Considerations

Objective: Establishment of outpost site for long-term occupation.
  “…sustained human presence on the Moon…”

Environmental considerations (lighting, thermal) may be paramount.

Resource potential may be important.

Scientific objectives not likely to be a driver.

International cooperation, commercial ventures, ….

Different from Apollo and Mars robotic missions.

*Raison d’être for lunar outpost must be established.*
*It defines what characteristics are important.*
Apollo Site Selection

Environment
- Define surface characteristics
- Assess hazard potential
- Topography of landing site and effects on LM landing radar performance

Safety
- Free return trajectory – landing site ±5° latitude
- Navigation: emerge from eastern limb, acquire signal, calculate position
  - Required location uncertainty of ground reference points <1500’ (450 m)
  - Large uncertainties near limb – landing site ±40° longitude (later ±45° longitude)
- Landing zone: 185 miles (300 km) x 1500 miles (2400 km)
- Lighting for lunar landing and surface temperature and lighting at KSC for launch

Primary and two backups to deal with launch delays

Science secondary early on.
- 1962 Iowa summer study
- 1965 Woods Hole study
- Falmouth conference on lunar exploration
- Continuous study and modification
- Became a greater consideration in later missions
"DESTINATION MOON"
COLOR BY TECHNICOLOR

NEVER BEFORE HAS ANY WOMAN...

EXPLORERS ON THE MOON

...SENT HER MAN ON SUCH AN EXPLOIT!
## Environment

<table>
<thead>
<tr>
<th></th>
<th>Non Polar</th>
<th>Polar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td>-150°C to +100°C</td>
<td>-50°C ± 10°C</td>
</tr>
<tr>
<td><strong>Sunlight</strong></td>
<td>~354 hours ± 90° Incidence Angle</td>
<td>~ 530 to 708 hours ± 1.7° Incidence Angle</td>
</tr>
<tr>
<td><strong>Darkness</strong></td>
<td>~354 hours</td>
<td>0 to 148 hours (discontinuous)</td>
</tr>
<tr>
<td><strong>H Content (avg.)</strong></td>
<td>10-90 ppm</td>
<td>&gt;150 ppm</td>
</tr>
</tbody>
</table>
| **Resource Potential** | Solar wind gases  
Bound oxygen                | Solar wind gases  
Bound oxygen  
Shadowed volatiles |
| **Direct Earth Communications** | Continuous on near side                     | Discontinuous but predictable  
(~ ½ time in Earth view) |
The Moon is not JSC-1
The Moon is not Terra Incognita
Spatially Independent

Regolith physical properties
Chemistry (major element)
Dust
Surface disturbance on landing
Rock frequency
Radiation
Micrometeoroids
Magnetic field***
Atmosphere**
Surface charging / levitated dust*
Regolith Physical Properties

Apollo 16: Station 10 ALSEP
Regolith Particle Size-Frequency Distribution
Apollo 16 Regolith Grain Size vs. Rock Frequency

Apollo 16: Average grain size at different stations.

Apollo 16 EVA Map

Average grain size 114 μm

Average grain size 55 μm
Agglutinates

Individual particles – aggregates of smaller particles (mineral grain, glass, rocks, older agglutinates) bonded together by vesicular flow banded glass in varying proportions. 30-80% glass
Melting and remixed during micrometeoroid bombardment
Small agglutinates (e.g., <45 microns) are fragments of originally larger (90-150 micron) bodies
Irregular shape, branching or dendritic morphology
Usually <1 mm
25-30% volume average; 5-65% range, up to 60% volume in mature soil

Vesicles (holes): liberated solar wind gases and generated H₂O (FeO + 2H = Fe + H₂O)
Contain minute droplets of near pure Fe metal (very fine grained single domain Fe⁰, 30-100Å mounds and trains of metal Fe, attached to grains
Glass composition mimics <10 micron size-fraction of the regolith
Contain solar wind gases (e.g., He, H) in higher concentration than other particles

Mare: composition mimics regolith plus a feldspathic component
Composition generally matches the composition of <10 micron fraction better than the <1 mm fraction
<table>
<thead>
<tr>
<th>Material Type</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>FeO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>A11 Mare Basalt</td>
<td>40.46</td>
<td>10.41</td>
<td>10.08</td>
<td>19.22</td>
<td>7.01</td>
<td>11.54</td>
<td>0.38</td>
</tr>
<tr>
<td>A11 Soil and Regolith Breccia</td>
<td>41.99</td>
<td>7.94</td>
<td>12.58</td>
<td>16.40</td>
<td>7.93</td>
<td>11.74</td>
<td>0.47</td>
</tr>
<tr>
<td>A12 Mare Basalt</td>
<td>44.88</td>
<td>3.62</td>
<td>8.93</td>
<td>20.48</td>
<td>10.64</td>
<td>9.81</td>
<td>0.25</td>
</tr>
<tr>
<td>A12 Soil and Regolith Breccia</td>
<td>46.21</td>
<td>2.61</td>
<td>12.13</td>
<td>17.19</td>
<td>10.42</td>
<td>9.85</td>
<td>0.41</td>
</tr>
<tr>
<td>A17 Mare Basalt</td>
<td>39.03</td>
<td>11.94</td>
<td>9.00</td>
<td>18.82</td>
<td>8.54</td>
<td>10.82</td>
<td>0.39</td>
</tr>
<tr>
<td>A17 Soil and Regolith Breccia</td>
<td>44.47</td>
<td>2.84</td>
<td>18.93</td>
<td>10.29</td>
<td>9.95</td>
<td>12.29</td>
<td>0.43</td>
</tr>
<tr>
<td>Anorthosite</td>
<td>45.57</td>
<td>0.08</td>
<td>33.4</td>
<td>1.00</td>
<td>1.21</td>
<td>19.1</td>
<td>0.40</td>
</tr>
</tbody>
</table>
Apollo LM Descent

Apollo 11
Dust: 73-33 m (240-110')
75% Obscuration at Touchdown
Material moved along surface – deflected by rocks

Apollo 12
Dust: 53 m (175')
Obscuration 12 m (40')
Surface altered below 9-12 m altitude

Apollo 14
Dust: 33 m (110')
Erosion of 10 cm 1 m SE of nozzle

Apollo 15
Dust: 45 m (150')
Obscuration 18 m (60')

Apollo 16
Dust: 25 m (80')
Block and small crater visible to surface

Apollo 17
Dust: 20 m (65')
No obscuration
Evidence of plume interaction with surface across 50 m

The amount of material disturbed by the LM descent engine is a strong function of the approach trajectory and speed. Oblique trajectory causes the least disturbance of the surface. Vertical descent (A15) caused the most disturbance.
Apollo 12 LM Descent

LM descent engine scoured the surface during the final phases on landing.

Material was blown onto the Surveyor spacecraft.
Dust

Dust readily kicked up by walking and the LRV and adheres to everything.

Some portions of the rover became coated with dust. Coating depended upon the material.

Suits were easily coated with dust
Bearing surfaces on gloves / helmets scratched

Coating on Surveyor was thin, but hard to rub off
Dust

Dust: <50 μm size fraction
- consists largely of impact produced glass
- complicated shapes, jagged edges, large surface area
- <20 micron size fraction: 20 wt % of soil

Different composition from bulk regolith.

Impact generated glass and nano-phase Fe increase with decreasing grain size.
- ~80 wt. % at sizes <10 micron

Taylor et al. (2007) and Liu et al. (2007) data on size-frequency distribution of dust-sized material (20 microns-20 nm).

Two samples 10084-70051 both display peaks at 100-200 nm
- >95% are <2 micron
- A11-10084: 50% of particles are <0.1 micron
- A11-10084: >40% ultrafine (<100 nm) particles
- A17-70051: 50% of particles are <0.3 micron
Levitated Dust

Surveyor Observations
Glow observed after sunset on horizon at Surveyors 5, 6, 7, and maybe 1
Extends about 6° across horizon ±3° from point of sunset
No polarization anomaly detected
Horizon in glow matches illuminated horizon

Model
Visible sunlight forward scattered by electrically charged dust grains \(\sim 5-6\) micron radius electrostatically levitated above partially illuminated rocks or surface irregularities (Rennilson and Criswell 1974)
Strength of local electrostatic field 600 V cm\(^{-1}\)
Source region 10-30 cm high and deep (along line of sight)
Source region is meters to km west of Surveyor

But
Rocks not coated with dust
Laser reflectors continue to operate 35 years later

Orbital observations
Surveyor observations
Spatially Dependent

Lighting
Thermal
Topography
Communication / Earth View
Resources
Science
Commerce
Flight
  Precision landing
  Delta V budget
  Approach over shadowed terrain

*These are the site discriminators.*
## Surface Lighting

<table>
<thead>
<tr>
<th>Mission</th>
<th>EVA 1</th>
<th>Local Time</th>
<th>EVA 2</th>
<th>Local Time</th>
<th>EVA 3</th>
<th>Local Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apollo 11</td>
<td>14.0°-15.4°</td>
<td>6.93-7.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apollo 12</td>
<td><strong>7.5°-9.5°</strong></td>
<td>6.50-6.63</td>
<td>15.8°-17.8°</td>
<td>7.05-7.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apollo 14</td>
<td>13.0°-15.5°</td>
<td>6.87-7.03</td>
<td>22.0°-24.3°</td>
<td>7.47-7.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apollo 15</td>
<td>19.6°-22.9°</td>
<td>7.31-7.51</td>
<td>31.0°-34.7°</td>
<td>8.07-8.31</td>
<td>41.7°-44.3°</td>
<td>8.78-8.95</td>
</tr>
<tr>
<td>Apollo 16</td>
<td>22.2°-25.7°</td>
<td>7.48-7.71</td>
<td>34.1°-37.9°</td>
<td>8.27-8.53</td>
<td><strong>45.8°-48.7°</strong></td>
<td>9.05-9.25</td>
</tr>
<tr>
<td>Apollo 17</td>
<td>15.3°-19.0°</td>
<td>7.02-7.27</td>
<td>27.3°-31.2°</td>
<td>7.82-8.08</td>
<td>39.0°-42.6°</td>
<td>8.60-8.84</td>
</tr>
</tbody>
</table>

Time: Decimal hours with 6.00 as sunrise / 12.00 as noon.
Illumination: degrees above horizon
Apollo 12 EVA 1 had the lowest illumination angle
Apollo 16 EVA 3 had the highest illumination angle
LOI $\Delta V$ (km/s), No Loiter, CEV WA minimized

**Method 1:** 2nd LOI burn occurs at Apolune, pure plane change
Lunar Arrival 9/18/2024 12:00, 4-day transfer, Nominal mission, Beginning of TLI Window

Min = 0.883 Max = 1.382
Resources - H

Epithermal neutrons (counts / 8-sec)
Resources - Ice?

Margot et al. Earth-based radar

Clementine Bi-Static Experiment
Topography

Radii (km)

- 1,741.7 - 1,745.5
- 1,738.7 - 1,739.6
- 1,737.1 - 1,737.6
- 1,736.1 - 1,736.5
- 1,734.7 - 1,735.3
- 1,732.7 - 1,733.6
- 1,739.7 - 1,741.6
- 1,737.7 - 1,738.6
- 1,736.6 - 1,737
- 1,735.4 - 1,736
- 1,733.7 - 1,734.6
- 1,728.2 - 1,732.6
Science

Science of, from and on the Moon

NRC Decadal Survey
LEAG
NASA Advisory Council

Not a driver, but at present, can not provide constraints.
Commercial

Propellant production
Mining
Solar power - outpost / beaming
Manufacturing
Tourism / Gaming

Presently can not provide any constraints.
What Really Needs to Be Measured at the Moon?

Risk Reduction / Cost Control / Optimization

Apollo-like Sortie

Polar
- Geodetic control – enabling
- Topography - enabling
- High-resolution imaging (hazards) - enhancing

Non-Polar
- Nothing – enabling
- High-resolution imaging (hazards) - enhancing

Outpost – Being There (Just land safely)

Polar
- Topography - enabling
- Geodetic control – enabling
- Lighting model – enhancing
- High-resolution imaging - enhancing

Non-Polar
- Nothing – enabling
- High-resolution imaging – enhancing

Global
- Dust toxicity – TBD
- Electrical charging – TBD
What Really Needs to be Measured at the Moon?

**Outpost with** Resource Utilization

- Resource distribution (ore characterization)
  - H form, concentration, distribution in polar regions (lighted and shadowed)
- Highlands composition
- Pyroclastic composition
- Regolith physical properties
  - Pyroclastic deposits
  - Permanently shadowed

**Polar**

- Topography - enabling
- Geodetic control – enabling
- Lighting model – enhancing
  - High-resolution imaging - enhancing

**Non-Polar**

- High-resolution imaging – enhancing

**Global**

- Dust toxicity – TBD
- Electrical charging – TBD