Lunar Surface Innovation
CONSORTIUM

Extreme Environments Focus Group November Telecon

November 10, 2020

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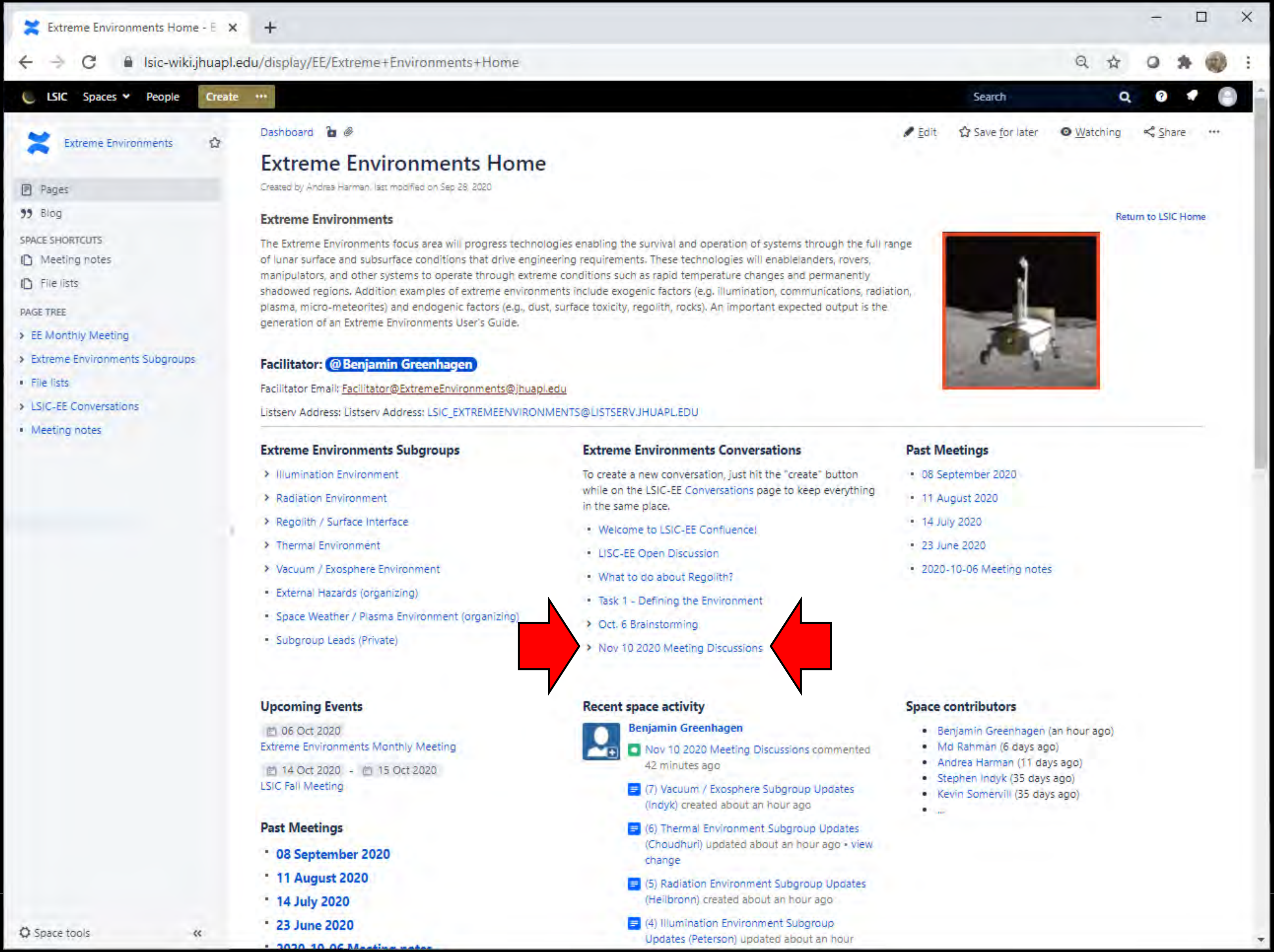
Today's Agenda

- Facilitator updates plus ISRU request (5 min - Greenhagen)
- POC updates and NASA opportunities (10 min - Somervill)
- Regolith / Surface Interface subgroup intro package with quad chart (10 min - Barker)
- Illumination Environment subgroup updates (5 min - Peterson)
- Radiation Environment subgroup updates (5 min - Heilbronn)
- Thermal Environment subgroup updates (5 min - Choudhuri)
- Vacuum / Exosphere subgroup updates (5 min - Indyk)
- Open floor (time permitting)

- Next month: No December LSIC-EE monthly meeting!
  - Next meeting is Tuesday, January 12th 2021

Join the Discussion on Confluence



Extreme Environments Home

Created by Andrea Harman, last modified on Sep 28, 2020

Return to LSIC Home

Extreme Environments

The Extreme Environments focus area will progress technologies enabling the survival and operation of systems through the full range of lunar surface and subsurface conditions that drive engineering requirements. These technologies will enablelanders, rovers, manipulators, and other systems to operate through extreme conditions such as rapid temperature changes and permanently shadowed regions. Addition examples of extreme environments include exogenic factors (e.g. illumination, communications, radiation, plasma, micro-meteorites) and endogenic factors (e.g., dust, surface toxicity, regolith, rocks). An important expected output is the generation of an Extreme Environments User's Guide.

Facilitator: @Benjamin Greenhagen

Facilitator Email: Facilitator@ExtremeEnvironments@jhuapl.edu

Listserv Address: Listserv Address: LSIC_EXTREMEENVIRONMENTS@LISTSERV.JHUAPL.EDU

Extreme Environments Subgroups

- Illumination Environment
- Radiation Environment
- Regolith / Surface Interface
- Thermal Environment
- Vacuum / Exosphere Environment
- External Hazards (organizing)
- Space Weather / Plasma Environment (organizing)
- Subgroup Leads (Private)

Extreme Environments Conversations

To create a new conversation, just hit the "create" button while on the LSIC-EE Conversations page to keep everything in the same place.

- Welcome to LSIC-EE Confluence!
- LISC-EE Open Discussion
- What to do about Regolith?
- Task 1 - Defining the Environment
- Oct. 6 Brainstorming
- Nov 10 2020 Meeting Discussions

Past Meetings

- 08 September 2020
- 11 August 2020
- 14 July 2020
- 23 June 2020
- 2020-10-06 Meeting notes

Upcoming Events

06 Oct 2020
Extreme Environments Monthly Meeting

14 Oct 2020 - 15 Oct 2020
LSIC Fall Meeting

Past Meetings

- **08 September 2020**
- **11 August 2020**
- **14 July 2020**
- **23 June 2020**

Recent space activity

Benjamin Greenhagen

Nov 10 2020 Meeting Discussions commented 42 minutes ago

(7) Vacuum / Exosphere Subgroup Updates (Indyk) created about an hour ago

(6) Thermal Environment Subgroup Updates (Choudhuri) updated about an hour ago • view change

(5) Radiation Environment Subgroup Updates (Heilbronn) created about an hour ago

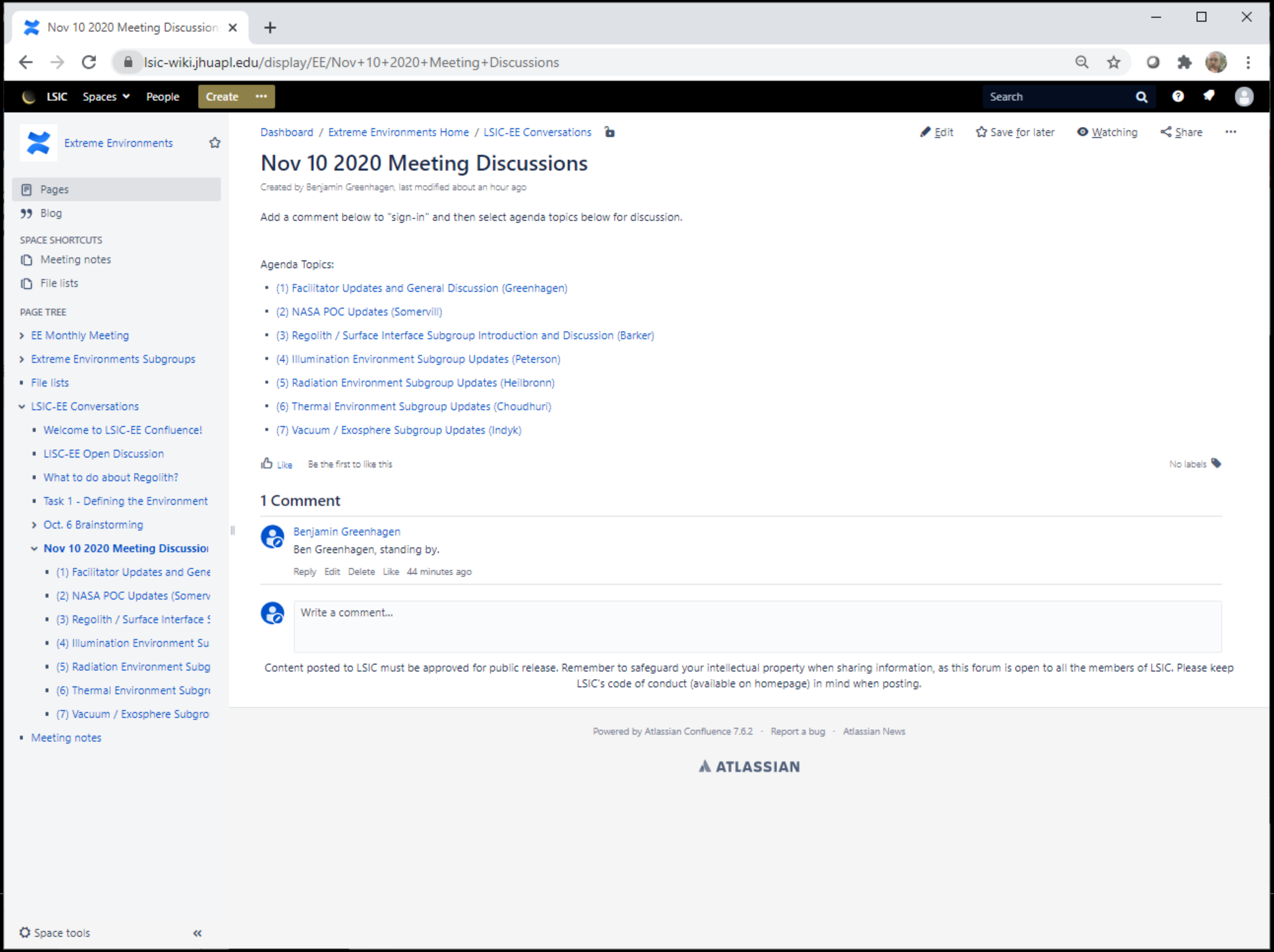
(4) Illumination Environment Subgroup Updates (Peterson) updated about an hour

Space contributors

- Benjamin Greenhagen (an hour ago)
- Md Rahman (6 days ago)
- Andrea Harman (11 days ago)
- Stephen Indyk (35 days ago)
- Kevin Somervill (35 days ago)
- ...

https://lsic-wiki.jhuapl.edu/display/EE

Join the Discussion on Confluence



Nov 10 2020 Meeting Discussions

Created by Benjamin Greenhagen, last modified about an hour ago

Add a comment below to "sign-in" and then select agenda topics below for discussion.

Agenda Topics:

- (1) Facilitator Updates and General Discussion (Greenhagen)
- (2) NASA POC Updates (Somervill)
- (3) Regolith / Surface Interface Subgroup Introduction and Discussion (Barker)
- (4) Illumination Environment Subgroup Updates (Peterson)
- (5) Radiation Environment Subgroup Updates (Heilbronn)
- (6) Thermal Environment Subgroup Updates (Choudhuri)
- (7) Vacuum / Exosphere Subgroup Updates (Indyk)

1 Comment

Benjamin Greenhagen
Ben Greenhagen, standing by.

Content posted to LSIC must be approved for public release. Remember to safeguard your intellectual property when sharing information, as this forum is open to all the members of LSIC. Please keep LSIC's code of conduct (available on homepage) in mind when posting.

1. Add a comment to "sign-in"
2. Select an agenda topic and comment your thoughts
3. You can comment before, during, or after the presentations
4. Check back later to see what others have commented!

Fall Meeting Recap

- Thank you for your involvement in both days of the LSIC Fall Meeting!

- Breakout Session 1 – Envisioning a future sustained lunar presence for different power constraint categories
  - 10 kW continuous power
  - 100 kW with 70% duty cycle
  - >1 MW continuous power

- Breakout Session 2 – Key technologies and knowledge gaps to be addressed to achieve envisioned future from Breakout Session 1
  - Continue within your session 1 group

- Breakout Session 3 – Critical factors linking envisioned futures
  - All groups together within each power category

- Lots of information distillation ongoing; big out brief in the works
  - Most likely will be during the next Surface Power monthly meeting (TBD) with all focus groups invited

ISRU Focus Group Request

- ISRU Focus Group Facilitator, Karl Hibbitts, is looking to enhance collaboration between the ISRU, Dust Mitigation, and Extreme Environments Focus Group by identifying a SME or few SMEs interested in regular attendance of ISRU meetings

- At the ISRU November monthly meeting (November 18th at 3pm EST) a terrestrial engineer, Dale Boucher, will present and provide insights on mining regolith

- Followed by a discussion regarding specific challenges of working in the lunar environment with an opportunity to give a lightning talk (if desired)

- If interested, contact Karl Hibbitts, Karl.Hibbitts@jhuapl.edu

Space Technology Mission Directorate
Technical Integration Manager for Extreme Environments

Kevin Somervill | Lunar Surface Innovation Consortium | 2020-11-10

Agenda

- LSIC Focus Group NASA PoC Role and Background
- Interests
- Game Changing Development Program
- Lunar Surface Innovation Initiation Overview
- LSII Implementation Strategy

NASA PoC Role and Background

- NASA POC role
  - Liaison between NASA STMD, LSII and LSIC working with the focus group lead and team
  - Communicate ideas, information, and questions between the group
  - Provide insight into NASA’s perspective and learn from your shared perspectives, expectations, and observations
  - Round up support and participation in our topics

- My Background
  - M.S. Computer Engineering
  - Engineering career in hardware development for data systems (command and data handling) and measurement systems (instrumentation suites) for in-space applications
  - Projects supported has provided experience with environmental concerns (radiation, thermal, vacuum, surface charging)
  - During Constellation, served as the Avionics Lead for Lunar Surface Systems
  - Since then, work technology development ranging from radiation experiments to cryogenic fluid management to materials research to entry, descent, and landing technologies

Interests

- Identify topics and technologies of interest complementary with and beyond the scope of NASA missions
  - Better understand potential commercialization of lunar surface
  - Refined use cases for destinations of interest on the moon
- Modeling capabilities aligned to credible use cases
  - Bound and better understand environments at destinations of interest
- Understand implications and considerations for technologies and systems that enable us to go “anywhere on the moon” vs. “everywhere on the moon”
- Hoping this forum can help with these – and that I/we can help you with your objectives and interests

NASA Game Changing Development (GCD) Program

GCD aims to advance exploratory concepts and deliver transition-ready solutions that enable new capabilities or radically alter current approaches

- Lead, motivate, and inspire technology development and innovation through collaborative relationships between government, academia, and commercial entities
- Goal to focus on high-risk, high-reward technologies
- Target maturation of technologies to be transitioned into NASA missions and advance commercial technologies and markets

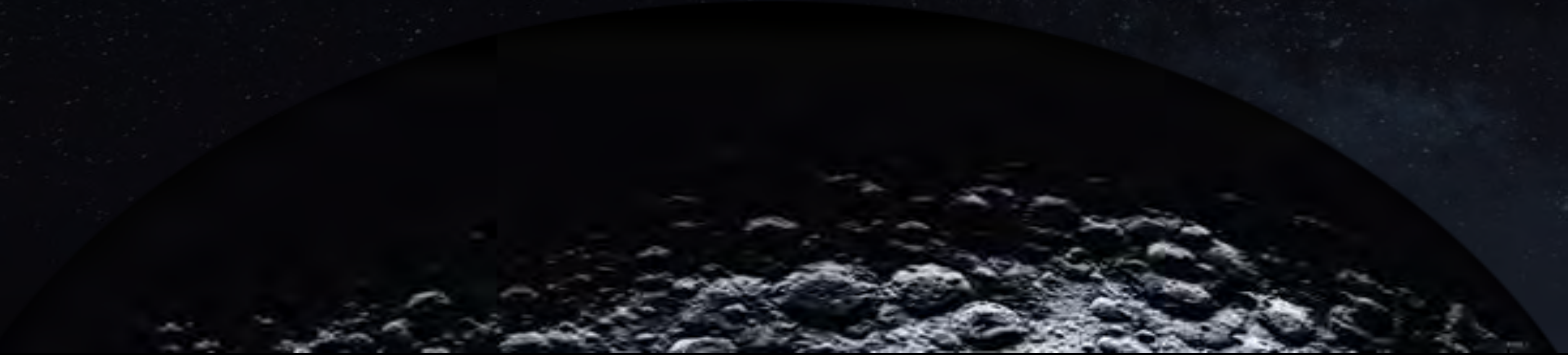
What is the Lunar Surface Innovation Initiative (LSII)?

LSII Aims to spur the creation of novel technologies to develop transformative capabilities for lunar surface exploration. LSII activities are implemented through a combination of unique in-house activities, competitive programs, and public-private partnerships.

- LSII ensures that there is an **ambitious, cohesive, executable Agency strategy** for development and deployment of key lunar surface technologies.
  - LSII is utilizing early uncrewed lunar surface flight opportunities to inform key technology development

- LSII integrates a broad spectrum of stakeholders, including industry, academia, other government agencies, and international partners to efficiently ***enable robust collaborations and partnerships*** and accelerate techology development.
  - LSII established the Lunar Surface Innovation Consortium (LSIC), operated by the Johns Hopkins Applied Physics Lab (APL), comprised of a nationwide alliance of academia, industry, non-profits and other government agencies.

NASA LSII
Implementation Strategy



Lunar Surface Innovation Initiative (LSII) Capability Development

SpaceTech matures technologies in order for the primary technology hurdles to be retired for a given capability at a relevant scale. While there may be additional engineering development required for scale-up, there should be none required for the foundational technologies.

In-Situ Resource Utilization

Collect, process, store and utilization of materials found or manufactured on the lunar surface.

- Sub-scale ice mining and 02 extraction demonstrations targeted for mid-2020's
- ISRU Pilot Plant demonstration by late 2020's

Sustainable Power

Enable continuous power throughout lunar day and night.

- Regenerative Fuel Cell (RFC), Wireless Charging, Chemical Heat Integrated Power Source (CHIPS), and Lunar Surface Solar Arrays demonstrations in mid-202's
- Targeting Fission Surface Power demonstration in late 2020's

Extreme Access

Access, navigate, and explore surface/subsurface areas.

- Subsystem and component-level demonstrations throughout the 2020's, including the Cooperative Autonomous Distributed Robotic Explorer (CADRE) in 2023

Surface Excavation & Construction

Enable affordable, autonomous manufacturing or construction.

- Targeting a Small Pilot Lunar Surface Excavation demonstration in mid-2020's
- Scaled Construction demonstrations in mid- and late-2020's

Lunar Dust Mitigation

Mitigate lunar dust hazards through active, passive, and operational measures.

- Targeting multiple Lunar Dust Mitigation demonstrations (component and subsystem-level) starting in early 2020's

Extreme Environments

Enable systems to operate through out the full range of lunar surface conditions.

- Targeting demonstrations on Lunar Night and Material Survivability, Lunar Exposure Platform (Lunar MISSE), Planet & Lunar Environment Thermal Toolbox Elements (PALETTE), COLDArm, starting in early 2020's

LSII Technology Demonstration Planning

LSII leverages early lunar missions to accelerate development of core surface technologies

2020 **2030**

ISRU

Polar Resources Ice Mining Experiment (PRIME)

Volatiles Investigating Polar Exploration Rover (VIPER/SMD)

ISRU Ice-Mining Demo

ISRU Oxygen Extraction Demo

ISRU Processing Demo

ISRU Pilot Plant

Surface Power

Regenerative Fuel Cell Power

Wireless Charging for Lunar Surface Demo

Vertical Solar Array Technology (VSAT)

Chemical Heat Integrated Power Source (CHIPS)

Fission Surface Power Demo

Dust Mitigation

Electrodynamic Dust Shield

Lunar Dust Level Sensor & Affects on Radiators

Lunar Dust Smart Sensor for Crewed Environments

Lunar Dust Removal Tool

Lunar Dust Separation

Extreme Environments

Lunar Arm w/ Bulk Metallic Glass Gears

Lunar Materials Demo

Lunar Camera

Lunar Thermal Toolbox

Lunar Night Material Survivability

Extreme Access

Surface Robotic Scouts

Lunar Navigation Demo

Video Guidance System

Day/Night Lunar Rover Obstacle Avoidance

Autonomous Robotics

Deployable Hopper

Autonomous Exploration of Lunar Pits

Excavation & Construction

ISRU Pilot Excavator

Lunar Surface Construction Demo 1

Lunar Surface Construction Demo (Landing Pad)

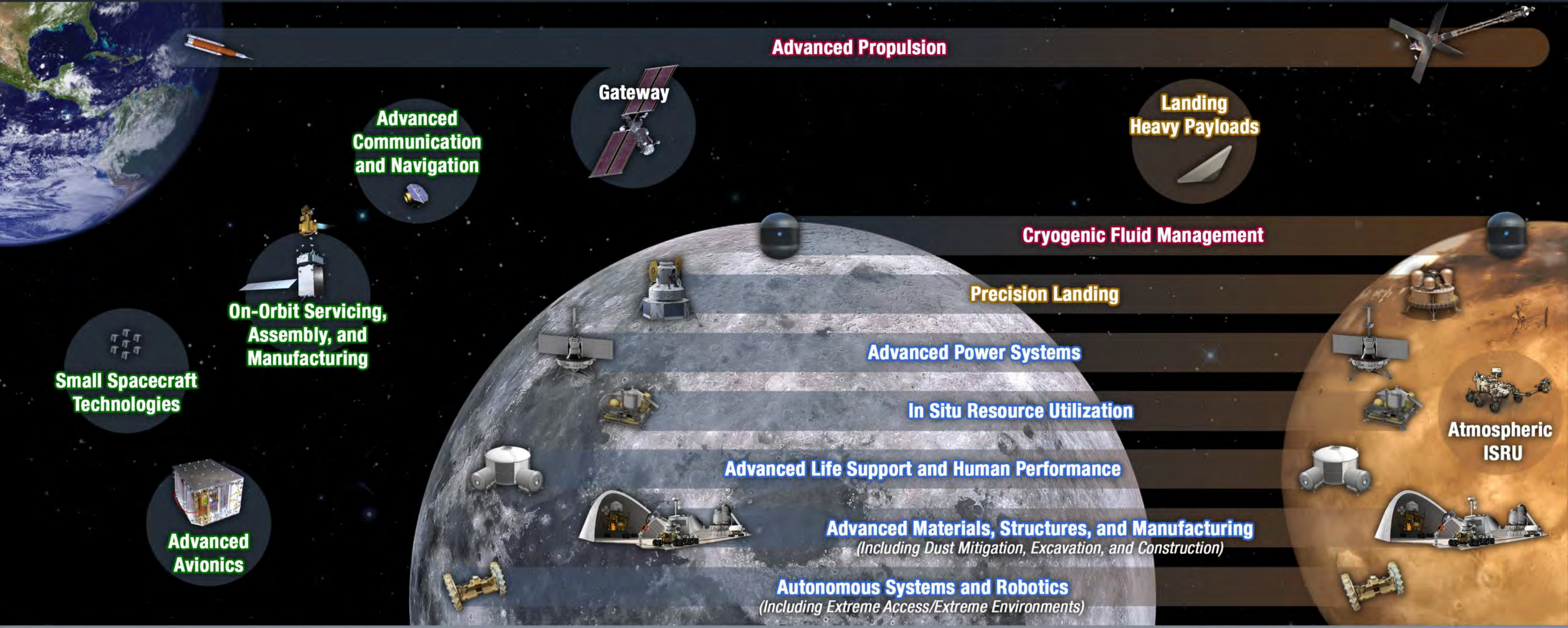
TECHNOLOGY DRIVES EXPLORATION

Rapid, Safe, and Efficient Space Transportation

Expanded Access to Diverse Surface Destinations

Sustainable Living and Working Farther from Earth

Transformative Missions and Discoveries



Advanced Propulsion

Gateway

Advanced Communication and Navigation

Landing Heavy Payloads

On-Orbit Servicing, Assembly, and Manufacturing

Small Spacecraft Technologies

Advanced Avionics

Cryogenic Fluid Management

Precision Landing

Advanced Power Systems

In Situ Resource Utilization

Atmospheric ISRU

Advanced Life Support and Human Performance

Advanced Materials, Structures, and Manufacturing

(Including Dust Mitigation, Excavation, and Construction)

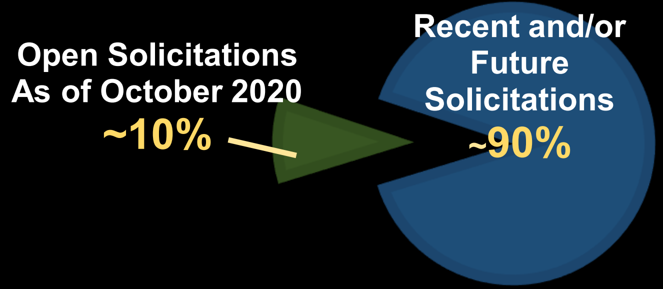
Autonomous Systems and Robotics

(Including Extreme Access/Extreme Environments)

2020 GO | LAND | LIVE | EXPLORE 203X

SPACE TECHNOLOGY OPPORTUNITIES

Space Technology anticipates awarding ~$600M to academia and industry supporting 2020 solicitations and awards.



Note: Funding awards are approximate and subject to change.

NextSTEP Broad Agency Announcements (BAAs):	*Varied Release Dates*	Varies
SmallSat Technology Partnerships (STP):	*September – November 2021*	$3M
Vertical Solar Array Technology (NRA,REDDI)	*November 2020*	$7.5M
Centennial Challenges:	*“Watts on the Moon” Surface Power (September 2020)* *“Break the Ice Challenge” (November 2020)*	$10M
NASA Breakthrough, Innovative, Game-changing (BIG) Idea Challenge:	*July – December 2020*	$1M

$250M	**Space Technology Tipping Point Multiple Awards:**	*January – March 2020*
$212M	**Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) Phases I, II, II-E, Civilian Commercialization Readiness Pilot Program (CCRPP), Sequential:**	*Phase I Solicitation, January – April 2020*
$30M	**Space Technology Research Institutes (STRI):**	*June – November 2020*
$20M	**Lunar Surface Technology Research (LuSTR) Opportunities:**	*July – September 2020*
$19M	**NASA Space Technology Graduate Research Opportunities (NSTGRO):**	*September – November 2020*
$10M	**Announcement of Collaborative Opportunity (ACO):**	*January – March 2020*
$10M	**Flight Opportunities Tech Flights:**	*February – May 2020*
$9M	**Early Stage Innovations (ESI):**	*April – October 2020*
$6M	**Early Career Faculty (ECF):**	*February – April 2020*
$4M	**NASA Innovative Advanced Concepts (NIAC) Phases I, II, III:**	*Phase I Solicitation, June – July 2020*

Please visit the STMD Solicitation website for more information: https://www.nasa.gov/directorates/spacetech/solicitations

Regolith/Surface Interface

Lead: Donald C Barker, donald.c.barker@att.net

- *I have over 22 years of experience in human spaceflight (subsystem engineering, flight control and science).*
- *I have a PhD in Geology where I analyzed and continue to work with Apollo 15 and 17 soil samples.*
- *I am supporting this effort on my own time, but make a living now as a part of the team assessing lunar dust environments and developing the new lunar EVA suits.*

- *Supporters:*
  - Greenhagen, Ben; benjamin.greenhagen@jhuapl.edu
  - Roth, Melissa; melissa@offplanetresearch.com
  - Siegler, Matt; matthew.a.siegler@gmail.com
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  - Zacny, Kris; kazacny@honeybeerobotics.com
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Regolith/Surface Interface

- *Scope*

  To focus information needs for designing, developing and implementing permanent, sustainable lunar habitation.

- Define regolith: a layer of unconsolidated, breccia, rock fragments and dusty debris that varies in thickness from roughly 5 m on mare surfaces to 10 m on highland surfaces. **the finest fraction (dust) is not being considered herein.
- What data exists to characterize the environment?
  - Apollo regolith samples
    - Grain sizes, shapes, compositions, electrostatics
  - Remote sensing data
    - Slopes
    - Minerology
    - Illumination

- Primary Characteristics/Qualities
  - *Temperatures 127°C to -248°C (including PSRs) repeated in Md Mahamdur's slides – I still don't understand this focus…..lots of wheel reinventing…!!*
  - *Plasma, Ionizing & Charging *not including radiation-human effects*
  - *Regolith Profile:*
    - *Particle Size Distribution (PSD)*
    - *Grain Shape Characterization*
  - *Volatiles*
  - *Grain Surface Chemistry*
  - glass vs. mineral
  - endogenic vs. exogenic
  - Adhesiveness
  - abrasiveness

- *Environmental Variability for Hardware Design and Survival*
  - *Equatorial vs Polar:*
    - *Temperature*
    - *Volatiles*
    - *Contamination Potential*
  - *Highland vs Basaltic Plains*
    - *Regolith Depth*
    - *Particle Size Distribution (PSD)*
    - *Trafficability*

- *Challenge to Technology Development*
  - Physical Characterization Needs: adhesion, cohesion, charging, movement, abrasion, emissivity, thermal conductivity.
  - How regolith affects materials, how materials affect regolith, what happens when regolith is changes environment
  - How human activity can change or destroy the local lunar environment – how to design to prevent this?
  - Design, Development and Testing: selecting and using proper environments, simulants and techniques.

Regolith/Surface Interface

Data Gathering Concept

- In deciding what information to gather and present we should consider, from the vast body of knowledge, the latest and most accurate characterization of environments possible that will directly interact with and effect the designs and materials for infrastructure and hardware to be deployed on the lunar surface.
- Simultaneously focusing on and highlighting the exact characteristics and knowledge gaps that are needed to advance human habitation of the Moon (without recreating what is currently known well enough).

Radiation Environment

- *Lead: Lawrence Heilbronn, University of Tennessee, Lheilbro@utk.edu*
  - *Professor, Nuclear Engineering Department*
  - *Member of the National Council on Radiation Protection and Measurements*
- *Supporters:*
  - *Hugh Barnaby (Arizona State University)*
  - *John Schaf (MOOG Inc Space and Defense Group)*
- *Participants:*
  - *Brenda Clyde (JHUAPL); Michelle Donegan (JHUAPL); Bonnie Dunbar (Texas A&M University); Connor Geiman (University of Washington); Robbie Gitten (Blue Origin); Ben Greenhagen (JHUAPL); Susan Ip-Jewel (AvatarMEDIC, LLC; Mars Academy USA, LLC); Angeliki Kapoglou (European Space Agency); Jake Matthews (Zeno Power Systems); Heather Meyer (JHUAPL); Michaela Musilova (International MoonBase Alliance); Amit Pandey (Lockheed Martin); Jamie Porter (JHUAPL); Michael Poston (Southwest Research Institute); Leonardo Regoli (JHUAPL); Melissa Roth (Off Planet Research, LLC)*

Member list updated November 6, 2020

Radiation Environment

SOHO coronagraph of a SEP event (left), habitat that incorporates regolith for shielding (right)

- *Primary Characteristics*
  - *Galactic Cosmic Rays (GCR)*
  - *Solar Energetic Particles (SEP)*
  - *Albedo from GCR and SEP interactions in lunar regolith*
  - *Man-made sources used for power (radioisotope power systems, fission surface power systems)*

- *Environmental Variability*
  - *GCR always present, but intensity varies with solar cycle*
  - *SEP events can last up to several days*
  - *SEP energies and intensity vary from event to event*
  - *Incident radiation and dose depends on location on Moon (near a crater wall, on a flat, open location) and amount of habitat shielding*

- *Challenge to Technology Development*
  - *Uncertainty in radiation transport model predictions of fluence and dose in shielded environments*
  - *Prediction of SEP occurrence, duration and intensity*
  - *Uncertainty of risks to humans and electronics from the high-energy, heavy-ion components of space radiation*

Estimated crew exposures from GCR

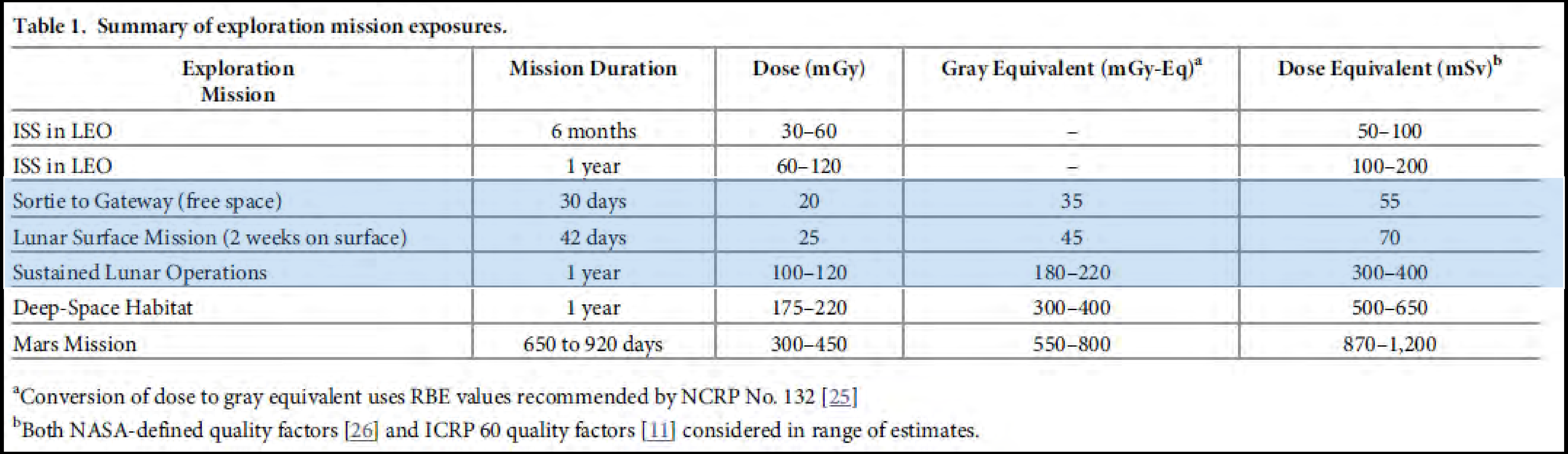


Table 1. Summary of exploration mission exposures.

Exploration Mission	Mission Duration	Dose (mGy)	Gray Equivalent (mGy-Eq)[a]	Dose Equivalent (mSv)[b]
ISS in LEO	6 months	30–60	–	50–100
ISS in LEO	1 year	60–120	–	100–200
Sortie to Gateway (free space)	30 days	20	35	55
Lunar Surface Mission (2 weeks on surface)	42 days	25	45	70
Sustained Lunar Operations	1 year	100–120	180–220	300–400
Deep-Space Habitat	1 year	175–220	300–400	500–650
Mars Mission	650 to 920 days	300–450	550–800	870–1,200

[a] Conversion of dose to gray equivalent uses RBE values recommended by NCRP No. 132 [25]

[b] Both NASA-defined quality factors [26] and ICRP 60 quality factors [11] considered in range of estimates.

Simonsen et al. Plos Biology https://doi.org/10.1371/journal.pbio.3000669

Permissible Exposure Limits (PEL)

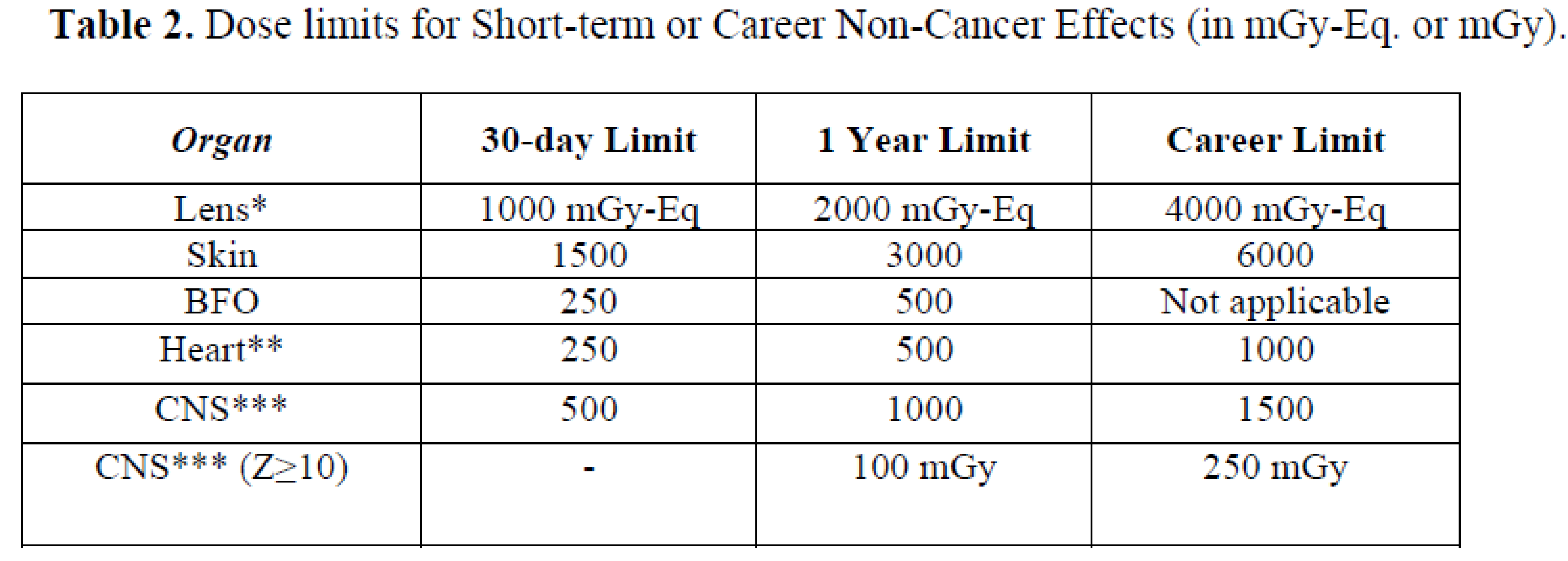


Table 2. Dose limits for Short-term or Career Non-Cancer Effects (in mGy-Eq. or mGy).

Organ	**30-day Limit**	**1 Year Limit**	**Career Limit**
Lens*	1000 mGy-Eq	2000 mGy-Eq	4000 mGy-Eq
Skin	1500	3000	6000
BFO	250	500	Not applicable
Heart**	250	500	1000
CNS***	500	1000	1500
CNS*** (Z≥10)	-	100 mGy	250 mGy

Cucinotta, https://three.jsc.nasa.gov/articles/astronautrad limitsFC.pdf

PEL lifetime limits

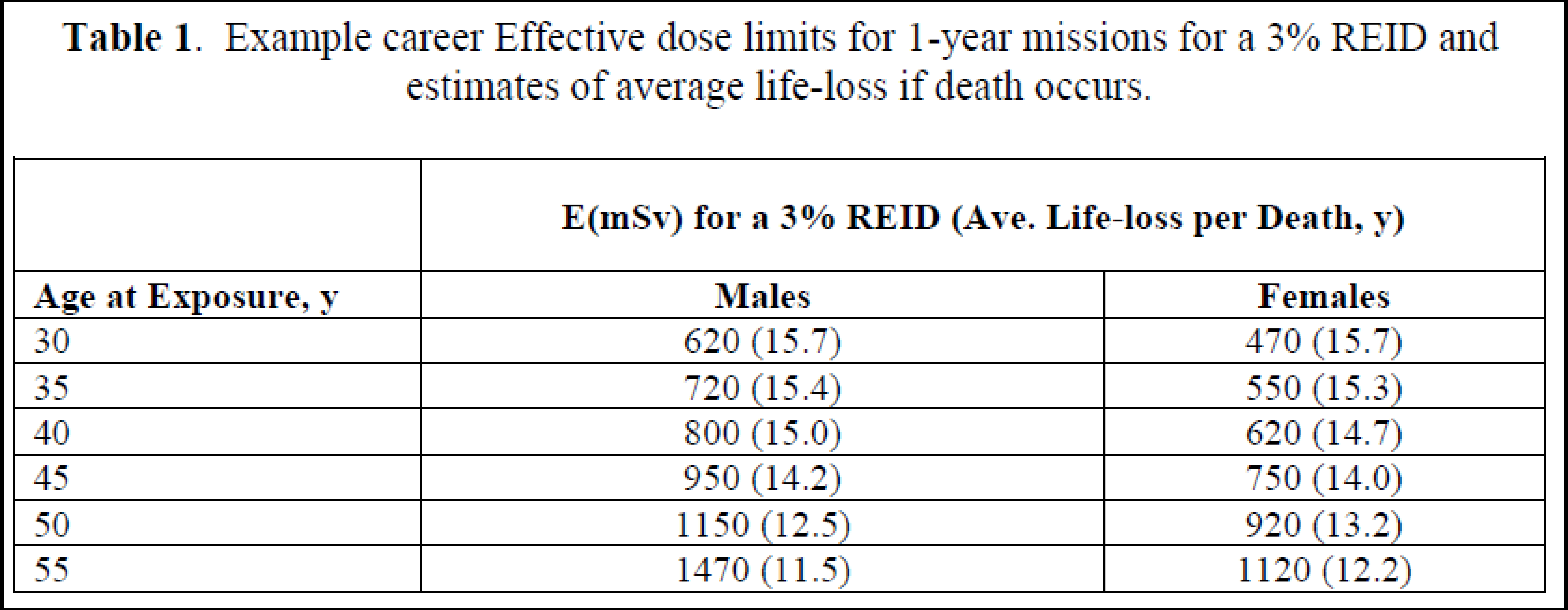


Table 1. Example career Effective dose limits for 1-year missions for a 3% REID and estimates of average life-loss if death occurs.

	E(mSv) for a 3% REID (Ave. Life-loss per Death, y)	
Age at Exposure, y	**Males**	**Females**
30	620 (15.7)	470 (15.7)
35	720 (15.4)	550 (15.3)
40	800 (15.0)	620 (14.7)
45	950 (14.2)	750 (14.0)
50	1150 (12.5)	920 (13.2)
55	1470 (11.5)	1120 (12.2)

Loss of life per death estimates based on low-LET radiation. Expect higher values for high LET radiation, such as GCR

Cucinotta, https://three.jsc.nasa.gov/articles/astronautrad limitsFC.pdf

Electronics Rad Effects

Much work needed here

Solar particle event protection

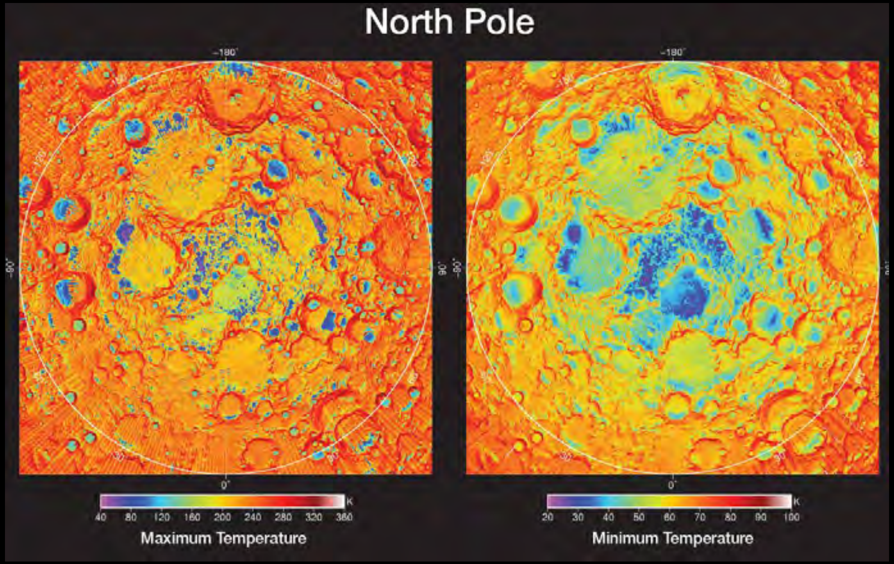
New Technology Development

- Enhancement of regolith for use in habitat shielding
- Prediction of solar particle events (onset, timing, intensity)
- Instrumentation to determine directionality of albedo and secondaries on lunar surface

Thermal Environment

- *Lead: Ahsan Choudhuri, The University of Texas at El Paso, ahsan@utep.edu*
  - *Associate Vice President for Aerospace Center; Founding Director, NASA MIRO Center for Space Exploration & Technology Research*
  - *Research Interests: Propulsion, Hypersonics, Robotic Landers, Small Spacecraft, and Lunar Surface Operations*
- *Supporters:*
  - *Marshall Eubanks; Space Initiatives Inc*
  - *Ben Greenhagen; Johns Hopkins Applied Physics Laboratory*
  - *CraigPeterson; Trans Astronautica Corporation*
  - *Matt Siegler, Planetary Science Institute*
  - *Kris Zacny, Honeybeer Robotics*
- *Participants:*
  - *Daoru Han, Missouri University of Science and Technology*
  - *Angeliki Kapoglou, European Space Agency*
  - *Michael J Poston, Southwest Research Institute*
  - *Tracie Prater, NASA*
  - *KT Ramesh, Johns Hopkins Applied Physics Laboratory*
  - *Melissa Roth; Off Planet Research*
  - *Howard Runge, Runge Tech*
  - *Doug Stanley, National Institute of Aerospace*
  - *Paul van Susante, Missouri University of Science and Technology*
  - *Md Mahamudur Rahman, University of Texas at El Paso*

Thermal Environment



Temperature Variation
Lunar Reconnaissance Orbiter
nasa.gov

- *Primary Characteristics*
  - *Wide Temperature Range: 400 K-40 K*
  - *Heat flux (incident solar flux 0 - 1414 W/m^2; planetary IR flux 0 – 1314 W/m^2; and albedo 0.076 - 0.297)*
  - *Surface Roughness*
  - *Local Topography (e.g. Local time, Elevation Contour)*
  - *Latitude*
  - *Albedo*

- *Environmental Variability*
  - *Equator: 140 K – 400 K; 94 K (average minimum) – 392 K (average maximum); mean 215 K.*
  - *Polar (poleward of 85°): 50 K (average minimum) – 202 K (average maximum); mean 104 K; minimum 25 K in the floor of the Moon's Hermite Crater.*
  - *Thermophysical properties*

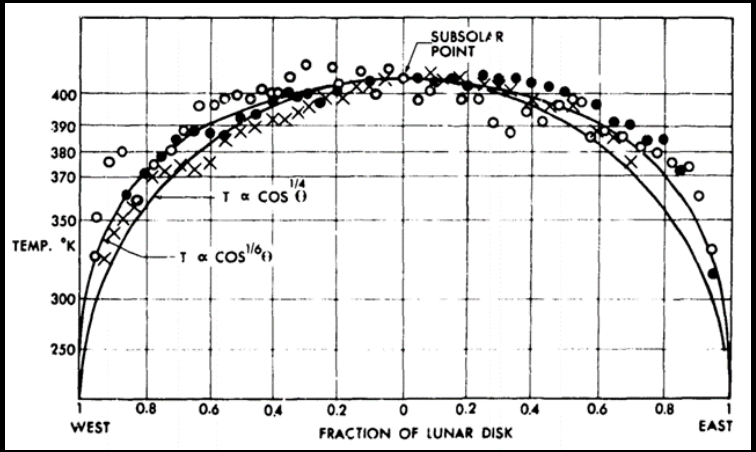
- *Challenge to Technology Development*
  - *Low temperature: electronic performance in extreme cold environments*
  - *Brittle phase transitions of metals with abrupt changes in properties, the effects of combined low temperature and radiation*
  - *Thermal cycling: thermal performance and fatigue for 40 K- 400 K thermal cycling in every month*

Notes from 11/03/2020 Meeting

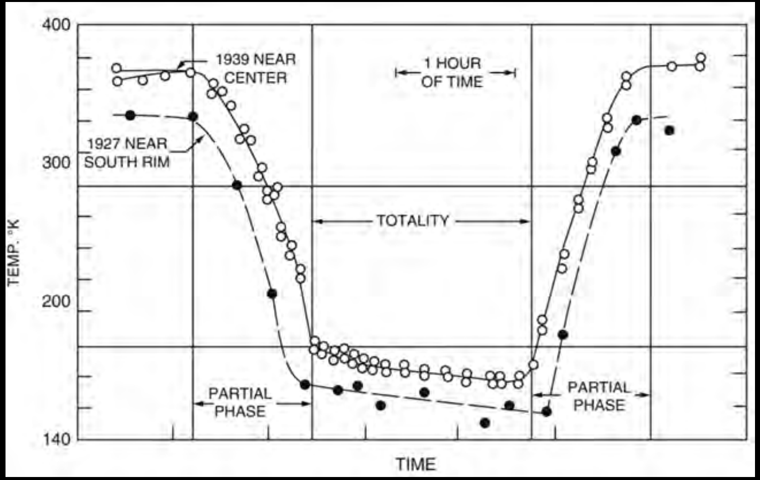
- Monthly WebEx Update Meeting: 4:00p(Center)/3:00p(Mountain)| First Tuesday of Every month until December | Duration: 25 mins | Next Meeting-12/01
- UTEP has assigned a doctoral student to collect and catalog articles on Lunar Surface Temperature
- UTEP has completed reviewing 22 articles | First Summary Report and Presentation Complete
- UTEP submitted First Summary Report and Presentation file to the team members for review
- Team members will forward any information they might have relevant to Lunar Thermal Environment to Ahsan

Moon Temperature

Important Factors that affect Surface Temperature:
- Surface Roughness
- Local Topography (e.g. Local time, Elevation Contour)
- Latitude
- Albedo



Moon's Temperature: [Pettit and Nicholson (1930)]
- Follows a cosine function of the incidence angle $\cos^{1/6}$
- Sunrise temperature ~109 K
- Noon temperature 380 K – 405 K
- Sunset temperature range ~170 K to 181 K
- During lunar eclipse, the usual noon temperature (380 K – 405 K) goes down to 140 K to 120 K.



Surveyor-I spacecraft data: [Lucas et al. (1967)]
- A variation of more than 280 K has been observed.
- Day time temperature ~384 K.
- Night time temperature ~102 K.

Apollo 17 site reported nearly: [Lucas et al. (1967)]
- 10 K higher temperatures throughout the night.
- The midnight temperatures of ~106 K.

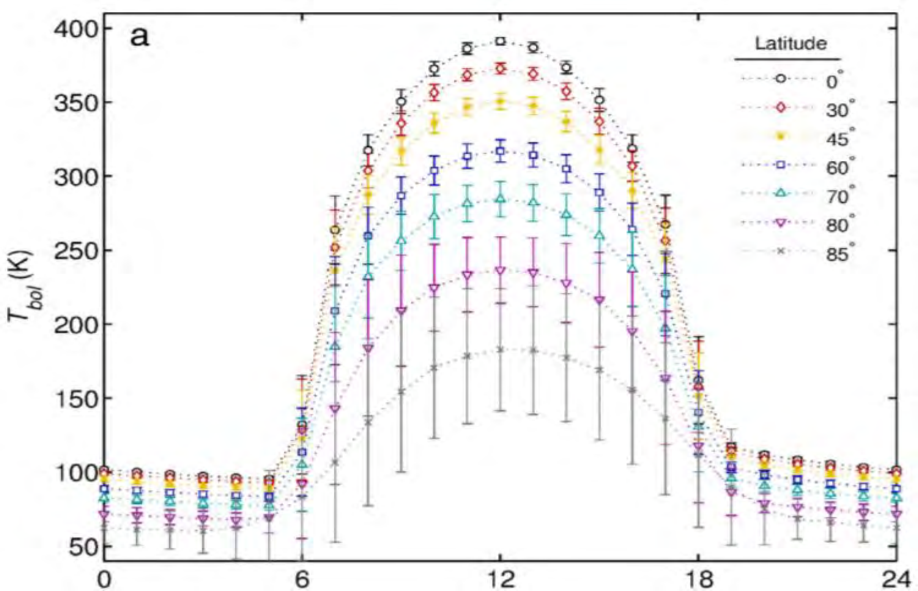
Bolometric Temperature

Bolometric Brightness Temperature (South Pole): [Paige et al. (2010)]
- Mid-day bolometric brightness temperatures as low as 29 K.
- Model-calculated annual average temperature at a depth of 2 cm, are close to 38 K.
- The Moon's cryogenic regions extend to depths of at least 10 m below the surface.

Bolometric Temperature (Latitude): [William et al. (2017)]

At equator:
- Daytime temperature ~387–397 K
- Just before sunrise dropped to ~95 K
- Average maximum temperature 392.3 K
- Average minimum temperature 94.3 K
- Mean temperature 215.5 K

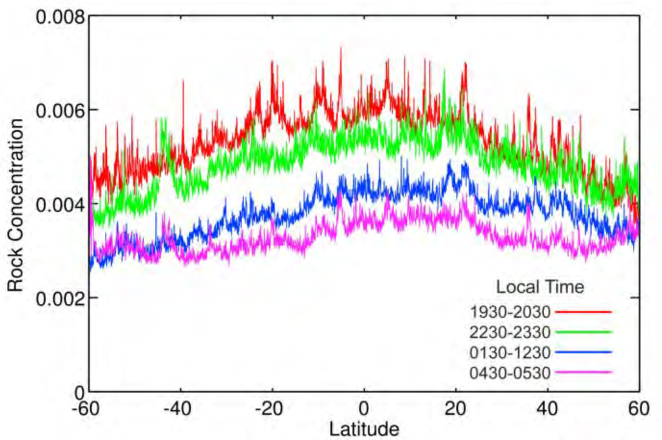
In the polar regions:
- Average maximum temperature: 202 K
- Average minimum temperature : 50 K
- Mean average temperature: 104 K.



Regolith Temperature and Cold Spot

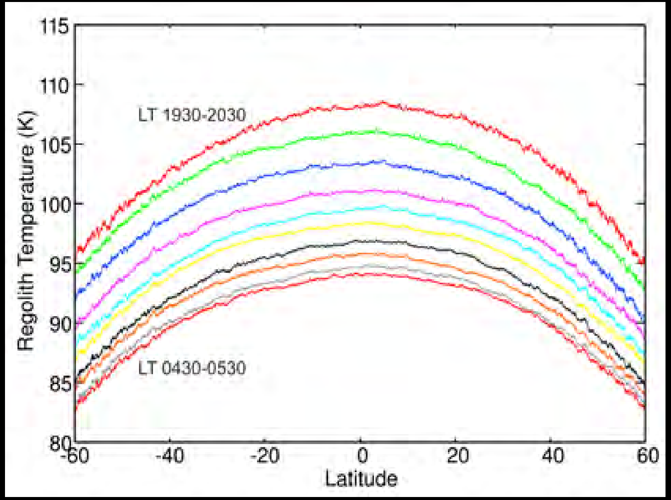
Regolith Temperature (Rock Concentration): [Bandfield et al. (2011)]

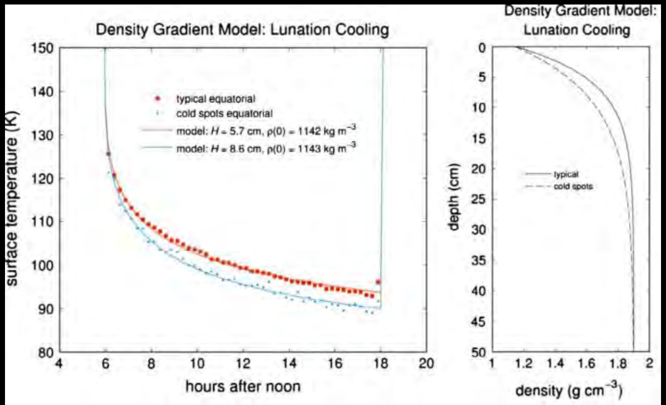
- Rock-free regions~ 40–110 K.
- Global average regolith temperatures decrease from 103.6 K to 90.1 K.
- Post-sunset temperatures ~108 K to 95 K between 0° and 60°N/S latitude
- Pre-dawn temperatures~94 K to 83 K between 0° and 60°N/S latitude



Cold Spot: [Bandfield et al. (2014, b)]

- Identified 2060 individual cold spots between 50°S and 50°N
- Studied 24 spots diameters of 0.14–1.54 km and within 10 degrees of the equator.
- Total area for the 24 cold spots is 42,131 km2 , which is 0.64% of the lunar surface
- Estimated to be around 4000 more cold spots around the whole moon.
- Have a temperature 2 K less that the average equatorial regolith temperature
- Rock-free regolith temperatures up to 10 K cooler than the average surrounding
- Rock abundances are low (<0.5%)





Heat Flux

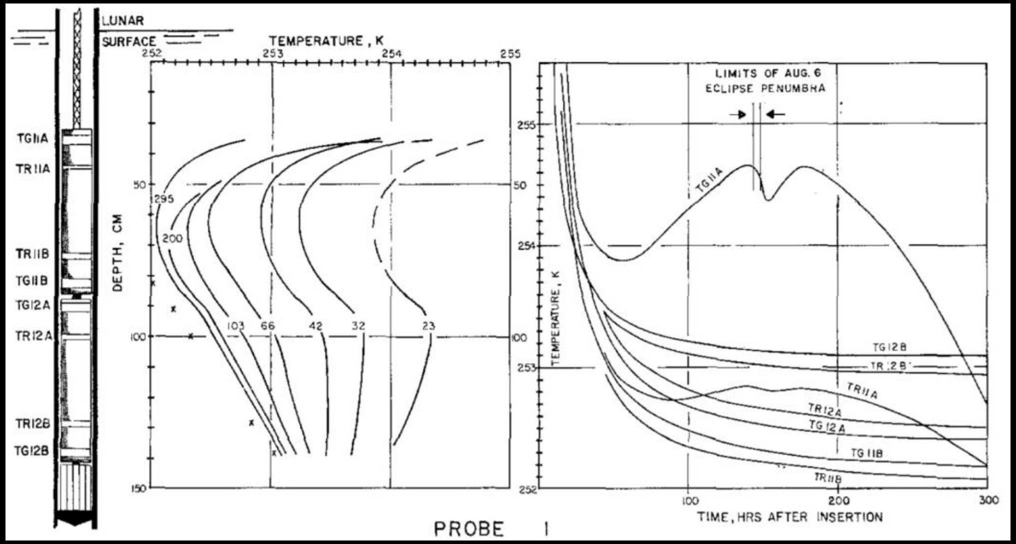
Langseth et al. (1972a, b):

- Derived heat flow probes and values from Apollo 15 and Apollo 17.
- Heat flow values from Apollo 15 is 21 mW/m^2
- Heat flow values from Apollo 17 is 16 mW/m^2
- These measurements were carried out at Hadley Rille and Taurus-Littrow valley having uncertainties of around ±15%.

Robert K. Mgconnell, Jr. And Paul W. Gast [13]:

- Introduced two models:
- For GM-4B model the conduction, volcanic and total heat flux found 1.87, 0.37, 2.24 μW/cm^2 respectively.
- For GM-6 model the conduction, volcanic and total heat flux found 1.77, 0.46, 2.23 μW/cm^2 respectively.

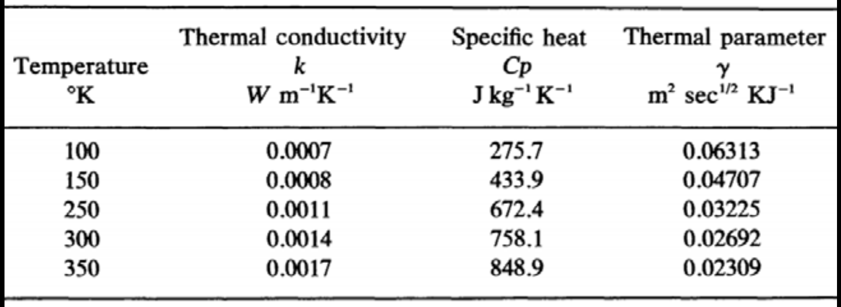
From Apollo measurements, Keihm and Langseth (1977) estimated a mean heat flow of 14–18 mW/m2



Thermal Properties

Langseth and Keihm (1974)

- Summery of thermal conductivity measurements of Apollo 15 and Apollo 17 HFEs
- 1.2–1.5 mW/m.K at surface layer
- 10–15 mW/m.K at below 10 cm from the surface.

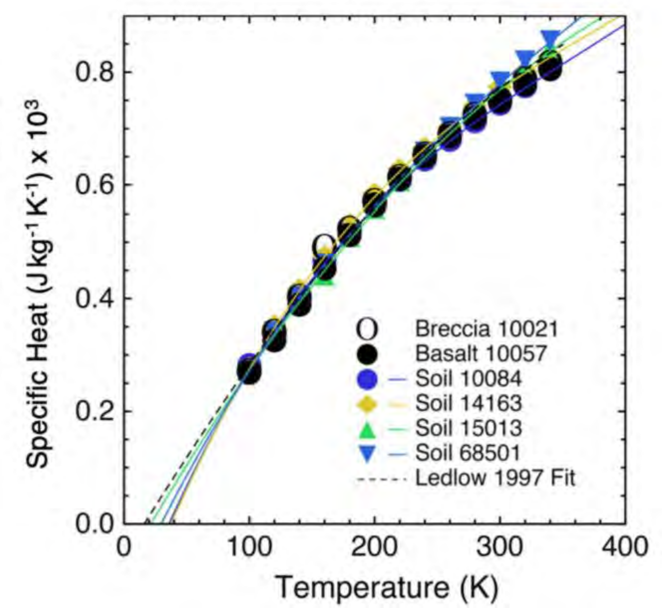


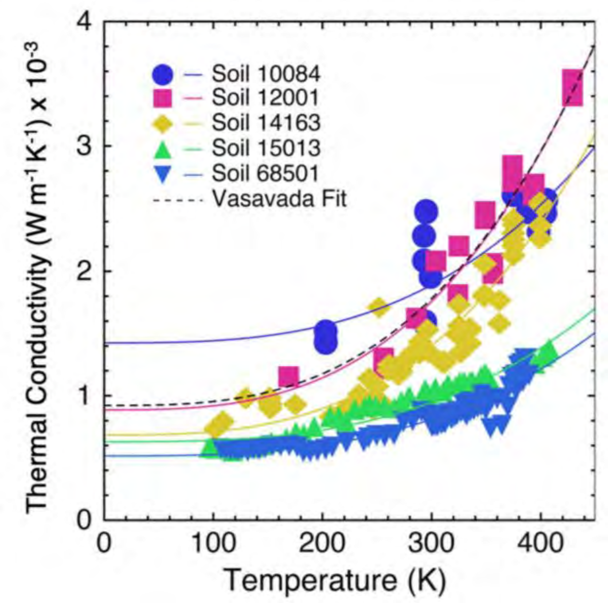
Temperature °K	Thermal conductivity k $W\ m^{-1}K^{-1}$	Specific heat Cp $J\ kg^{-1}\ K^{-1}$	Thermal parameter γ $m^2\ sec^{1/2}\ KJ^{-1}$
100	0.0007	275.7	0.06313
150	0.0008	433.9	0.04707
250	0.0011	672.4	0.03225
300	0.0014	758.1	0.02692
350	0.0017	848.9	0.02309

Hemingway et al. (1973): introduced Laboratory measured specific heat values for surface temperature between 90 to 350 K for various soil samples from Apollo 14, 15 and 16.

Woods-Robinson et al. (2019)

- Specific heat ranges from 0.22 to 0.9 KJ/kg.K
- Thermal Conductivity ranges from 0.5 to 3.7 mW/m.K





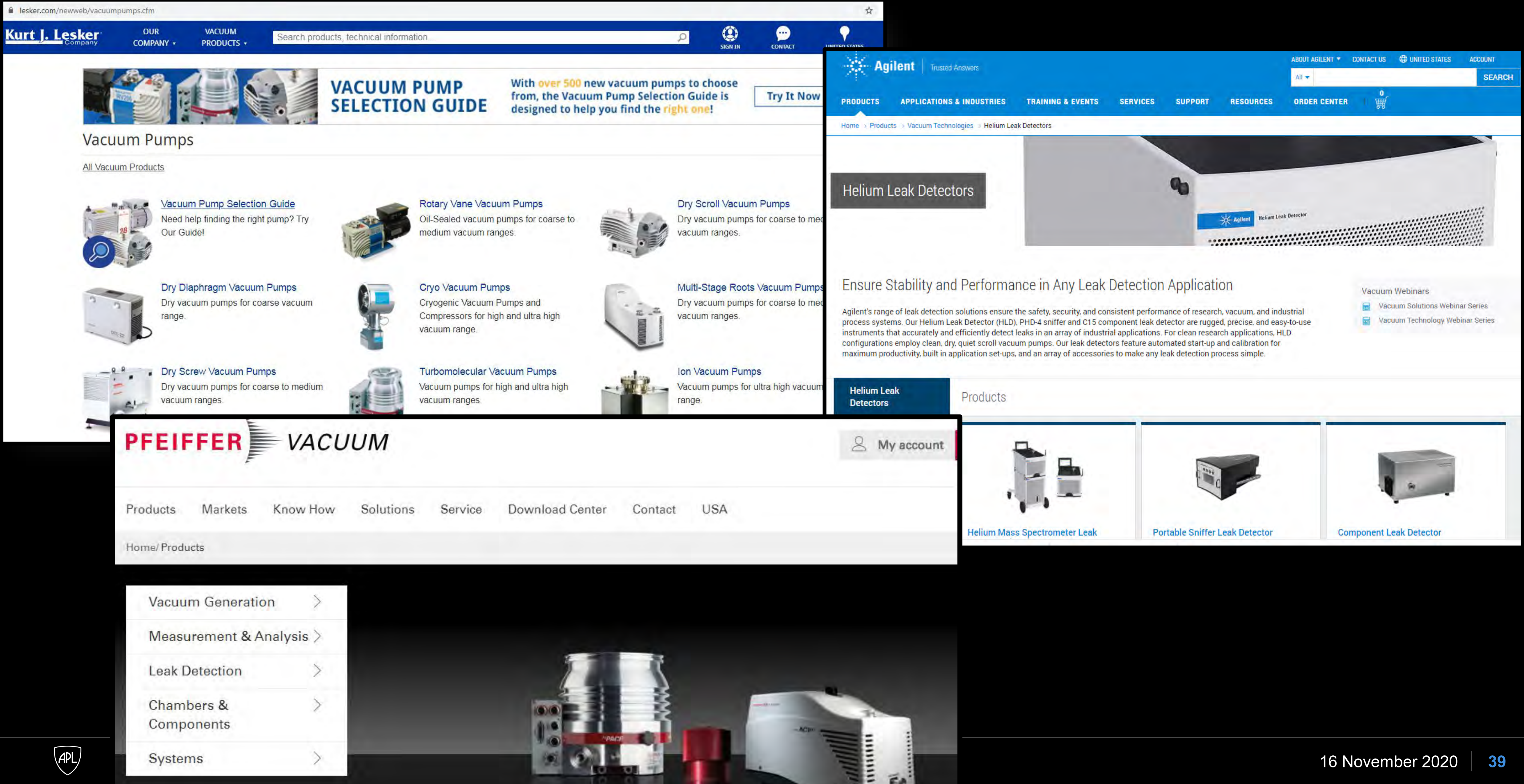
Vacuum Environment

- *Lead: Stephen Indyk, Honeybee Robotics, sjindyk@honeybeerobotics.com*
  - *Background in mechanism development for planetary environments, including lunar structures*
  - *8 years of experience in Mars rover operations*
- *Supporters:*
  - *Donald Barker; University of Houston*
  - *Marshall Eubanks; Space Initiatives Inc.*
  - *Matt Siegler; Planetary Science Institute*
- *Participants:*
  - *Ahsan Choudhuri (University of Texas at El Paso)*
  - *Bonnie Dunbar (Texas A&M University)*
  - *Ben Greenhagen (Johns Hopkins Applied Physics Lab)*
  - *Daoru Han (Missouri S&T); Angeliki Kapoglou (ESA)*
  - *Michael Poston (Southwest Research Institute)*
  - *Melissa Roth (Off Planet Research)*
  - *Paul van Susante (Michigan Tech)*
  - *Kris Zacny (Honeybee Robotics)*

Confluence

- Basic definition of the vacuum environment
- Relevant publications
  - Open to suggestions and inclusions
- Relevant instruments and missions
  - LPI literature and NASA literature
- Guidelines on vacuum chamber testing
  - Assume a base vacuum testing knowledge
  - Difficult to reach lunar vacuum, but is the necessary?
  - Dirty chamber testing basic guidance

Vacuum Chamber Equipment



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Dry Diaphragm Vacuum Pumps Dry vacuum pumps for coarse vacuum range.	Cryo Vacuum Pumps Cryogenic Vacuum Pumps and Compressors for high and ultra high vacuum range.	Multi-Stage Roots Vacuum Pumps Dry vacuum pumps for coarse to me vacuum ranges.
Dry Screw Vacuum Pumps Dry vacuum pumps for coarse to medium vacuum ranges.	Turbomolecular Vacuum Pumps Vacuum pumps for high and ultra high vacuum ranges.	Ion Vacuum Pumps Vacuum pumps for ultra high vacuum range.

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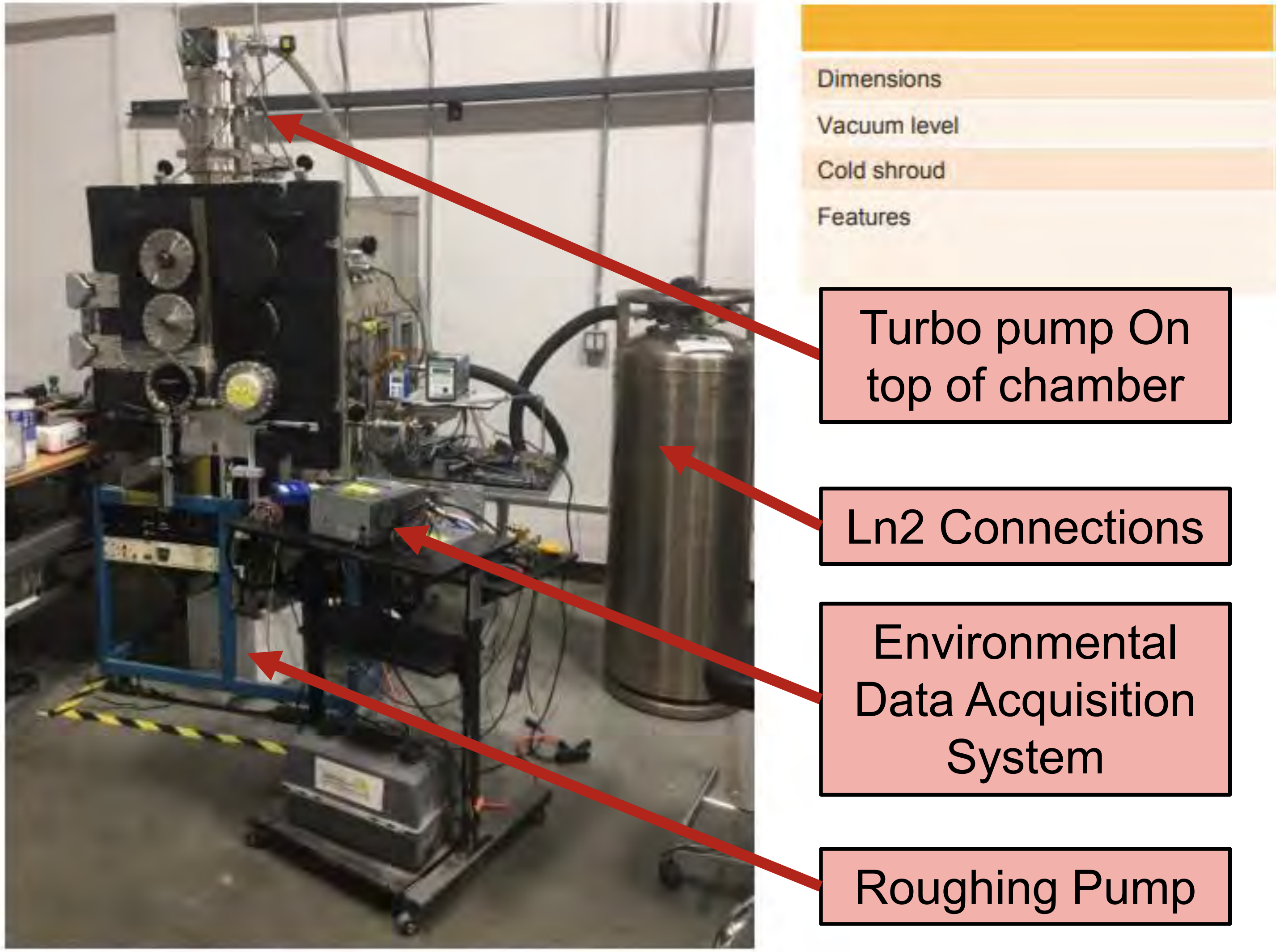
Phantom Limb Tek-Vac Chamber

	Specification
Dimensions	30" x 30" x 36" (deep)
Vacuum level	1E-6 Torr
Cold shroud	Yes
Features	IR transmissive window for FLIR IR camera Used for TVAC tests of MER RAT, Phoenix ISAD, Sentinel SCS


Turbo pump On top of chamber

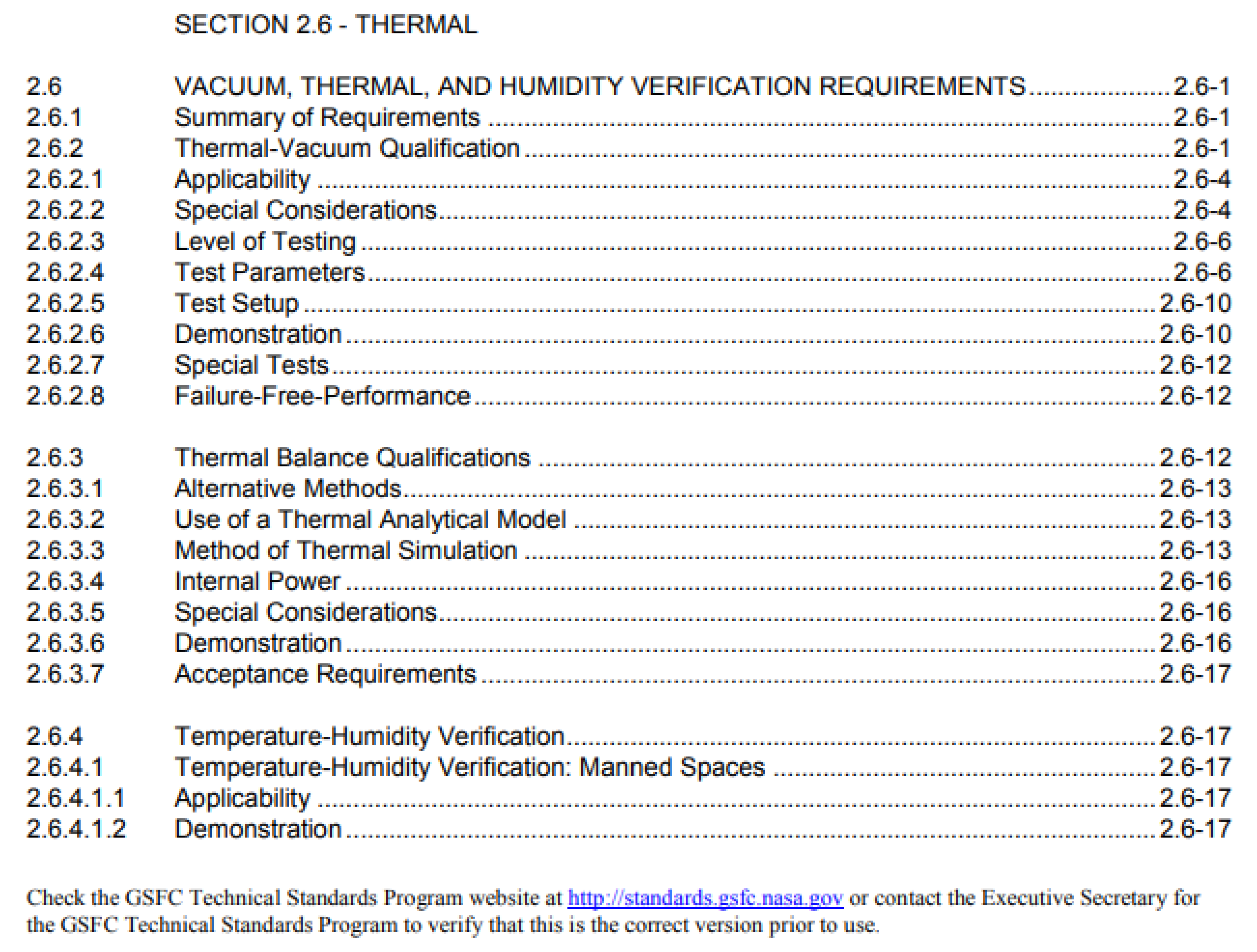
Ln2 Connections

Environmental Data Acquisition System

Roughing Pump

GSFC-STD-7000

- Vacuum chamber test guidance
  - Other organizations have different standards depending on environment, component, instrument, system or space craft
- Does not explicitly state vacuum requirements, but gauges criteria with requirements
- Suggest conditions for incrementing TRL for appropriate environment
- https://standards.nasa.gov/standard/gsfc/gsfc-std-7000



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