mHH1, 2, 4, 5</td>
<td>0.005</td>
<td>5</td>
</tr>
<tr>
<td>-80°C</td>
<td>mHH1, 2, 4, 5</td>
<td>0.005</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL ESTIMATED SAMPLE MASS, kg</td>
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<td></td>
<td>11</td>
</tr>
</tbody>
</table>

Estimated +4°C sample return = 5 kg
Estimated -80°C sample return = 5 kg
Estimated non-conditioned sample return = 1 kg
∑ Estimated biomedical sample return mass = 11 kg

Estimated mass for +4°C Refrigerator (based on current technology) = 15 kg
Estimated mass for -80°C Freezer (based on current technology) = 20 kg
∑ Conditioned stowage mass = 35 kg

∑ Estimated total return mass for biomedical samples = 46 kg

Volume of +4°C Refrigerator = 0.06 m³
Volume of -80°C Freezer = 0.06 m³

∑ Estimated total return volume for biomedical samples = 0.12 m³
Engineering Sample Return

• It is expected that it will be necessary, on a case-by-case basis, to return to Earth equipment or engineering samples that have been exposed to the lunar environment, either to analyze failures or to determine the effects of long term exposure to the lunar environment.
• Such returns are expected to be varied and non-recurring and, as such, make it difficult to allocate as specific mass for each lunar return flight.
• It is assumed that samples will either be relatively small material samples (e.g., module shielding samples to examine radiation damage), or parts that have failed earlier than expected, and are consequently of variable size, shape and mass.
• Given those conditions, engineering samples can be treated as contingency samples whose mass and volume will be taken “off the top” of the geological and biomedical sample allocation for a particular flight.
Total Estimated Lunar Sample Return Requirements

**MASS**
Estimated total return cargo mass for biomedical samples, including conditioned storage = 46 kg
Return cargo mass requirements for geologic samples, including sample containers = 184 kg
\[\sum \text{LUNAR SAMPLE RETURN MASS REQUIREMENT/FLIGHT} = 230 \text{ kg}\]

**VOLUME**
Estimated total return conditioned volume for biomedical and geological samples = 0.12 m³
Return volume requirements for geologic samples = 0.09 m³
\[\sum \text{LUNAR SAMPLE RETURN VOLUME REQUIREMENT/FLIGHT} = 0.21 \text{ m³}\]
Lunar Sample Return Status

- At present, there is a formal risk in the Constellation Risk Management System that identifies the issue with insufficient lunar sample return mass within the Constellation requirements documentation
  - This risk formally identifies the issue to the program in such a way that it must address the issue
  - Constellation management is very concerned about having accommodations within the hardware and operations practices to support a robust science return from all lunar missions, and I believe that this issue will be taken care of before the dust settles on Orion and the lunar lander designs
  - Stay tuned…
- Having said all this, the fact remains that with surface increments of up to 6 months per crew, at least 500 km pressurized roving capability, and even with 230 kg sample return mass, the crews will be collecting far more sample than can be returned
- This leads to the next half of this presentation, which considers the issue of what we will do on the surface to sort through the samples returned to the Outpost area and come up with a suite of representative samples to be returned to Earth
Lunar Surface Sample Analysis Issues

• The issue of sample analysis on the lunar surface is (what, again?) a complicated one, and (what, again?!?) is a classic spaceflight dilemma - too much that we can do and never enough mass to the lunar surface to do it all (at least early on in the program)
• The horns of the dilemma lie in deciding what we can realistically do on the surface to reduce the mass of samples returned to an Outpost area, particularly from long roves, to get a representative suite
• There has been a lot of verbiage about this issue, but so far no plan to sort it out
• No matter how many flights to the surface we have, and how much mass to the surface, we will always be constrained by mass, volume and cost
  • Consequently, we need to ensure that whatever approach we take, we recognize the issues associated with getting stuff built and flown to the Moon, as well as the operational and technology development constraints associated with any proposed implementation
• The rest of this talk is an attempt to start from scratch by looking at the historical record from Apollo and then attempting to extrapolate that effort forward by logically considering what is reasonable to do on the surface
  • Based on those considerations, there are a number of areas that can be traded to understand what we can reasonably do on the surface, given the constraints of mass/volume/power/crew time/technological maturity
But First, An Etymological Note…

• According to the Random House Webster’s College Dictionary (1992):

**Tri-age, n. adj, v., -n.** 1. The process of sorting victims, as of a battle or disaster, to determine the priority of medical treatment, with the highest priority usu. given to those having the greatest likelihood of survival. 2. the determination of priorities in an emergency…
They’re dead, Jim...
Lunar Surface Sample Analysis Considerations: General

Do Sample Analysis?  
Y  
N  
Done

Why?
Reduce sample return mass by reducing individual sample size to a minimum volume/mass while preserving sample character; minimize sample mass while maximizing science return
Inform continuing science operations by understanding samples collected; feedback into EVA planning process

What (Possible Approaches)?
Apollo Preliminary Examination Team Example:
• Mass
• Density
• Surface features
• Mineralogy
• Petrology
• Position on the lunar surface (correlation of mission photography with sample in the LRL to determine exposure, sample identification)
• Noble gas abundances
• Major, minor & trace element abundances
• Abundance of g-emitting nuclides
• Abundance of organic chemicals
• Presence of fossils

Present Lunar Science Program - Possible deltas Off Apollo PET
• ISRU - composition & process efficiency for volatile extraction
• ISRU - quality of products made from lunar regolith, such as bricks, sintered roadways
• Fossils? Do we really think there is any money to be made looking for lunar fossil after Apollo (except maybe as a feed forward to Mars?)?

Lunar Surface Sample Analysis Considerations: Mission Set Considerations

Do Sample Analysis?

What Mission Set?

Sortie?
No; based on:
• Insufficient Crew Time
• Insufficient Mass:Surface
• Inappropriate Use of Limited Crew Time

Super-Sortie (Crew Time 7 days < x ≤ 30 days)?
Possible; dependent on:
• Mass to surface
• Hab volume
• Hab power
• Crew time, specifically EVA & IVA mix

Outpost (Crew Time 7 days ≤ x ≤ 180 days)?
Yes

Done

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Lunar Surface Sample Analysis Considerations: Outpost

Do Sample Analysis?

Y

What Are The Limitations on Capabilities?

- Mass
  - Mass of Facilities in Hab as part of total Hab system
    - Rack
    - Analytical instruments
  - Mass of external facilities not integral to Hab system
    - Structure
    - ECLSS
    - Analytical instruments
    - Remote manipulation hardware

- Volume
  - Volume needed for facilities in Hab
  - Need for sample isolation
    - Regolith control
    - Limit sample exposure to O₂, H₂O

- Power
  - Total power limitations for Hab system
  - Power draw of analytical equipment, ECLSS & remote manipulator in external facility

- Cost
  - Development of integral Hab capability
    - COTS equipment
    - New instrument development
  - Development of external facility,
    - Outfitting approach
    - ECLSS
    - Remote operations approach
    - Analytical instruments

LAT Ph II Hab geoscience lab mass bogie = 500 kg
LAT Ph II Hab geoscience lab volume bogie = 1.6 m³
LAT Ph II Hab geoscience lab volume power = 300 w
LAT Ph II Hab geoscience lab cost estimate for integral Hab system vs. external facility development

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Lunar Surface Sample Analysis Considerations: Outpost

Do Sample Analysis?

N

Y

Done

What Are The Limitations on Capabilities?

Assembly Difficulty - Turnkey vs. “Some Assembly Required”
• Internal Hab system
• Separate external facility

LAT Ph II Hab geoscience lab pre-integrated vs. the difficulty of adapting discarded logistics carrier for external analysis facility

Degree of Operations Difficulty
• Internal Hab system
• Separate external facility

Operations
• Operating integral Hab capability
  o Maintaining sample isolation from lunar surface into Hab facility
  o Regolith control
  o Operations in gloves
  o Maintenance of internal atmosphere that preserves samples & makes human operations possible (vacuum vs. dry N₂ atmosphere)
  o Logistics - analytical supplies, spares
• Operating external facility
  o Manipulating samples remotely
  o Operations/maintenance of remote facilities in vacuum, including manipulators & analytical equipment
  o Logistics - analytical supplies, spares
Lunar Surface Sample Analysis Considerations: Super Sortie

Do Sample Analysis?

Y

N

Done

What Are The Limitations on Capabilities?

Crew time
- >7, ≤30 days
- Mobility sufficient for 10-25 km radius of travel (?)
- >7 day stay means more crew time available for IVA analysis

Single landed cargo delivery limits facilities to a lab-in-the-Hab concept

Mass of facilities in Hab
- "Rack" for facility mounting (e.g., ISPR w/ interfaces)
- Mass of outfitting w/ selected instruments

LAT Ph II Hab geoscience lab mass bogie = 500 kg

Volume
- Volume needed for rack in Hab
- Volume limitations w/in rack for outfitting instruments

LAT Ph II Hab geoscience lab volume bogie = 1.6 m³

Power
- Total power limitations for rack
- Power draw of analytical equipment

LAT Ph II Hab geoscience lab volume power = 300 w

Cost
- Development of integral Hab capability
  - COTS equipment
  - New instrument development

LAT Ph II Hab geoscience lab cost estimate for integral Hab system

Operations
- Need for sample isolation
  - Regolith control
  - Limit sample exposure to O₂, H₂O
  - Internal pressure/gas mix

The analytical capability suggested for a super-sortie “box” is very similar to the Outpost Lab-in-Hab capability, implying one development may have several uses.
## Lunar Surface Sample Analysis Approaches: Data Needs, Techniques and Equipment Matrix

<table>
<thead>
<tr>
<th>Information Needed</th>
<th>Data Generated</th>
<th>Analytical Technique</th>
<th>Sample Preparation</th>
<th>Equipment Needed</th>
<th>Ancillary Data Needs</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Mass</td>
<td>Sample weight</td>
<td>Weighing</td>
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<td>Balance</td>
<td>None</td>
<td>Correct for g to get mass</td>
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<td>Density</td>
<td>Mass &amp; Volume</td>
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<tr>
<td>Surface Features (zap pits, coatings, radiation damage)</td>
<td>Description, measurement of surface characteristics</td>
<td>Observation</td>
<td>Removal of regolith coating</td>
<td>Binocular microscope or video equivalent</td>
<td>None</td>
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<tr>
<td>Mineralogy/Petrography</td>
<td>Description of mineral type, habit, groundmass</td>
<td>Observation</td>
<td>Removal of regolith, splitting sample, poss. prep of flat, polished surface, thin section prep</td>
<td>Binocular microscope, rock splitter, poss. petrographic microscope, thin section/polish surface prep</td>
<td>None</td>
<td>Flat surface preparation suggested by MER Science Team members</td>
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<tr>
<td>Position/Orientation on the Lunar Surface</td>
<td>Description of surface orientation, burial/exposure relationships</td>
<td>Analysis of surface photos in comparison w/ samples</td>
<td>None</td>
<td>Electronic or hard copies of surface images</td>
<td>Input from sample documentation photos</td>
<td></td>
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<tr>
<td>Noble Gas Abundances</td>
<td>Chemical analyses</td>
<td></td>
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<td>NEED INPUT - SHOULD WE DO THIS?</td>
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<tr>
<td>Major, Minor &amp; Trace Element Abundances</td>
<td>Chemical analyses</td>
<td>Wet chemistry, XRD, microprobe</td>
<td>Preparation of polished sections</td>
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<td>NEED INPUT - SHOULD WE DO THIS?</td>
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<tr>
<td>Presence of Microbes or Fossils</td>
<td>Description of sample</td>
<td>Observation</td>
<td>SEM sample coating</td>
<td>Binocular microscope or video equivalent, SEM</td>
<td>Mars-forward technique for astrobiology</td>
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Lunar Surface Sample Analysis Considerations: Next Steps

- Given the LAT Phase II Habitat mass-volume-power bogies, we should use the suite of instruments from the Approaches matrix to see how far we can fill up the LAT Habitat geoscience analytical facility “box”
  - Use an existing ISS facility (Microgravity Sciences Glovebox, Life Sciences Glovebox) as a starting point for the rack facility into which the instrumentation would be put
  - Use COTS instruments available today
  - Determine what facilities are not COTS and will need to be developed as a separate tech dev activity
  - Determine the costs of implementation
  - Determine what work should be done on both outpost and super-sortie missions

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</tbody>
</table>
Lunar Surface Sample Analysis Considerations: Next Steps (cont.)

• Look at the option of outfitting a used logistics carrier on the lunar surface as a remote lab, to include:
  o Establishing the analytical equipment we want to use
  o Establish what the minimum ECLSS that will be needed to allow the facility to operate
  o Determine realistic work levels necessary to outfit such a facility on the lunar surface, given that the cargo carrier will arrive on the surface loaded with cargo and without any of the necessary capabilities for an analytical facility
  o Determine the cost of sending the analytical equipment to the lunar surface as a separate cargo package
  o Get realistic ideas of the difficulty of manipulating samples remotely in order to conduct the necessary analytical activities with a reasonable level of efficiency, including an unbiased evaluation of robotic capability (e.g., compare sample manipulation robotically to a human working the same operations in a glove box)
  o Determine costs of implementation

• In addition, there are a number of operations issues that should be investigated
  o For an in-Habitat science area, work out the requirements and general implementations for keeping samples isolated from the internal environment of the Habitat, including transfer from the lunar surface to the interior of the analytical facility
    – Scientific airlock (approached used on Skylab and JEM Module on ISS)
    – Transfer box similar to an ALSRC
  o Determine what gas mix and differential pressure should be used in an in-Habitat glove box
  o For both in-Hab and remote facility implementations, determine the recurring logistics needs for any analytical effort
    – Gasses
    – Research supplies
    – Spare parts/maintenance items
Lunar Sample Management Issues - Conclusions

• Work is underway to increase the amount of returned sample mass from the lunar surface to at least 230 kg
  • As with Apollo, continued experience with the various vehicles (Orion, lander) will allow us to understand the performance of our systems and to take advantage of increased capability not necessarily evident early on in the vehicle development process
• Regardless of how much mass capability we have, we will likely have more samples on the surface than we have mass/volume for, requiring preliminary analysis on the lunar surface to return a representative sample suite to the Earth for more detailed analysis
• It is likely that we will not do sample analysis on short term sortie missions, due to limited time on the lunar surface and the need to use surface crew time wisely
• How we “parse out” our activities in an Outpost laboratory will be based in part on what it makes sense to do scientifically, and what mass, volume, power and development budget we have to pursue this capability
• If you have input for me to answer the questions raised by this presentation, please drop me an e-mail at dean.b.eppler@nasa.gov