Effects of ISRU on the Lunar Environment

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- Lunar environment and ISRU effects
  - Atmosphere
  - Dust
- Special issues for a polar outpost
- Outstanding problems
- Requirements/Architecture fit
Lunar atmosphere

- The lunar atmosphere is a thin, surface-bounded exosphere
  - Nighttime densities are about $10^5$/cm$^3$
  - Total global mass is several metric tons
  - Gas releases disperse rapidly (expansion velocity of km/s)
  - Solar wind is the main source ($\sim$30 gm/sec), with smaller endogenous sources (e.g. Na, K, Ar)
  - Rapid loss by solar-wind ion pickup at the photoionization time ($10^6$ to $10^7$ s)

- Modification by Apollo was short-lived
  - 8,000 kg of rocket exhaust
  - cabin venting of 3 kg
  - astronaut suit life support at 1 kg/hr of H$_2$O

- Significant increase (by $10^3$?) may result in a long-lived atmosphere (requires about $10^4$ tons and 30 kg/s)
Lunar atmosphere - ISRU effects

- Regolith contains volatiles of solar wind origin
  - Apollo: 100 ppm of H₂, He, CO₂, CH₄, N₂, (+H₂O?)
  - ~70% released by heating to 600 C; ~90% at 1400 C
  - recovering 1 ton of volatiles requires processing at least 10,000 tons of regolith
- Oxygen can be recovered by regolith chemical processing
- Some TBD fraction of volatiles or extracted oxygen will escape into the environment

Modest ISRU (few tons per year) could exceed the natural global atmospheric abundance (few tons, 30 gm/s), but might not have any persistent global effects
Lunar Dust Environment

- Dust might be a problem for operations, for human physiology, and possibly for astronomical observations
- Some dust sticks to surfaces mechanically
- Uncharged dust settles by gravity, so effects are local
- Dust may become electrically charged by sunlight/plasma effects or by tribocharging
  - electrostatically adheres to surfaces
  - horizontal transport and lofting by the surface electric field resulting from solar wind interaction, particularly at the sunlight terminator
Lunar Dust Environment - ISRU Effects

- ISRU activities will generate dust as a TBD fraction of regolith that is excavated. Particles smaller than 5 microns comprise about 5% of the regolith. These are 500 times more abundant than volatiles.
- Release of fine dust could result in a substantial increase to the natural dust cloud thought to exist at the sunlight terminators, with degradation of optical astronomy.
- An unknown is the dust fraction that might be charged and lofted.

Column mass density of \( \sim 4 \) grams per \( \text{km}^2 \)

Particle size: \( \sim 0.5-5 \) microns

May be brighter than the terrestrial night sky

Terminator dust cloud observed from Apollo (McCoy, 1976)
Special issues for a polar outpost

- **Atmospheric gases**
  - Dispersal of gas releases will be complicated by delayed release from nearby intermittently-shadowed regions and by the proximity to the nightside.
  - The gas release rate will greatly exceed the natural solar wind flux to the PSRs (0.7 kg/yr/km²). Consequences are TBD.

- **Dust**
  - The pole is always near the terminator, so charged fine dust from ISRU might result in a high-altitude dust cloud. This could interfere with optical astronomy.
  - Dust might flow one-way into PSR without exit, with consequences TBD.
Some Outstanding Problems/Questions

• What are the composition and variability of the natural lunar atmosphere?
• What are its sources, losses, and resiliency?
• How do gas releases disperse across the lunar surface?
• How are volatiles transported to polar cold traps and what is their durability?
• Are there dust clouds at the sunlight terminators?
• What is the sky brightness at the poles?
• What is the electrodynamics of dusty plasmas at the lunar surface?
• What processes control the transport of charged dust?
• Does regolith excavation result in volatile emissions, dust release, and triboelectric charging?
Requirements to fulfill science objectives

• Measure the natural environment early with modern sensors so as to
  - identify natural components
  - understand processes that affect their variability
• Use observations, theory, and modeling to predict the consequences of ISRU
• Test methods to mitigate potentially adverse environmental effects
• Monitor the environment after the outpost is established
Requirements to Fulfill Objectives

Architecture Fit

• Measure the natural environment early with modern sensors so as to
  - identify natural components
  - understand processes that affect their variability

Prolonged measurements with robotic landers/orbiters prior to human return

• Use observations, theory, and modeling to predict the consequences of ISRU

Verify understanding with distributed measurements of dispersal and transport

• Test methods to mitigate potentially adverse environmental effects
  Can be done at outpost

• Monitor the environment after the outpost is established
  Use sensors at outpost and elsewhere