National Aeronautics and Space Administration

Fission Surface Power Project (FSP)

TDM Annual Review
March 4, 2021

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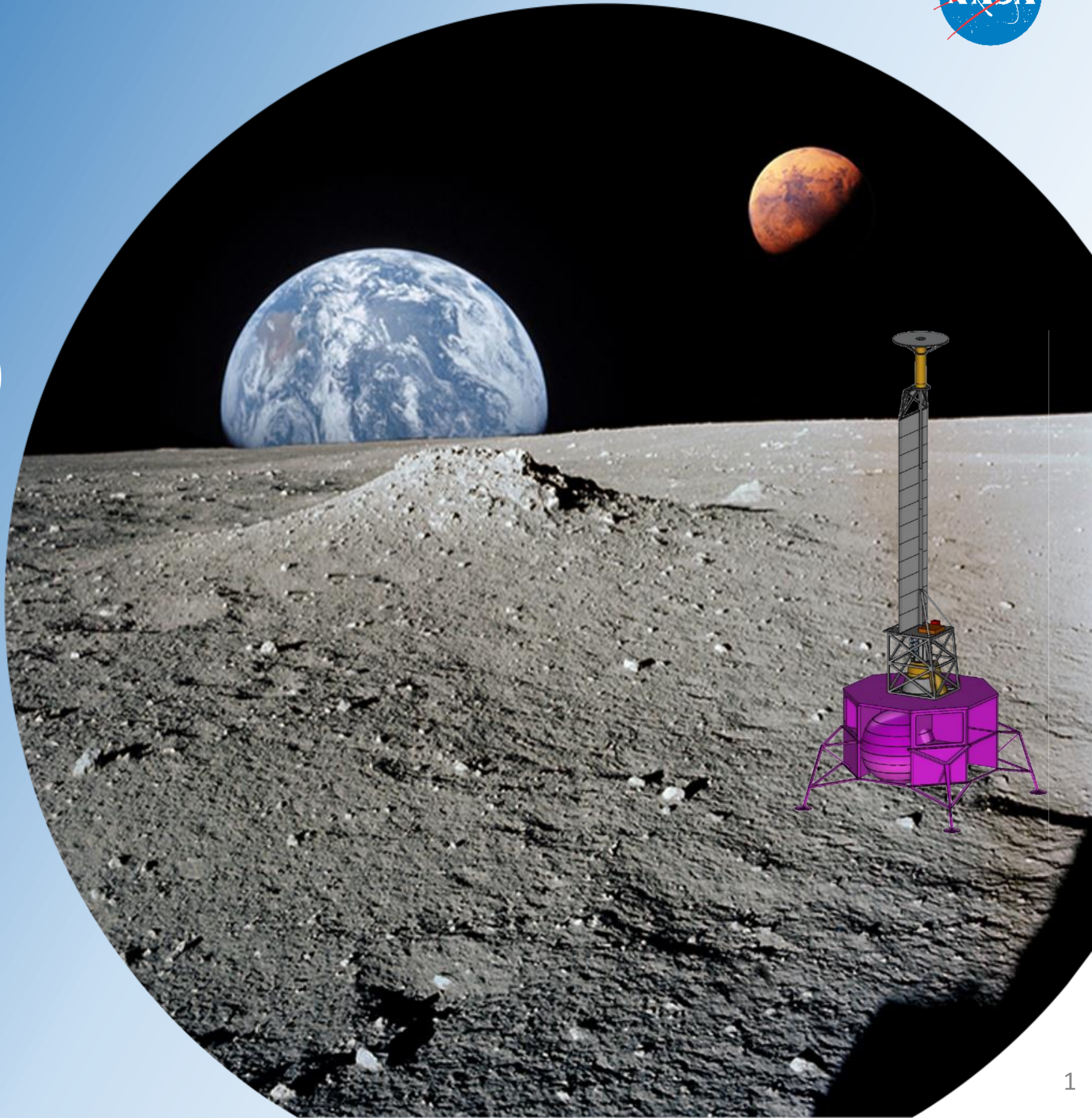
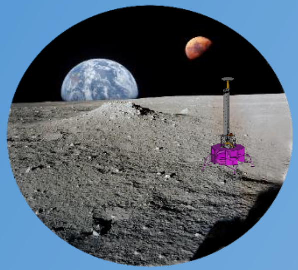




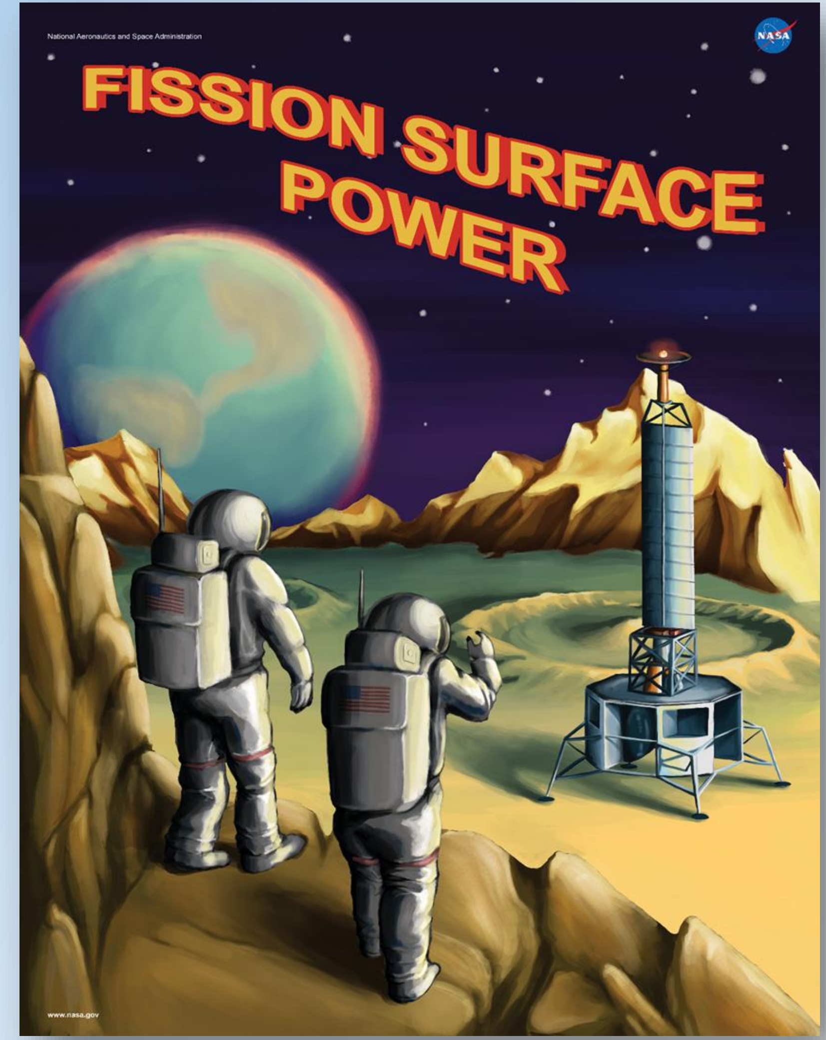
National Aeronautics and Space Administration

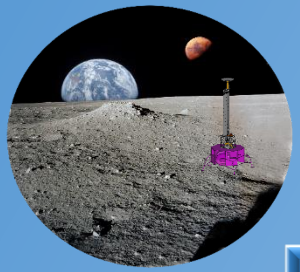
Fission Surface Power (FSP)

“The United States **will…establish a sustainable human presence on the Moon by the end of the decade and chart a future path for Mars exploration.”** [White House Fact Sheet, March 26, 2019]

“The United States will …..pursue goals for Space Nuclear Power and Propulsion (SNPP) development and utilization that are both enabling and ambitious…**Demonstrate a fission power system on the Moon.”** [SPD-6, December 16, 2020]

“In support of SPD-6, **NASA's near-term priority is to mature and then demonstrate a fission surface power system on the Moon.”** [NASA Supports America's National Strategy for Space Nuclear Power and Propulsion, Space Tech, December 16, 2020]



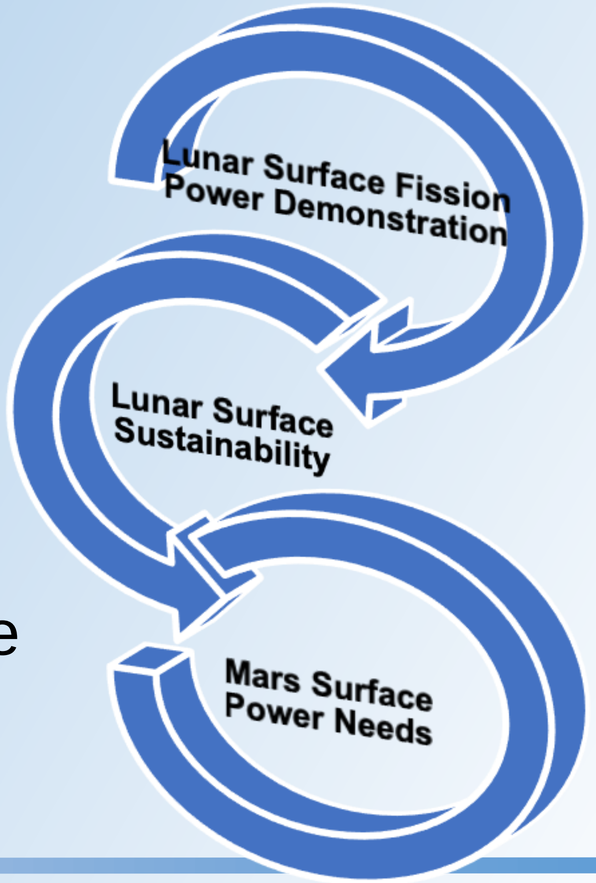


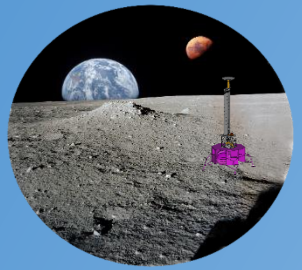
Fission Surface Power Project

National Aeronautics and Space Administration

NASA and DOE are collaborating on the development of a 10 kWe-class fission power system for a demonstration on the Moon by 2027, with extensibility to human Mars missions.

- ❑ Provides a near-term opportunity for fabrication, testing, and flight of a space fission system
- ❑ Will serve as a pathfinder for launching and operating other space fission systems
- ❑ Enables capabilities for lunar sustainable presence and crewed Mars exploration





National Aeronautics and Space Administration

A 10kWe Fission Power System

Advances in nuclear fuels and materials research may lead to smaller, compact reactor systems!

The initial lunar missions will greatly inform future FSP operations on Mars!

It's Powerful

Enough power to support NASA near term and future power needs

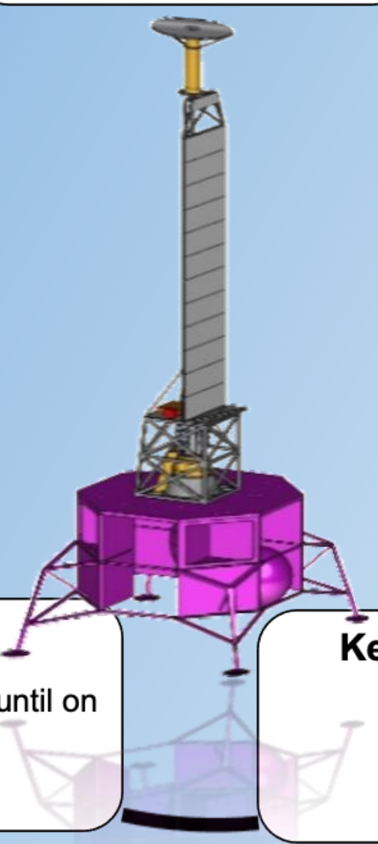
It's Compact

4 units could power outpost on Mars

It's Reliable & Flexible →

Enables lunar night operations

24/7 operation, non-reliant on sun!



It's Safe →

System not activated until on Moon surface

Fully contained

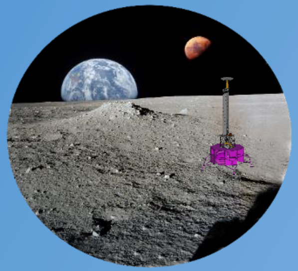
Keen Interest by Commercial Companies

Nuclear & Aerospace!

Supports even longer duration missions and operations on the Moon, and eventually for Mars and beyond!

Enables operations in extreme environments like the cold of the lunar night!

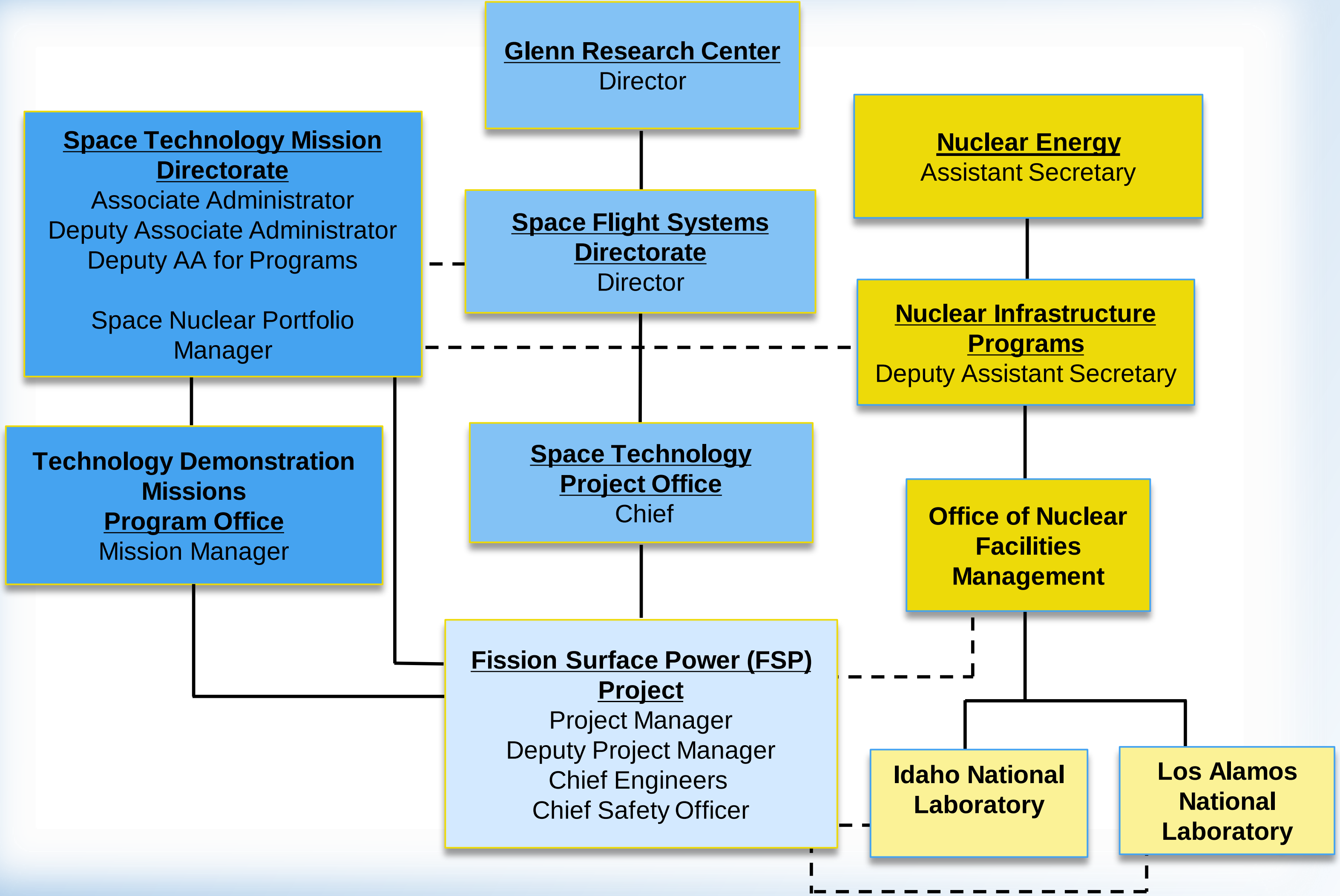
NASA's and DOE's leaderships and capabilities will be combined with innovation and contributions from the same sectors that fuel our nation and economy here on Earth!



Fission Surface Power Team

National Aeronautics and Space Administration

An Integrated Project Team is being developed to Capitalize on Expertise, Responsibility, Efficiency.

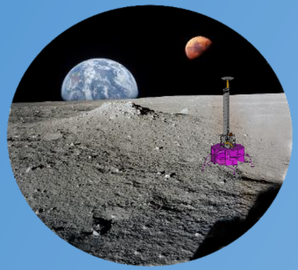


Project Managers: Todd Tofil - GRC/MT
Dr. Dionne Hernandez-Lugo - GRC/MT

Program Manager: Tawnya Laughinghouse - TDM

Mission Manager: Anthony Kelley - TDM

Space Nuclear Portfolio Mgr: Anthony Calomino - STMD



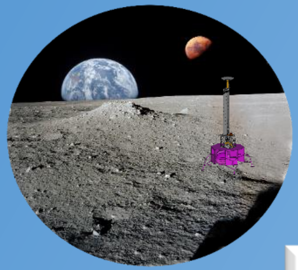
Project Accomplishments

National Aeronautics and Space Administration

Conducted a Government 10 kWe Fission Surface Power System Assessment

Aerospace Corporation's - Independent Assessment of Power Conversion Systems

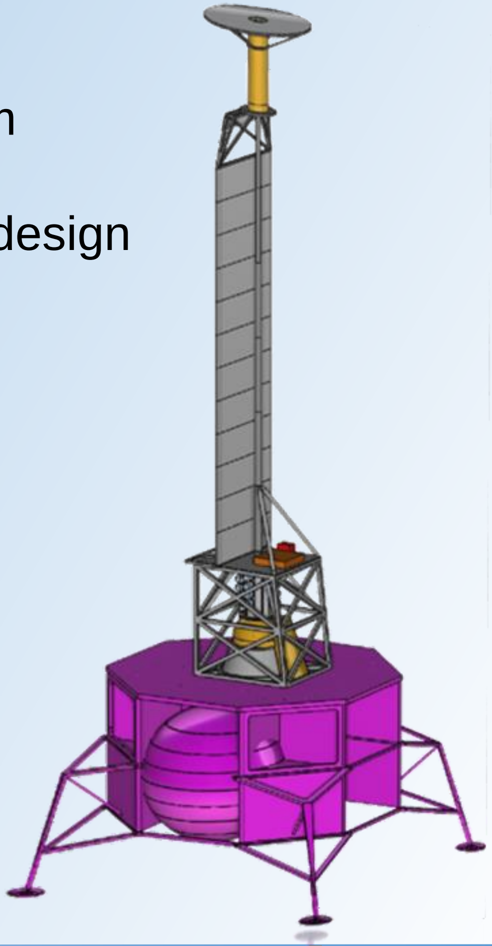
Initiated Industry Engagement



Reactor Trade & System Studies

National Aeronautics and Space Administration

In collaboration with DOE Los Alamos National Laboratory, the Fission Surface Power team at NASA Glenn Research Center completed a system level trade



Objectives

- Assess multiple reactor options that utilize HEU and LEU and power conversion system technologies
- Assess technology readiness levels and critical technology maturation needs for each design option

Study Requirements

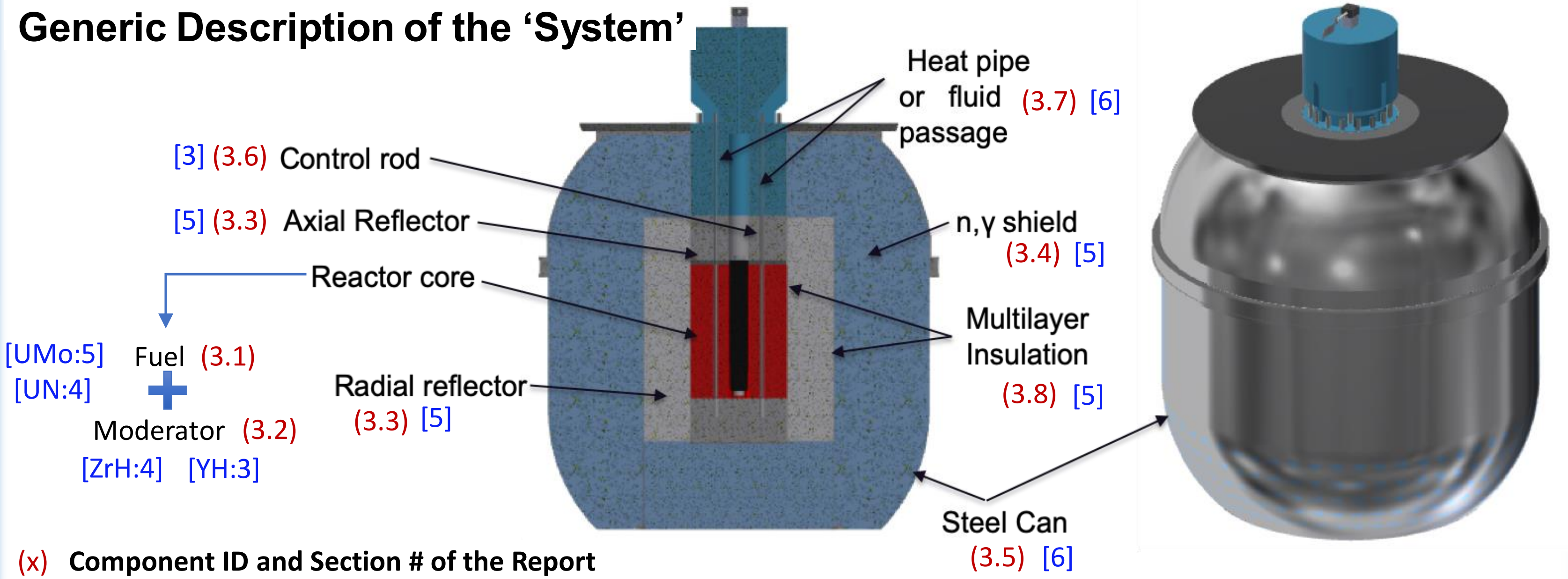
- **Power Level:** 10 kWe (EOL) at end user
- **Launch Date:** 2027
- **Operation:** 1 year (redundancy based on design life of 15 years)
- **Mass Requirement:** 3500 kg
- **Environments:** Lunar and Mars
- **Shielding and Radiation Protection:**
  - Gamma and neutron dosage for electronics and equipment consistent with applicable NASA radiation tolerance standards
  - ‘Target’ value of 5 Rem/year to the habitat and no less than 1 km *(TBR)*

Reactor System & Shielding Studies

National Aeronautics and Space Administration

- Started with Legacy Designs
- Formulated a Generic Configuration for Reactor System
- Technology Readiness Levels for Individual Components and Materials
- Integration Risk based on:
  - Availability of test data for the validation of design tools
  - Insights from the phenomena identification and ranking tables for the generic moderated design

Generic Description of the 'System'

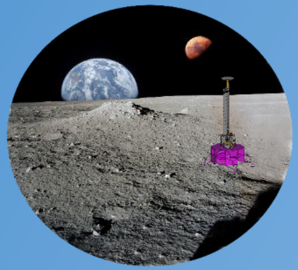


(x) Component ID and Section # of the Report
[x] Technology Readiness Level

Estimated Mass Range for the Four Classes

	HEU-Fast (kg)	HALEU-Fast (kg)	HALEU-YH (kg)	HALEU-ZrH (kg)
Core	240-310	850-1050	250-350	280-410
Core + Shield	900-1100	1450-1650	900-1100	900-1200
TRL	5	5	3	4

"The four design classes reasonably envelope trade options." Peer review team.



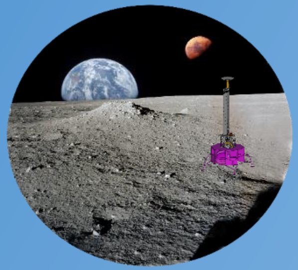
Reactor Trade and FOM's: Project Assessment of Relative Benefits & Drawbacks

National Aeronautics and Space Administration

- A 10 kWe FSP system can be landed on the moon using large, commercial class lander
- Various reactor options exist that meet system level requirements such as mass, power level, radiation dose, schedule, and outlet temperature
- HEU-Fast reactor options have less design risk and shorter technology development schedule, because validated design tools and prototype test data already exist
- HALEU-Moderated reactor options require early technology maturation and prototype demonstrations to establish feasibility

FOM	HEU Fast	LEU Fast	LEU-YH	LEU-ZrH
Reactor Design Risk	🟢	🟢	🟠	🟡
Nuclear TRL	🟢	🟢	🟠	🟡
Extensibility (10-40 kW; 10-15 yrs)	🟢	🟢	🟡	🟢
System Level Mass Risk	🟢	🟠	🟢	🟢
Schedule Risk	🟢	🟢	🟠	🟡
Reactor Outlet Temperature Capability	🟢	🟢	🟡	🟢

🟢 = Lowest risk ; 🟡 = Intermediate risk; 🟠 = Highest risk



Technology Maturation - Assessment Study

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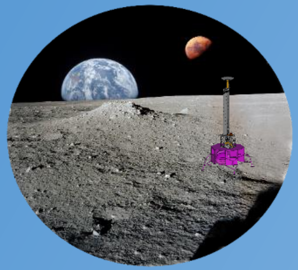
Nuclear Reactor - Technology Maturation

- **Collaboration with DOE and its FFRDCs: Separate & Independent of Industry Contracts**
  - **Design-neutral technology maturation for critical components**
    - Technology common to any lunar nuclear system design irrespective of fuel type, moderator usage, mode of cooling, and/or power conversion
    - Purpose is: (a) to reduce overall program/schedule and (b) to aid in industry design assessments
  - **Preliminary technology maturation plan could include:**
    1. Neutronic Data and Qualification of Moderator Materials
    2. Low Specific Weight Gamma- and Neutron-shield
    3. High Reliability Control and Plant Health Monitoring System



Project Accomplishments

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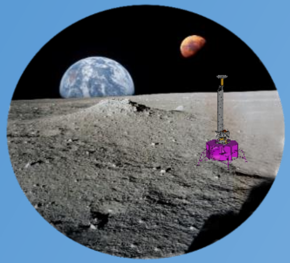


Aerospace Corporation – Independent PCS Assessment (1 of 2)

National Aeronautics and Space Administration

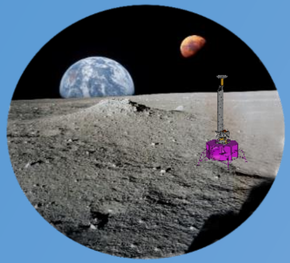
Purpose: Assess the performance of a variety of power conversion cycle architectures

Requirements:

- **Power Levels →** 10 kW_e and 20 kW_e at End of Life (EOL)
- **Location →** Support human exploration of the Lunar surface by 2027 and Mars by 2035
- **Schedule →** TRL6 by **2023** * Ground Demo by **2025** * Qual Unit & Flight System by **2027**
- **Constraint →** Study was specific for power conversion system technologies only
  (No reactor design included in this study)***

Scope of the Work:

- Identify and assess viable power conversion technologies per mission needs
- Assess technology readiness & timeline for maturing technology ready for a flight development
- Compare strengths and weaknesses relative to the requirements and estimate cost and schedule to develop the PCS



Aerospace Corporation – Quick Look at Final Report (2 of 2)

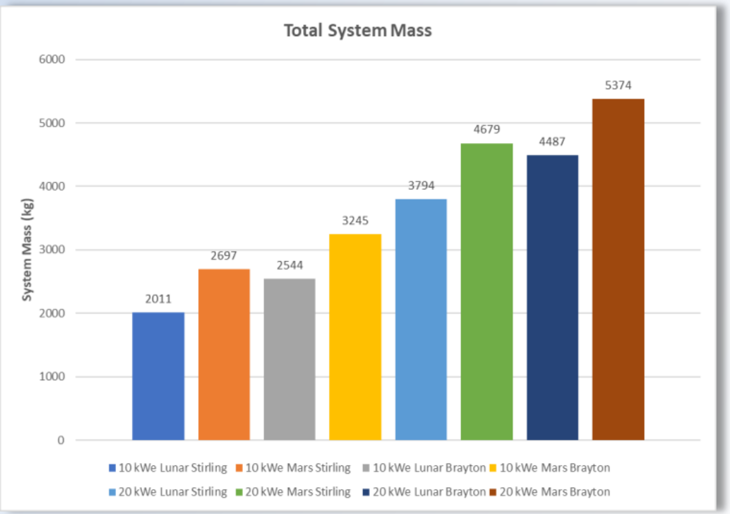
National Aeronautics and Space Administration

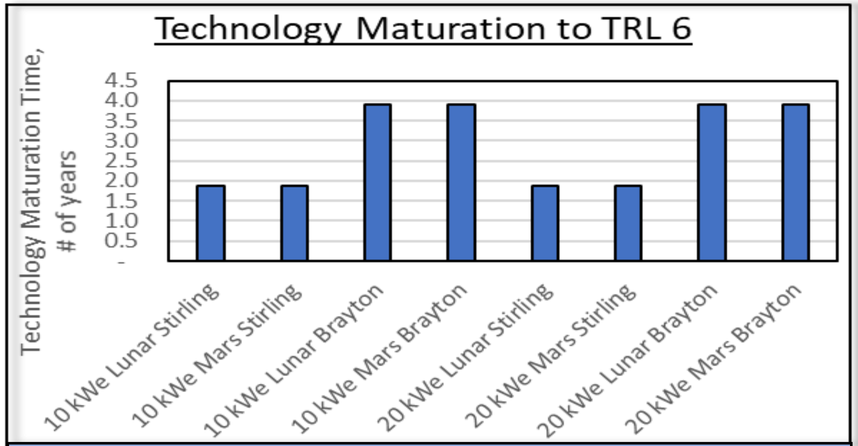
- **Architectures**
  - ***Stirling conversion cycles trade more favorably for both power levels & both locations (less mass & volume)***

- **Industrial Base**
  - ***Various companies are capable of supporting PCS acquisition***

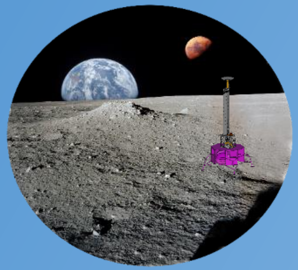
- **Technology Forecasting**
  - ***Stirling and Brayton have lowest development difficulty when considering technology maturation cost, time, & risk for desired power and efficiencies***

- **CONCLUSION**
  - ***Consider advancing Stirling conversion for near-term applications and Brayton for future Mars missions***





Stirling will take ~2 years to reach TRL 6.
Brayton will take ~4 years for TRL 6.



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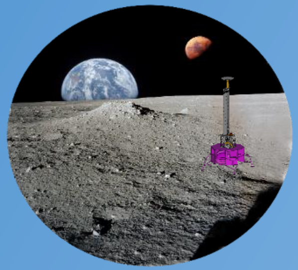
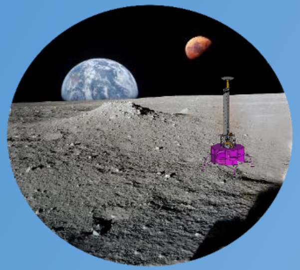


Industry Engagement

National Aeronautics and Space Administration

- Idaho National Laboratory - Battelle Energy Alliance (BEA) in collaboration with Department of Energy and NASA solicited industry input through a Request for Information (RFI) and a Draft Request for Proposal (RFP)

- **<u>The FSP Project is looking to:</u>**
  - Establish inter-disciplinary industry teams to partner with NASA and DOE to provide a full-mission concept leading to a launch-ready Fission Surface Power system by 2027
  - Identify critical technologies and manufacturing approaches required to advance fission surface power supply chain capabilities
  - Gain valuable insights into barriers and challenges faced by industry in furthering space nuclear power and propulsion technologies



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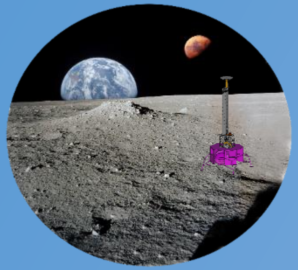
Industry Engagement - RFI

- RFI requested innovative technical approaches for a 10 kWe Fission Surface Power (FSP) system with a 1-year demo of the FSP system on the Moon, followed by 9 years of operations
- 22 Responses Received
- RFI Responses varied and covered multiple technical areas

System Level Areas	Industry Responses
Fuel Enrichment	HEU HALEU
Fuel Form	Ceramic or Metal Form TRISO UZrH Molten Salt Molten Fuel Thorium
Reactor Design	Fast Spectrum Thermal Spectrum using Moderators
Power Conversion System	Stirling Brayton Thermophotovoltaic Thermoelectric
Risks and Technology Maturation	Power Conversion & Thermal Management Instrumentation & Control Systems Hybrid Radiation Shielding Architectures



FSP System Development - Procurement Phasing

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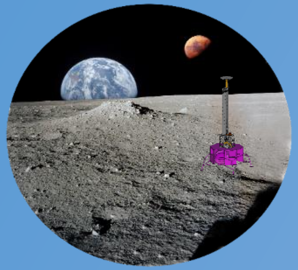
Phase 1: Industry Designs

Phase 2: Design, Build and Delivery of a Space-qualified FSP Flight System to Launch Site

Phase 1 Contracts are Independent of Phase 2 Contract.
Phase 2 will be a New Procurement.



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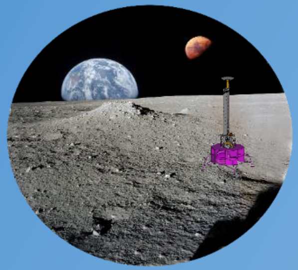
RFP1 (Phase 1) - Industry Designs

Draft RFP1 Released

- **DOE - Idaho National Laboratory will Manage the Contracts**

- **Up to 3 contracts Selected; 12 months Performance Period**
  - Planned <u>Final RFP1</u> - Release by end of this Fiscal Year 2021 or early next Fiscal Year

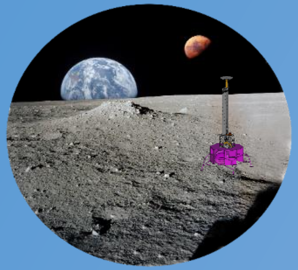
- **<u>Design Expectations:</u>**
  - Industry's design and construction standards may be used
  - The FSP-Qualification Unit design should be as similar as practicable to the Flight System in all ways
    - Design should represent the flight configuration and operation of the full power conversion system, heat rejection system, and all other subsystems
  - Deliver an Interim Review and a Final Review, contract documents
  - Typical Products should include: requirements development & decomposition to subsystems, internal interface definition, risk identification, technology development plan, modeling and analytical results, subsystem design specifications, drawings, cost and schedule for Phase 1 and Phase 2, contract document deliverables



Request for Proposal 1: Requirements

National Aeronautics and Space Administration

Title	Requirement
Power	The FSP shall be designed to operate at a minimum end-of-life10 kWe continuous power output for at least 10 years in the lunar environment.
Basic Mass	The total mass of the FSP system shall be less than 3500 kg which includes mass growth allowance and margin.
Volume	The FSP system shall fit within a volume 3.5 m deep, 3.5 m wide, and 6 m high in the stowed launch configuration.
Radiation Protection	The FSP system shall be designed to limit radiation exposure at the location that provides user access to 120 VDC to a baseline value of 5 rem per year above lunar background.
Power Cycles	The FSP system shall be capable of multiple commanded and autonomous on/off power cycling, estimated to be 4-10 times per year.
User Load	The FSP system should accommodate user loads that vary between 0 kWe and 10 kWe.
Command & Control	The FSP system should operate autonomously and have a “commanded” operation mode that permits earth-based control.
System Monitoring	The FSP system should have an instrumented radiation monitoring and digital control system with data storage and real-time data transfer during activation and surface operation.
Fault Detection & Tolerance	The FSP system should be capable of operating at no less than 5 kWE power output after a single credible non-safety failure.



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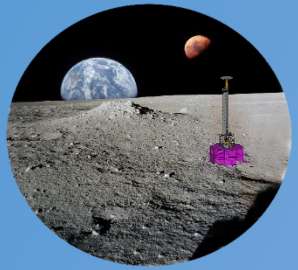
Draft RFP1 - Industry Responses

- **Received 18 Responses from Industry**

- **Common Areas included:**
  1. Further Clarity of FSP Design and Operational Requirements
  2. Fuel Selection evaluation criteria
  3. Radiation Shield concerns → Astronaut Presence/Involvement (if any) on FSP system Operations
  4. Meaning of ‘extensibility’ to higher power FSP systems and Mars
  5. Concept of Operations definition

RFP1 Status: **Comments are being incorporated into Final RFP1**

Strong, Keen Interest by Nuclear & Aerospace Industries!



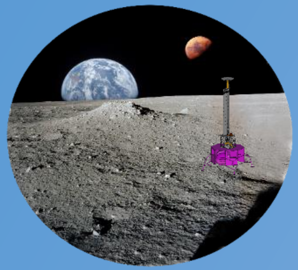
Preliminary Planning – Request for Proposal 2 (Phase 2)

National Aeronautics and Space Administration

- **RFP 2 – (Phase 2): Separate Competitive Procurement –** (assembled and test-qualified Flight System by Dec 2026)

Preliminary Planning

- Nominally 1 contract team will be selected
- Intended Tasks and Deliverables:
  - Support safety analysis and launch approval process
  - Mature Technologies and subsystems, as needed
  - Complete final design, hardware build, and nuclear ground-test of FSP Qualification Unit
  - Deliver test-qualified FSP Flight System (FSP-FS) to launch site for deployment to Moon
  - Develop all ground support equipment
  - Support lander integration
  - Support system operation during the 1-year Lunar demonstration



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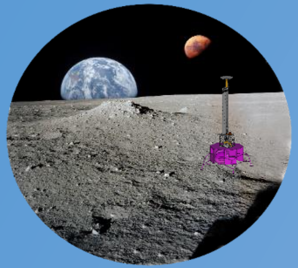
Project Concerns

- **Requirements are preliminary/notional with respect to mission definition and operational concept →** i.e. lander capabilities and interfaces, launch vehicle requirements, lunar location and environment, power user interfaces, etc.
  - Lunar demo concept may change when above requirements are matured and refined
- **System interface with Lunar Architecture →** Following areas need more definition: System Radiation Signature, Lander Providers, Concept of Operations
- **Targeted Launch Readiness Date for FSP system**
  - Uncertainty and delays in path forward are making advertised need date of 2026 infeasible
  - Current SPD-6 guidance evolving to HALEU fuel preferred → Impacts system readiness date



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Summary

- ✓ Completed a government 10 kWe Fission Surface Power Assessment → **Stirlings traded favorable and various reactor solutions exist that meet system and operational requirements**
- ✓ Completed an Independent Assessment of Power Conversion Technologies → **Stirling energy conversion was recommended for near-term 10 kWe and 20 kWe fission technology demonstration**
- ✓ Gathered industry inputs in collaboration with the Department of Energy – INL (BEA) → **Received a strong interest from Industry for the development of a 10 kWe Fission Surface Power System**
- ✓ **Moving Forward with Industry Designs for a 10 kWe Fission Surface Power System!**

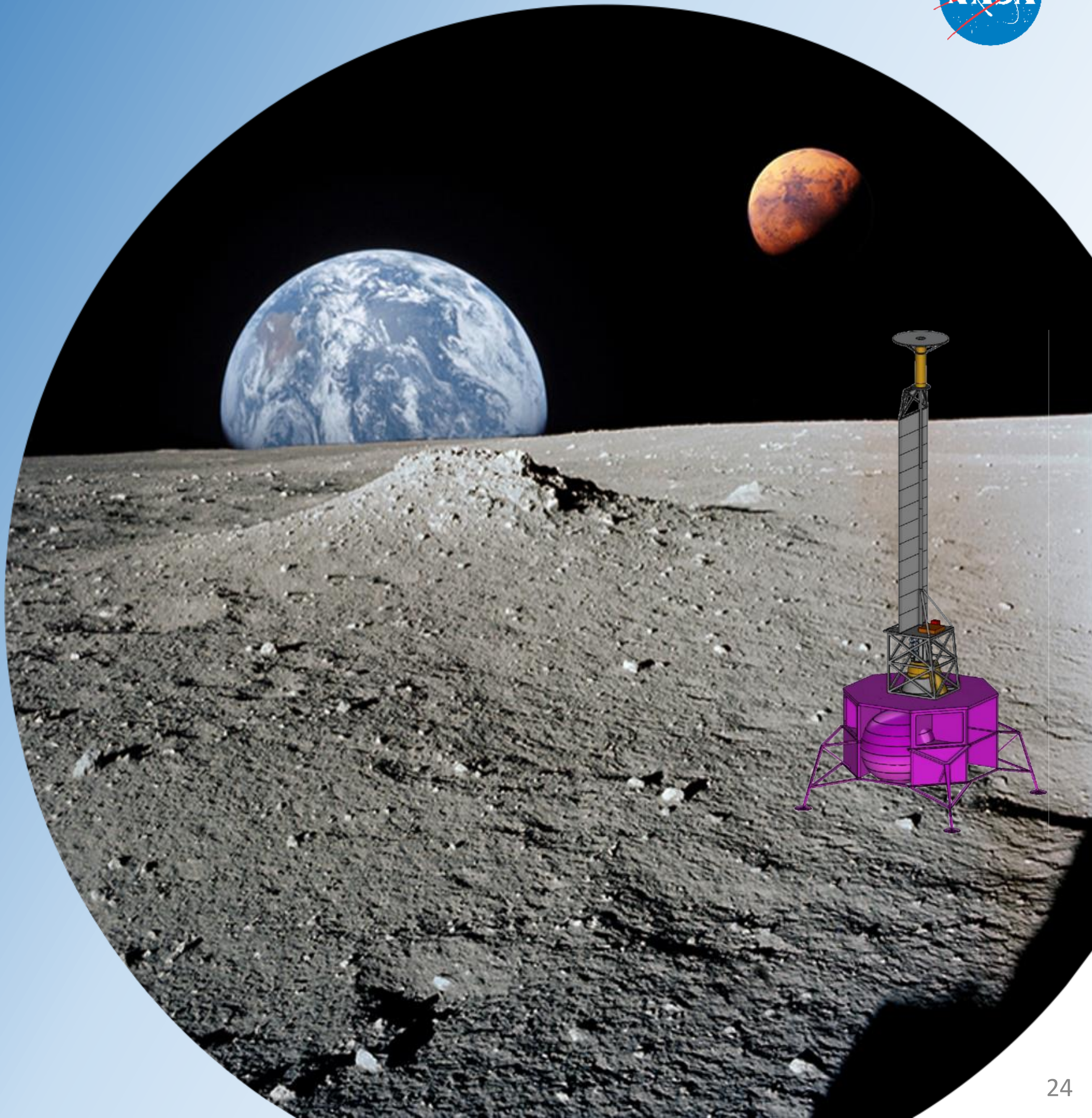
Fission Surface Power Project (FSP)

THANK YOU to EVERY FSP Team Member!!!

ANY QUESTIONS ?

Todd Tofil
Project Manager
NASA Glenn Research Center

Dionne Hernandez-Lugo, Ph. D. ***(Presenter)***
Deputy Project Manager
NASA Glenn Research Center



NASA