Life Support and Thermal Management Challenges in Space: Lunar vs LEO

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Agenda

Lunar vs LEO Environments Overview

Thermal Environment Considerations

Gravity Considerations

Radiation Environment Considerations

Dust Considerations

Cabin Environment Considerations

Lunar vs. LEO Environmental Challenges

Environmental Factor	Experience with ISS	Experience with Apollo	Anticipated Lunar S. Pole
Location	Low Earth Orbit	Lunar Equatorial (˜9°S to ˜26°N)	Lunar South Pole (84 - 90°S)
Thermal Environment	Solar flux source/deep space sink 90-min orbit	Solar flux and incidence angle drive thermal conditions[1,2] 27-day revolution	Topography of surface drives thermal conditions[1] 27-day revolution
Gravity	µg/free fall	1/6 g	1/6 g
Radiation	Limited by Earth's magnetic field and radiation belts[3]	No natural protection	No natural protection
Dust	Intermittent orbital debris Sources from ground Generated in-cabin	Sources from ground Generated in-cabin **Regolith**	Sources from ground Generated in-cabin **Regolith**
Cabin Environment	14.7 psia/21% O_2	5 psia/100% O_2	10.2 psia/26.5%O_2 or 8.2 psia/34% O_2

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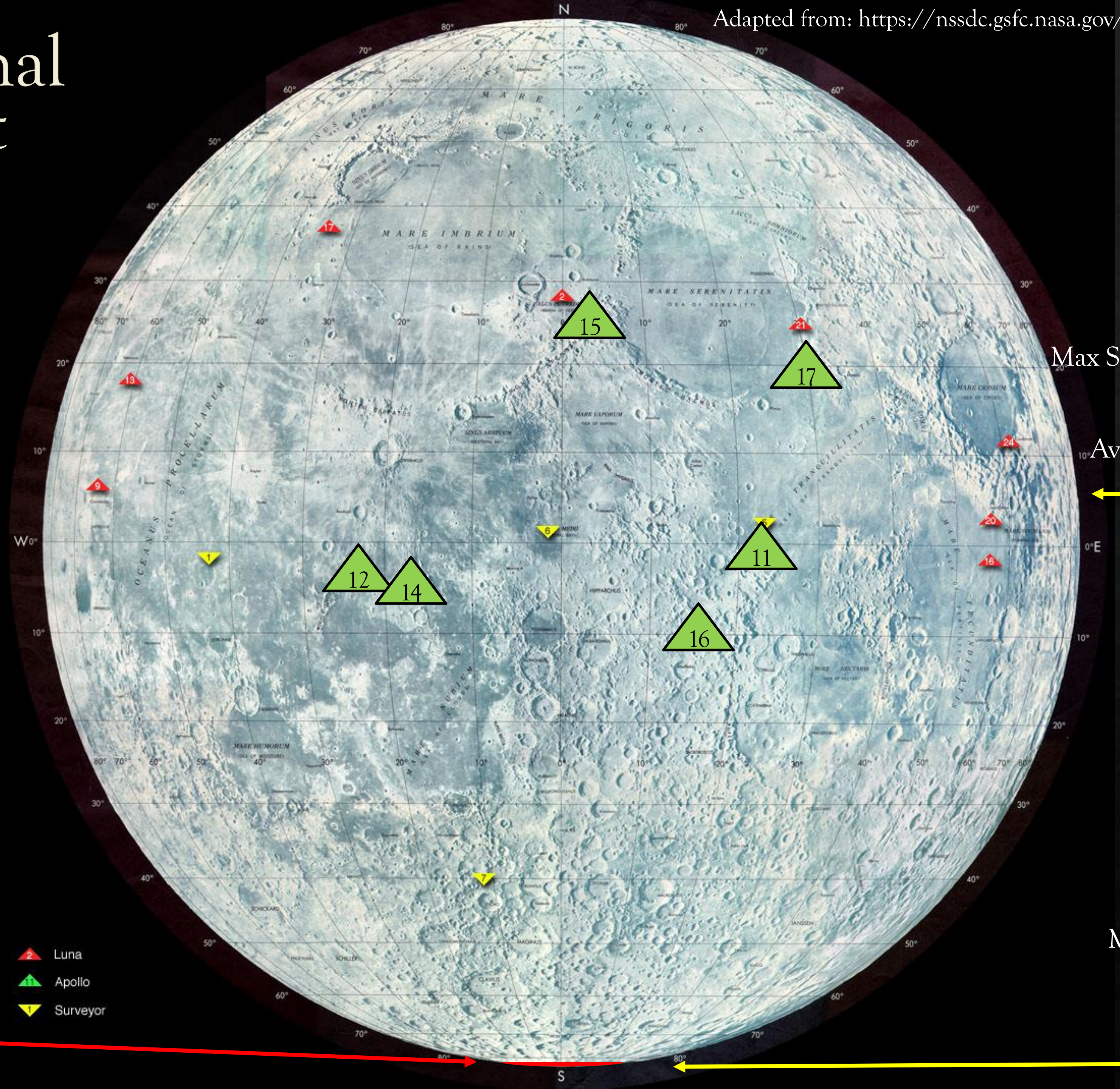
[1] Williams, J.-P., Paige, D.A., Greenhagen, B.T., Sefton-Nash, E., "The global surface temperatures of the Moon as measured by the Diviner Lunar Radiometer Experiment," *Icarus 283 (2017) 300-325.*

[2] Kaczmarzyk, M., Gawronski, M., Piatkowski, G., "Global database of direct solar radiation at the Moons surface for lunar engineering purposes," *SOLINA 2018*, E3S Web of Conferences 49, 00053 (2018).

[3] Lloyd, C.W., Townsend, S., Reeves, K.K., "Space Radiation," *NASA Human Research Program Engagement and Communications*, i-Book, (2017).

Lunar Thermal Environment

Adapted from: https://nssdc.gsfc.nasa.gov/planetary/lunar/moon_landing_map.jpg



Apollo
Landing Sites

Artemis
Proposed
Landing Sites

Angle of incidence ~0°

Max Solar Irradiance = ~1200-1400 W/m^2

ΔT (noon-midnight) ~290K

Ave. Min/Max = ~92K/387-397K[1]

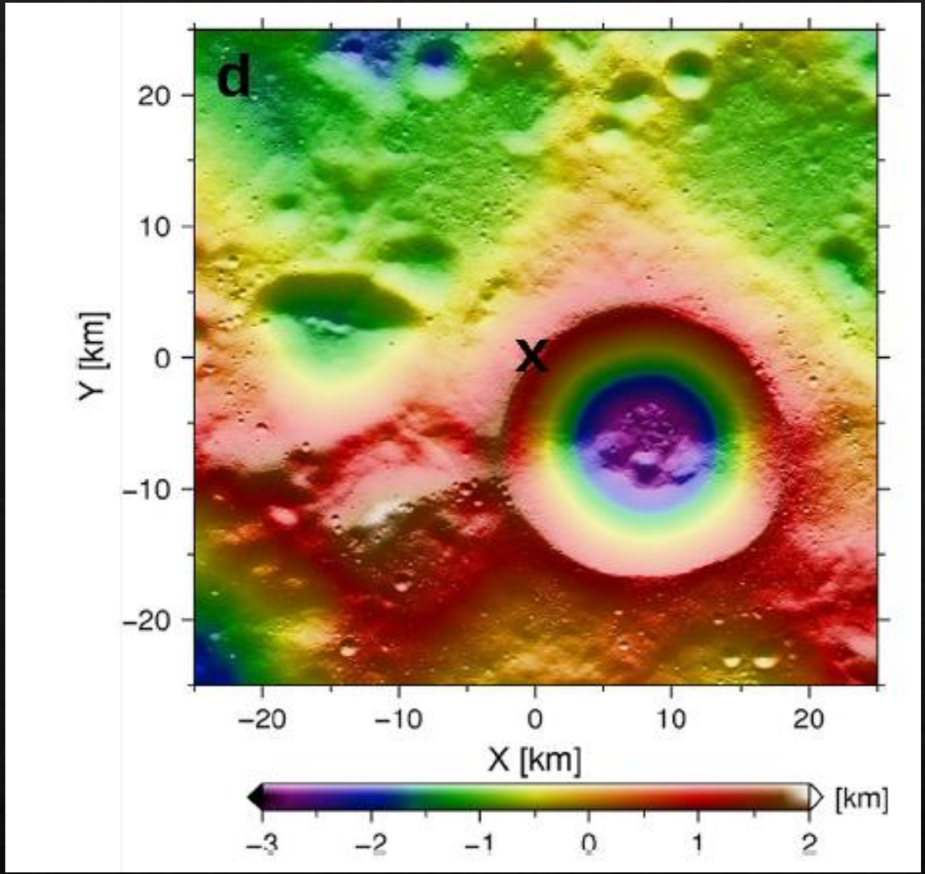
Angle of incidence ~90°

Max Solar Irradiance <250 W/m^2

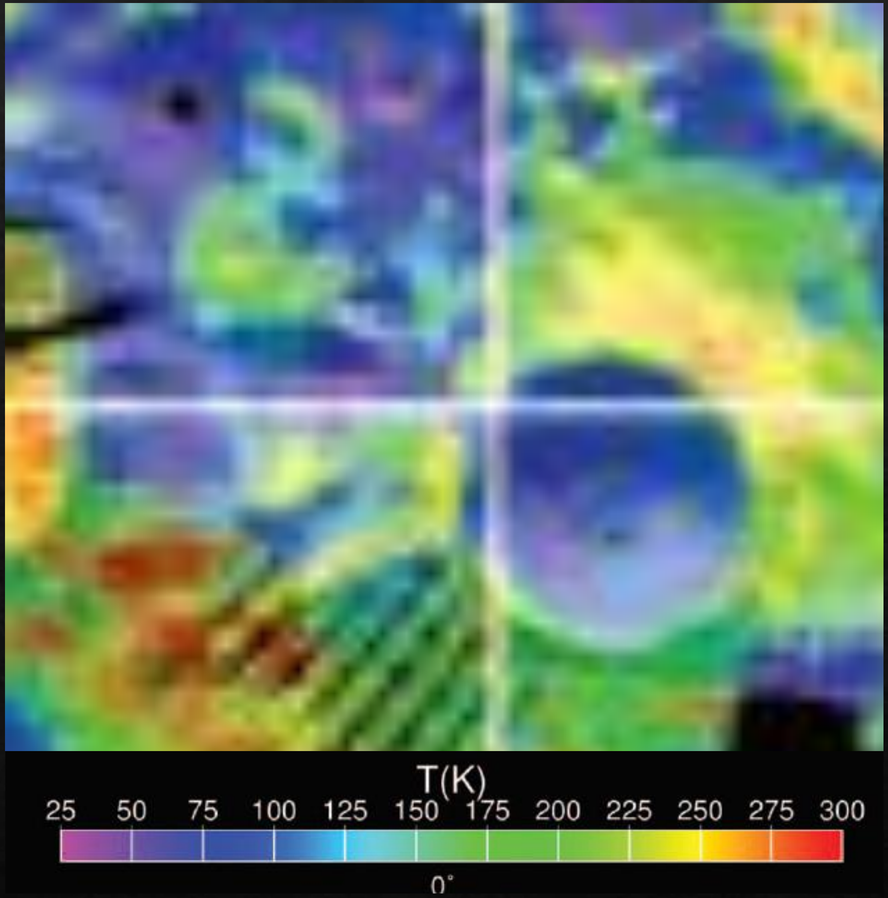
ΔT (noon-midnight) ~120K

Ave. Min/Max = ~60K/185K[1]

South Pole Topography and Surface Temperatures



Adapted from Glaser *et. al.* Fig 1d.[4] “Inset of the 50 x 50 km area of interest at the south pole, black cross in the center marks the position of the pole. All units are in kilometers and maps are displayed in stereographic projection.”



Adapted from Paige *et. al.* Fig 1A[5] “Diviner-measured daytime bolometric brightness temperatures acquired between 11.4 and 13.6 hours local time.”

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[4] Glaser, P., Oberst, J., Neumann, G.A., Mazarico, E., Speyerer, E.J., Robinson, M.S., “Illumination conditions at the lunar poles: Implications for future exploration,” *Planetary and Space Science 162 (2018) 170-178.*

[5] Paige, D.A. *et al*, “Diviner Lunar Radiometer Observations of Cold Traps in the Moon’s South Polar Region,” *Science* Vol 330, 22 October 2010, pg 479 – 482.

Lunar Thermal Environment Challenges to Life Support and Vehicle Thermal Design

- Both passive and active thermal vehicle design will be affected by significantly reduced solar flux
- Maintaining vehicle/hardware viability during prolonged periods of darkness* will require active thermal control (heating)
  - Proves more challenging with limited/no power
  - Minimum temperatures at S. Pole low enough to freeze N_2 and O_2
  - Life support hardware may need to remain above 273K in event water is stored
- Spacesuit materials must protect crew at significantly lower temperatures and in event of falls, where the crew may contact the ground (conduction)

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* Up to 6 months assuming zero elevation[6]

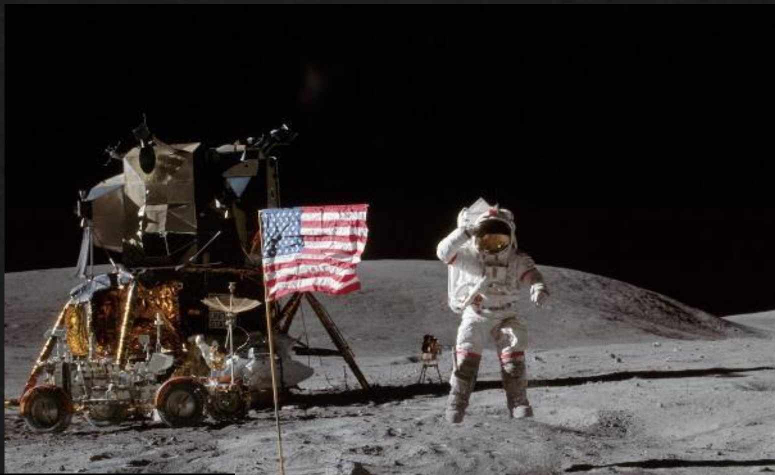
[6] Christie, R.J., Plachta, D.W., Hasan, M.M., "Transient Thermal Model and Analysis of the Lunar Surface and Regolith for Cryogenic Fluid Storage," NASA/TM-2008-215300, NASA 2008.

Gravity

Astronaut Marsha Ivins
on Space Shuttle

Astronaut Chris Cassidy
on ISS

Astronaut Buzz Aldrin
on the Moon



Astronaut John Young
Jumping Salute
on the Moon

Credit: NASA

Gravity Challenges/Benefits to Life Support and Vehicle Thermal Design

- Challenges
  - Fire: limited data on partial gravity fire behavior
  - Spacesuit design: flexibility of materials, durability of materials, total mass (currently ~280lbs Earth/~47lbs Moon)
  - Mass of systems: Mission concepts with post-flight system integration will need to reduce mass of hardware (e.g. oxygen generator = ~1500lbs Earth/250lbs Moon)[7]
    - Already a challenge in microgravity, but different type of challenge
- Benefits
  - Urine Processing Assembly distillation easier with help of gravity
  - Toilet hardware operation and use easier with help of gravity
  - Phase separation in systems like the oxygen generator and Sabatier carbon dioxide reduction systems easier
  - “Loose” items, water droplets, etc. will settle out rather than finding their way to vents, electronics, etc.

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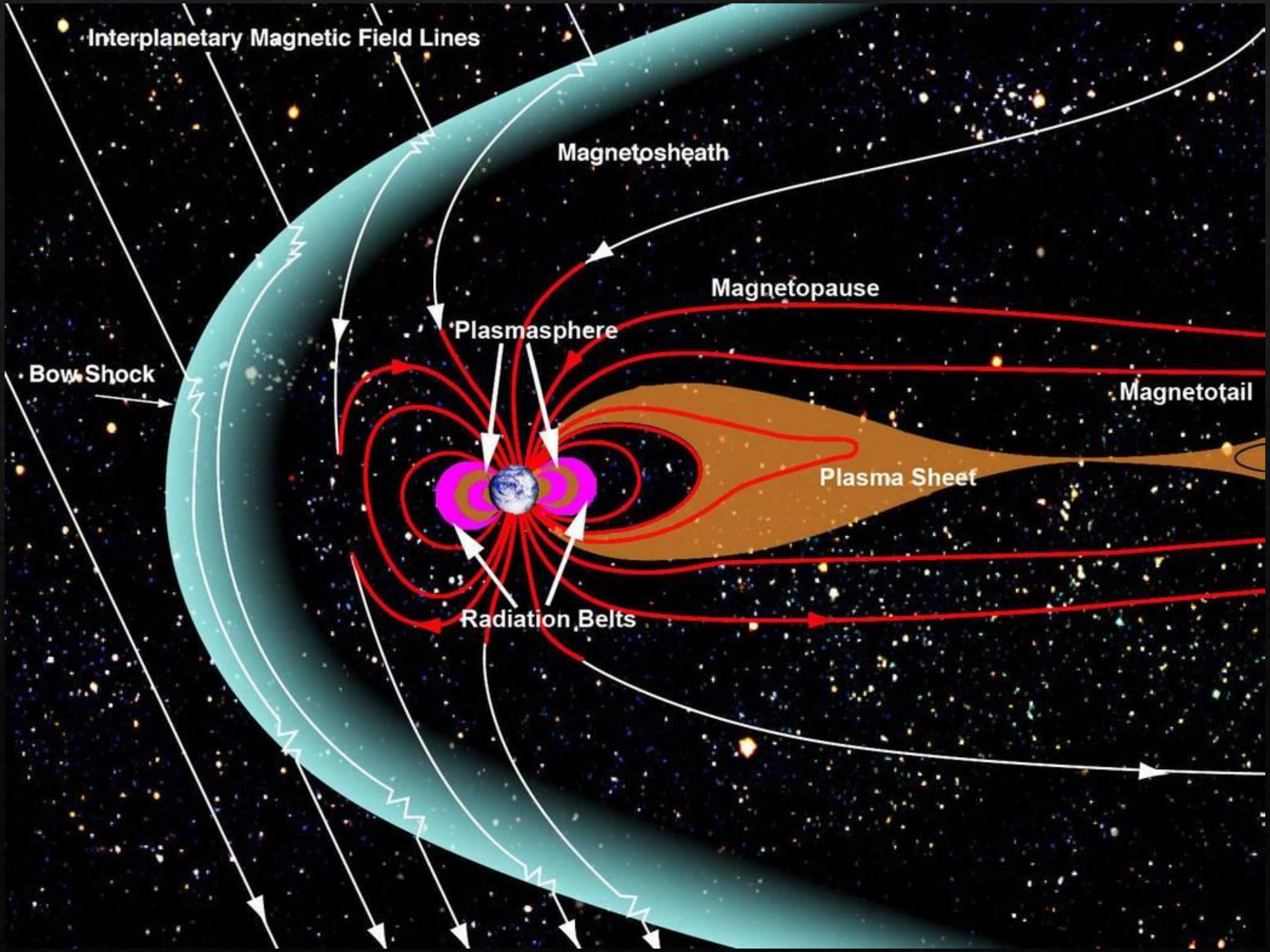
[7] Bagdigian., R.M., Dake, J., Gentry, G., Gault, M., “International Space Station Environmental Control and Life Support System Mass and Crewtime Utilization In Comparison to a Long Duration Human Space Exploration Mission,” ICES-2015-094, 45th International Conference on Environmental Systems 12-16 July 2015, Bellevue, Washington.

Radiation

- Localized, low level magnetic fields on the Lunar Surface – limited protection
  - Solar Particle Events (angle of incidence helps)
  - Galactic Cosmic Radiation
- Potential additive radiation of solar wind and Earth's magnetosheath near Full Moon[8]



Credit: NASA

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[8] Shang, W.S., Tang, B.B., Shi, Q.Q., *et al.* "Unusual Location of the Geotail Magnetopause Near Lunar Orbit: A Case Study," JGR Space Physics, Vol 125, Issue 4 (2020) pp. 1-13.

Radiation Challenges to Life Support

- Crew Protection during Habitation
  - General vehicle shielding
  - Safe haven
  - Crew quarters
- Crew Protection during EVA
  - Suit shielding
  - Space weather forecasting
- Effects of radiation on:
  - Food
  - Medicine

ISS Crew Quarters
Credit: NASA

Dust Challenges to Life Support and Thermal Design

- Vehicle Thermal Challenges
  - Dust on radiators
- Cabin Challenges
  - General cabin cleanliness
  - Crew health (respiratory)
  - Atmosphere Revitalization System cleanliness (HEPA filters, heat exchangers, carbon dioxide removal assembly, etc)
  - Hardware with fans and air cooling
- EVA Challenges
  - Triboelectric charging of suit
  - Thermal effects of dust adhered to suit materials
  - Durability of suit materials vs dust abrasion/infiltration

At the end of a long day on the moon, Apollo 17 astronaut Gene Cernan rests inside the lunar module Challenger. Note the smudges of dust on his longjohns and forehead. *Photo credit: Jack Schmitt*

Cabin Environment and Challenges

- Reduced pressure environment desirable for high-frequency EVA operations
  - Reduces pre-breathe durations
- Challenges*
  - Increased O_2 increases flammability risk
  - Decreased pressure causes reduced density air for cooling (less efficient)
  - Systems that reference ambient for pressure control, venting, etc. will require redesign to maintain performance

*Ongoing NASA Engineering & Safety Center Assessment to evaluate impacts to life support, thermal, emergency hardware, medical systems.

Summary

- Significant known differences between ISS environments and Lunar South Pole environments
- Differences will drive changes in life support and thermal systems
- Data is needed to better characterize these environments
- Data is needed to better understand the affects of the environments on life support and thermal systems

Thank you.

Are there any questions?