JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

LSIC Surface Power Telecon

August 26, 2021

Begins at 11:02

Lunar Surface Innovation
CONSORTIUM

Dr. Wesley T. Fuhrman
Johns Hopkins Applied Physics Laboratory
Space Exploration Sector

Wesley.Fuhrman@jhuapl.edu

Confluence Discussion:
https://lsic-wiki.jhuapl.edu/pages/viewpage.action?pageId=19039547

Overview

- Community updates
  - Other Focus group activities
  - Funding opportunities
  - Fall meeting
- Power Beaming Workshop Summary
- Space Tech DRAFT gap/closure plans
  - **Team formation to assess draft topics**

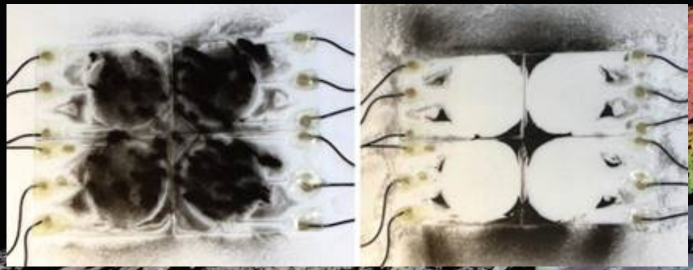
Lunar Surface Innovation CONSORTIUM

Dust Mitigation

- Next Dust Mitigation Focus Group meeting:
  - Thursday, August 26 at 12 PM EDT

- Sign-up to join the Dust Mitigation Subgroups:
  - Please fill out the short survey at the link below if interested or would like to sign-up:
  - https://docs.google.com/forms/d/e/1FAIpQLScB6iT2fgPqj2zIaP0s-rwWQDQ04TPfgVyiC5zn0AQPAT5CZA/viewform

- Help us improve the Dust Mitigation Focus Group!
  - Please fill out the feedback survey:
  - https://docs.google.com/forms/d/e/1FAIpQLSdjuTIK_TLMnCM4_aSMLAzLS762qtzbgmcOd2fgizICsab6KQ/viewform

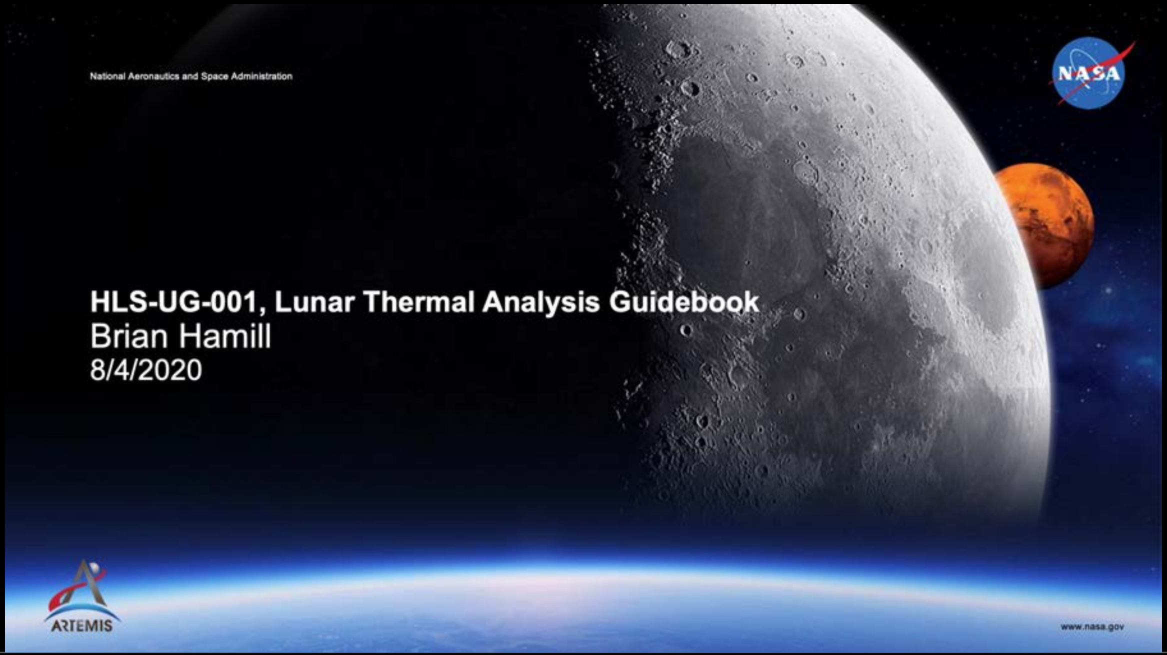
E&C Workshop on August 20th , 2021

- ***August 20th, 2 PM - 4:30 PM, Eastern***
- An extended monthly meeting in lieu of regular meeting.
- Workshop Theme: **High-TRL Technologies for initial infrastructure development and LLP.**
- Tentative Agenda:
  - NASA E&C Roadmap.
  - Break-out sessions:
    - High-TRL technology for initial infrastructure development
    - **Power needs for E&C**
  - Panel discussion on Landing and Launch Pads (LLP)

Extreme Environments

- New FG Facilitator, Dr. Jaime Porter
  - *Radiation Effects engineer specializing in radiation transport and charging effects for planetary missions*

- Featured Presentation, Brian Hamill
  - "Overview of the Lunar Thermal Analysis Guidebook - LTAG - HLS-UG-001"



Extreme Access FG Plan

✅ Identify areas and/or environments of interest

✅ Pick 1-2. –PSRs and Lunar pits/lava tubes

3. Identify specific architectures to enable exploration of these areas. What are the environments like? What are the needs for mobility, PNT, comms, autonomy?
4. Evaluate current technology availability, compare to what is needed for (3). This will likely involve standing up several smaller subgroups.
5. Identify gaps, prioritize which are more important to close first
6. Roadmap, determine recommendations for specific tech development and/or demos
7. Throughout: keep in mind where will need input or tech crossover from other focus groups. Where does technology development require multiple inputs?
8. Write a report of some sort

ISRU Focus Group Summary

- The ISRU FG has stood up four break-out groups for deep dives into:
  - Water-ice prospecting
  - O2 extraction
  - ValueChain mapping
  - Facilities Needs

Join the active discussions on the ISRU Confluence site

- Survey on Facility needs (not existing capabilities) is still active:
  - https://forms.gle/TxXbvb1LwN4XzQT47

LSIC Fall Meeting

LSIC Fall Meeting is confirmed for November 3-4, 2021

- Hosted at Bowie State University (Bowie, MD)
- Hybrid format with most content available virtually
- Theme: Autonomy and Robotics (EA and EE focus)
- Registration open! Abstracts submissions open through 8/31/21
- http://lsic.jhuapl.edu/News-and-Events/Agenda/index.php?id=148

Abstracts

This year's technical theme is Autonomy and Robotics. The overarching meeting theme will be used to focus invited presentations and the technical breakout discussions. We encourage abstracts pertaining to these topics, as well as those describing technology developments for any of the LSII focus areas or establishing a sustained presence on the lunar surface. Abstracts are limited to one page in length, and must be submitted by August 31st, 2021 in order to be reviewed by the technical organizing committee. Please be sure to use the attachment available on this page, "lsic-abstract-template.docx".

Solicitations

- https://www.nasa.gov/directorates/spacetech/solicitations

Open Solicitations and Opportunities

NASA TechRise Student Challenge
Student Registration Opens: August 18, 2021
Submission Deadline: November 3, 2021

Lunar Surface Technology Research (LuSTR) Opportunities
21LuSTR NOIs due: August 20, 2021
21LUSTRPro Proposals due: September 17, 2021

Lunar TORCH Challenge
Deadline: September 13, 2021

2022 Breakthrough, Innovative and Game-Changing (BIG) Idea Challenge: Extreme Terrain Mobility Challenge
Notice of Intent due: September 24, 2021
Proposal and Video deadline: January 18, 2022

NASA Human-Autonomy Teaming Task Battery Challenge
Deadline: December 29, 2021

- Coming Soon: Watts on the Moon phase 2, FSP (DoE)
- Gap/Closure plans (discussed today!) will inform future solicitations

LSIC | Why the Power Beaming Workshop

- Community-requested, sponsor-approved
  - Every registration-suggested topic was covered!

- Recent and pending solicitations

- Partners and outside stakeholders with additional expertise

https://lsic.jhuapl.edu/News-and-Events/Agenda/index.php?id=142

LSIC Power Beaming for the Lunar Surface workshop

- Webinar had steady ~120-130 participants day 1, ~100 on day 2
    - Understanding: Mean 3.5 -> 4.5 Median 3 -> 5
    - Diversity: Mean 4.4, Median 4
    - Inclusion: Mean 4.5, Median 5

- Plenary talks provided succinct insight to beginners and on SOA
  - Existing technologies are appropriate tech for our use case
  - No deal-breakers for power beaming on the lunar surface

- 40+ participated through the breakouts both days
  - Strong conversation 1+ hour into networking session
  - Networking session had more video use and audience participation than breakouts

LSIC Power Beaming Workshop: General Consensus

- Power beaming is a pragmatic solution for PSR prospecting and exploration. Marginal cost of extending range is trivially small for laser PB. Could also be used to connect regions with complementary illumination.

- Current PB hardware is not space-qualified but could be rapidly advanced

- Power Beaming Figure of Merit currently under consideration is not ideal, especially for laser power beaming

- PB reduces complexity compared to cabled-power for exploration

- Thermal management complicates design of high-power systems, but waste heat may be beneficial

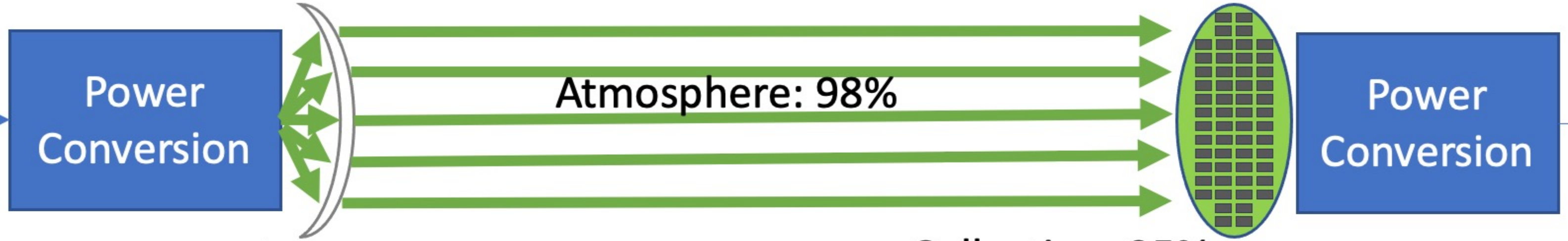
Challenges for Power Beaming

Power Beaming

µm: 170-216 W
mm: 700-840* W
Laser: 350-590 W

DC-µm : 85-95%
DC-mm: 50-60% (small scale)
DC-Laser: 50-60%

µm-DC: 80-90%
mm-DC: 35% (W band)
Laser-DC: 50-70%



Power Source

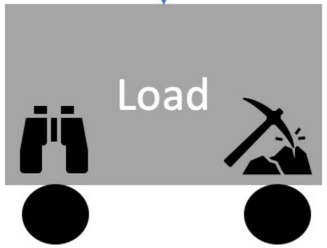
DC-DC: 90%

Diff/Optics: 90%

Collection: 95%

DC-DC: 90%

100 W



Emitter
- Coherence vs. Incoherence
- Optics and Beam Quality
- Continuous vs. Pulsed
- Emitted Spectrum
- Heat Dissipation

Transmit
- Atmosphere
  - Noble gases
  - Dust
- Distance
- Safety? (eyes, burns, etc.)

Receiver
- Aperture Size
- Collection Efficiency
- Conversion Efficiency
  - Heat Dissipation
  - Dual-purpose?

1. Fuel-DC
2. DC-DC
3. DC-EM
4. Shape Beam
5. Atmosphere
6. Hit Receiver
7. EM-DC
8. DC-DC
9. DC-Work

	Wavelength	DC-Efficiency	Coherence	Atmosphere	Aperture Size	Receiver Efficiency	TRL
µm	5 - 12 cm	85-95%	Optics	??	140 m	80-90%	
mm	0.3 - 3 cm	50-60% (TRL)	??	??	10 m	35% (TRL)	
Laser	500 - 1550 nm	50-60%	Diffraction	Dust?	.025 m	50-70%	

Approximate

Don Jenket, NREL

Lunar Surface Innovation Consortium (LSIC)

Nationwide alliance of universities, commercial companies, non-profit research institutions, NASA, and Other Government Agencies with a vested interest in our nation's campaign to establish a sustained presence on the Moon.

LSIC Objectives include:

- Identifying lunar surface technology needs and assessing the readiness of relative systems and components
- Making recommendations for a cohesive, executable strategy for development and deployment of the technologies required for successful lunar surface exploration
- Providing a central resource for gathering information, analytical integration of lunar surface technology demonstration interfaces, and sharing of results.

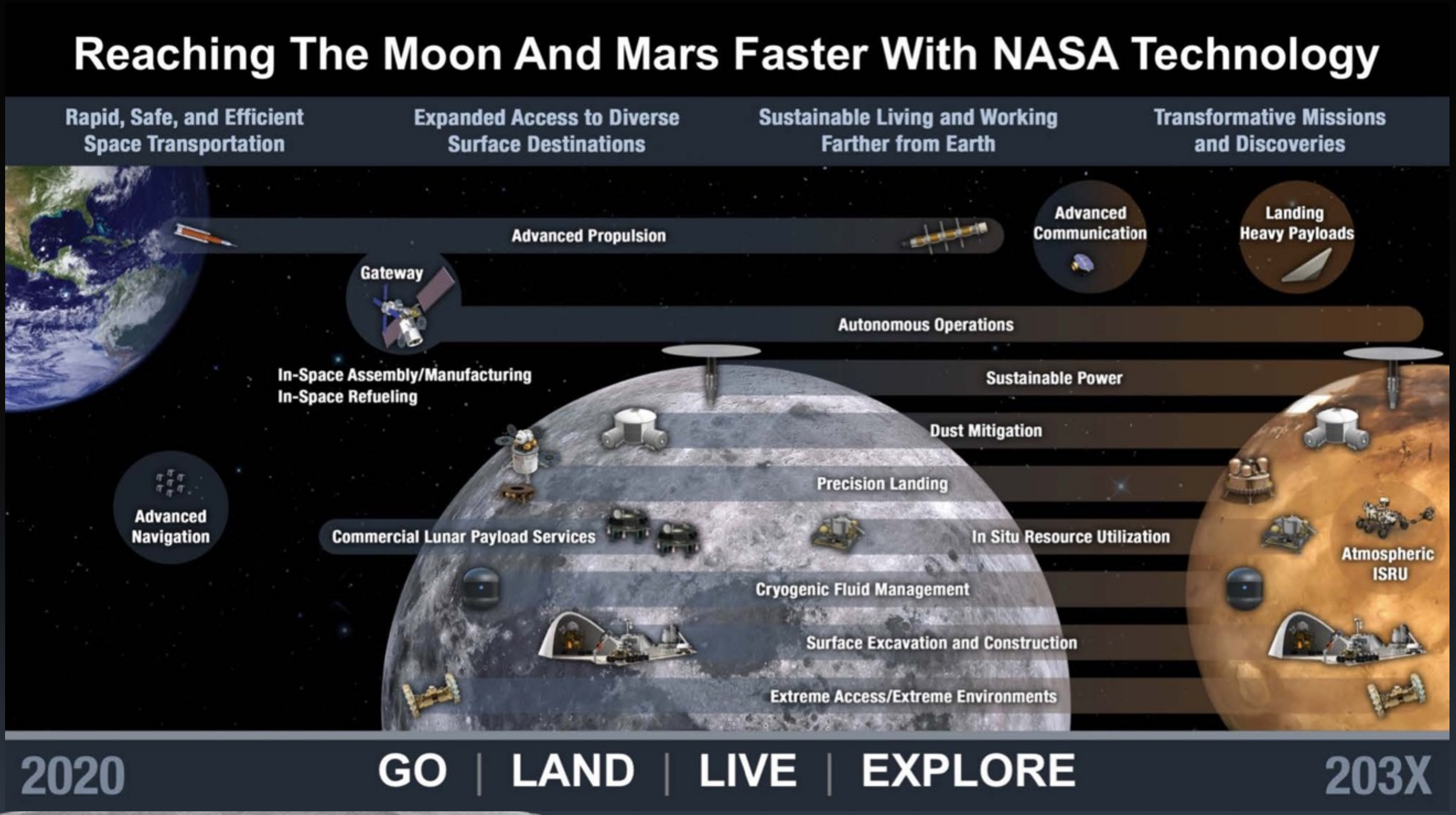
Focus Groups (FG) are the primary means for consistent interaction with the LSIC Community. This includes:

- Establishing collaborative relationships among members via virtual monthly forums, quarterly virtual workshops, and LSIC member site visits
- Building community and developing talent
- Compiling member input and reporting outcomes and recommendations

If interested in further information, please visit lsic.jhuapl.edu

NASA DRAFT GAP/CLOSURE SUMMARIES

- Gaps arranged around Thrusts
- Closure plans will inform funding opportunities
- LSIC Community core to assessment, including technology maturation level, acquisition options, funding structures, etc.



NASA Space Tech **DRAFT** Gap/Closure Summaries

- DRAFT gap topic themes
  - Rad-Hard Power Electronics
  - Low Temperature Batteries
  - Transmission: Power Beaming, Low-Mass Cable
  - Fuel Cells: Long-life RFC Storage, Mini RFCs, LO2/LCH4 Primary FCs
  - Durable PV Blankets

- Are there additional gaps? Open to discussion
  - Nuclear gaps not discussed today (e.g. FSP, NTP, etc.)
  - Strategy/deployment Roadmap

NASA **DRAFT** GAP/CLOSURE SUMMARY: Rad-Hard Electronics

Thrust: LIVE **Outcomes:** **Sustainable power sources and other surface utilities to enable continuous Lunar and Mars surface operations**
Scalable ISRU Production
Taxonomy Elements: **3.3.1, 3.3.3, 3.3.4**

GAP: Reliable, Rad-Hard Power Electronics. SOA power management and control electronics do not provide sufficient reliability and durability to support full scale ISRU operations in the Lunar Pole thermal, dust , and radiation environment. Mission architects must know what capability will be available to them once full-scale production operations are to start in the 2030s

CLOSURE: Bring to TRL 6 a suite of power management, control, and regulation circuits operating at up to 1000 V and at maximum specific power and which are maintainable in the Lunar dust environment and 0.99 reliable for 10 years in the Lunar Pole radiation and thermal environment.

NASA DRAFT GAP/CLOSURE SUMMARY: Batteries

Thrust: LIVE **Outcomes:** **Sustainable power sources and other surface utilities to enable continuous Lunar and Mars surface operations**
Scalable ISRU Production
Taxonomy Elements: **3.2.1**

GAP: <u>Low Temperature Batteries.</u> The principal challenge for battery technology is Artemis mobility energy storage for ISRU prospecting operations in PSRs. SOA batteries lose 75% of their room temperature (295 K) capacity with operating at 235 K. Cells that can deliver SOA 295 K performance at 235 K can increase specific energy for batteries in PSRs by a factor of 3.

CLOSURE: Bring to TRL 6 a 50 kWh-class battery module providing 150 Wh/kg specific energy at 235 K.

Thrust: EXPLORE Outcomes: **Develop vehicle platform technologies supporting new discoveries**

Taxonomy Elements: **3.2.2**

GAP: <u>Extreme Low-Temperature Primary Battery.</u> Ocean world missions would be enhanced by a primary battery capable of surviving extreme cold environments.

CLOSURE: Bring to TRL 6 a primary battery capable of surviving at 35 K and self-warming up to high rate discharge at 190 K with specific energy above 200 Wh/kg

NASA DRAFT GAP/CLOSURE SUMMARY: Power Transmission

Thrust: LIVE Outcomes: Sustainable power sources and other surface utilities to enable continuous Lunar and Mars surface operations
Scalable ISRU Production
Taxonomy Elements: 3.3.2

GAP: Wireless Power Transmission. Industrial scale mining of ice inside PSRs requires that power be transmitted from insolated regions to mobile assets at km-distances.

CLOSURE: Bring to TRL 6 a wireless transmission system delivering power at ~10 kW_e scale from an isolated region to a mobile vehicle in a Lunar pole PSR, losing no more than 80% source-to-load over 5 km and at maximized delivered power per unit of system mass.

Thrust: LIVE Outcomes: Sustainable power sources and other surface utilities to enable continuous Lunar and Mars surface operations
Scalable ISRU Production
Taxonomy Elements: 3.3.2

GAP: Low-Mass Transmission Cable. Industrial scale ISRU operations at the Lunar pole require that power be transmitted across the Lunar surface to fixed assets at km-distances.

CLOSURE: Bring to TRL 6 a transmission cable and connector system that can be unrolled and deliver power point-to-point at a multi-10 kW_e scale in the Lunar polar dust and thermal environment (both insolated and PSR), losing no more than 20% per km source-to-load and at maximized delivered power per unit of cable system mass.

NASA **DRAFT** GAP/CLOSURE SUMMARY: Fuel Cells

Thrust: LIVE **Outcomes:** **Sustainable power sources and other surface utilities to enable continuous Lunar and Mars surface operations**
Scalable ISRU Production
Taxonomy Elements: **3.2.2**

GAP: Long-Life RFC Storage. Eclipse-period support of industrial scale ISRU production facilities at the Lunar poles will require large-scale, long life, maintenance free energy storage

CLOSURE: Bring to TRL 6 H_2/O_2 regenerative fuel cell energy storage systems in MWh and 100 kW_e increments with maximum specific energy and maintenance free life in the Lunar polar environment of 50,000 hours and 500 charge/discharge cycles.

Thrust: LIVE (LAND) **Outcomes:** **Sustainable power sources and other surface utilities to enable continuous Lunar and Mars surface operations**
Scalable ISRU Production (Enable Lunar/Mars global access)
Taxonomy Elements: **3.2.2**

GAP: LO_2/LCH_4 Primary Fuel Cells. Primary power from LO_2/LCH_4 reactant storage may be the mass-optimal solution for certain Lunar/Mars mobility assets and Landers

CLOSURE: Bring to TRL 6 LO_2/LCH_4 primary fuel cell power generation systems in up to 10 kW_e increments with maximum specific energy and maintenance free life in the Lunar polar or Martian environments of 10,000 operating hours.

NASA DRAFT GAP/CLOSURE SUMMARY: Fuel Cells

Thrust: EXPLORE Outcomes: **Develop vehicle platform technologies supporting new discoveries**

Taxonomy Elements: **3.2.2**

GAP: Mini-RFC. Lunar science missions would be enhanced by low power, low mass regenerative fuel cell storage.

CLOSURE: Bring to TRL 6 a regenerative fuel cell of ~25 W_e capacity and of specific energy >300 Wh/kg.

NASA DRAFT GAP/CLOSURE SUMMARY: PV Blankets

Thrust: LIVE **Outcomes:** **Sustainable power sources and other surface utilities to enable continuous Lunar and Mars surface operations**
Scalable ISRU Production
Taxonomy Elements: **3.1.1**

GAP: Durable PV Blankets. Solar photovoltaic power in 100 kW_e increments is required to support industrial scale ISRU operations at the Lunar south pole. Reliability and durability in the Lunar radiation, thermal, and dust environment are mandatory.

CLOSURE: Bring to TRL 6 multi-100 kW_e scale, providing power at >200 V at 200 W_e/kg BOL and no more than 10 % degradation over ten years in the Lunar polar environment.

NASA DRAFT GAP/CLOSURE SUMMARY: Additional Gaps

- Open discussion
  - Nuclear gaps not included here (e.g. FSP, NTP, Pu alternatives, etc.)
  - Roadmap Analysis
  - Additional Gaps?

NASA DRAFT GAP/CLOSURE SUMMARY: Analysis Teams

- Teams can convene to discuss draft topics and final gaps when released

1. Rad-Hard Power Electronics
2. Low Temperature Batteries
3. Transmission: Power Beaming, Low-Mass Cable
4. Fuel Cells: Long-life RFC Storage, Mini RFCs, LO2/LCH4 Primary FCs
5. Durable PV Blankets
6. Nuclear topics (TBD)
7. Roadmap Analysis / additional gaps

OPEN DISCUSSION

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY