National Aeronautics and Space Administration

Overview of NASA's Fission Surface Power (FSP) Project

Nuclear TDT Meeting
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FSP Project Overview

STMD Space Nuclear Tech. Portfolio Mgr: Anthony Calomino

TDM Mission Manger: Larry Huebner

GRC Project Manager: Todd Tofil

Collaborative Organizations: NASA GRC, DOE-NE, INL

Project's Big Picture

- Develop and deliver a space qualified fission surface power source flight unit to the launch site by 2029
- Scope includes the fission power system flight hardware and all development hardware
  - The scope does not include the Lander, Launch Vehicle, Cable Cart, or Rover/Transporter
  - The scope does not include integration with the lander, launch ops or lunar demonstration
  - The Project is a collaboration with DOE and their FFRDCs
    - Idaho National Laboratory will manage the design and development contracts. Los Alamos provides reactor expertise.
- The Project, through flight hardware delivery, is funded entirely by STMD
- The Project is currently in Pre-formulation as a 7120.8 project

Draft Project Goals

#1: Design a fission power source that supports Lunar and Mars surface exploration requirements

#2: Leverage Industry design capability and terrestrial power technology investments

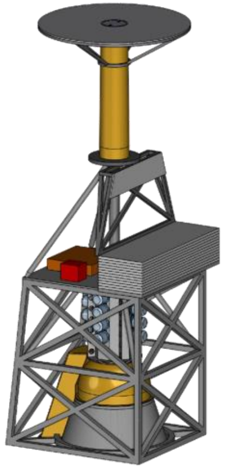
#3: Build and ground test a flight-qualified, fully-integrated power system for a lunar demonstration

Key Performance Points

- 40 kWe output at 120 Vdc
- 6000 kg mass limit, fits on a lander
- 5 rem/year above background radiation limit at 1km
- Transportable to locations away from the lander
- User loads from 0 to 100% power at the user interface

Project’s Approach to Achieve the Goals

<u>Develop a 40 kWe fission surface power system</u>

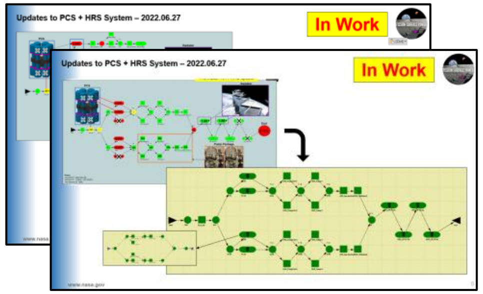


1. **Establish a Government Reference Design (GRD) of a FSP system**
2. **Establish Government-led Technology Maturations**
   - Risk reduction tasks and contracts concurrent with initial industry design contracts to mature nuclear and power conversion systems
3. **Procure an industry design & development for the FSP flight hardware system**

The Project has a technically sound path forward with a mix of a government reference design, industry & government technology maturations and industry flight development

FSP Project Status - Accomplishments in FY21-FY22

- Developed Government Reference Design (GRD) concepts for three different fission power systems
- Holding meetings on the Nuclear Flight Safety cycle
- Expanded reliability model and planning for Brayton-based reliability layout
  - Added Heat Rejection System assemblies in the Stirling-based reliability model.
  - Identified key assemblies for Brayton model and brainstorming bounding cases of engines (2-4)



- Planned for Technology Maturation
  - The following nuclear technology maturation efforts are design-neutral, low-TRL components that have limited heritage or relevant industry expertise:
    - Moderator and Core Materials Testing and Evaluation
    - Reactor Instrumentation and Control System
    - Shielding Materials and Architectures
  - Planning for Brayton technology maturation
- Released a Request for Proposal (RFP) through Idaho National Laboratory for initial designs of the FSP system
  - Selected three separate contractors to develop designs, contracts pending

Key Technical Challenges

- Relatively low technology readiness level (TRL) of key some technologies/subsystems
  - Stirling converters & controllers,
  - Brayton power conversion system
  - High voltage electronics
  - Moderator materials
  - Shielding
  - Radiation-hardened electronics
  - Reactor instrumentation and controls
- Lack of interface definition for the lunar lander and lunar rover/transporter

Purpose of the Government Reference Design

- **Develop a viable concept that shows the driving requirements are feasible**
  - The GRD is Independent from Industry Designs; it will not interfere or compete with industry
  - The government will not mandate an implementation or architecture
- **Provides identification of gaps, reliability drivers, and failure impacts**
  - Focus on high-risk items and interfaces (e.g., reactor, transportability, power conversion)
  - Perform deeper assessment, if necessary, on unknown or risk areas (e.g., power transmission)
- **Informs requirements and RFP development for Phase 2**
  - Identify realistic requirements that are likely to result in a viable industry design (mass, thermal control)
- **Enables assessment of industry designs and development; makes government a "smart buyer" because of design experience**

Government Concept - Requirements Compliance

	Title	Requirements	Compliance	Description
DR-1	**Power**	The FSP shall be designed to operate at a minimum end-of-life 40 kW_E continuous power output for at least 10 years in the lunar environment as detailed in Attachment A. Higher power ratings are desirable provided remaining DRs are satisfied.	Yes	Reactor designed for 240 kWth, generates 40 kWe at the user interface at the end of life
DR-2	**Launch & Landing Loads**	The FSP shall be designed to withstand structural loads as detailed in Attachment B.	Yes	Structure not designed, but it’s feasible. Mass estimate for structure generated.
DR-3	**Radiation Protection**	The FSP shall be designed to limit radiation exposure at a user interface location 1 km away to a baseline value of 5 rem per year above lunar background.	Yes	

Government Concept - Requirements Compliance

DG-	Title	Goals	Comply?	Description
DG-1	**Volume**	The FSP should fit within a 4 m diameter cylinder, 6 m in length in the stowed launch configuration.	Yes	Three separate pallets
DG-2	**Mass**	The total mass of the FSP should not exceed 6,000 kg which includes mass growth allowance and margin.	No	Total mass >6000 kg
DG-3	**Power Cycles**	As a safety feature, the FSP should be capable of multiple commanded and autonomous on/off power cycling.	Yes	
DG-4	**User Load**	The FSP should be capable of supporting user loads from zero to 100% power at the user interface	Yes	
DG-5	**Fault Detection & Tolerance**	The FSP should minimize single-point failure modes, should be capable of detecting and responding to system faults, and have the capability to continue providing no less than 5 kW_E under faulted conditions.	Yes	
DG-6	**System Transportability**	The FSP should be capable of operating from the deck of a lunar lander or be removed from the lander and placed on a separately provided mobile system and transported to another lunar site for operation.	Yes	Total mass is above the mass capability of a rover chassis. Chassis not specifically made for transporting the reactor

Government Reference Technical Concept

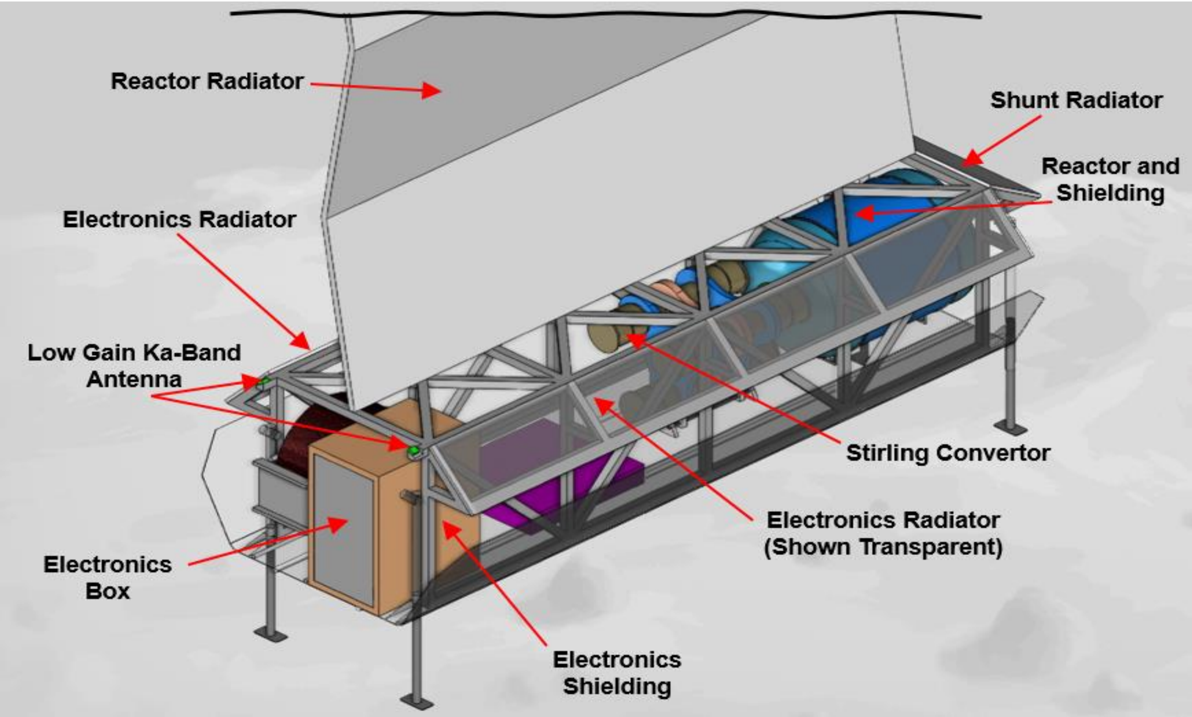
Operations Approach:

- Lander: Provides transit and delivery to the Moon; deploys the FSP System to the lunar surface
- Rover/Transporter: Six-wheel Pressurized Rover chassis

Concept Results (Glenn Research Center's COMPASS Team and FSP Project):

- FSP System delivered in 3 pallets on one lander: Reactor, Controller, Voltage Down-Converter Pallets
  - **Reactor Pallet:** Reactor, power conversion, radiator, RF communication, start-up battery
  - **Controller Pallet:** Stirling controllers, radiator, spool and 50 m cable
  - **Voltage Down-Converter Pallet:** Converts high transmission voltage to 120 Vdc at the user interface. Includes a radiator, spool and 1 km cable

The concept complies with the Phase 1 requirements

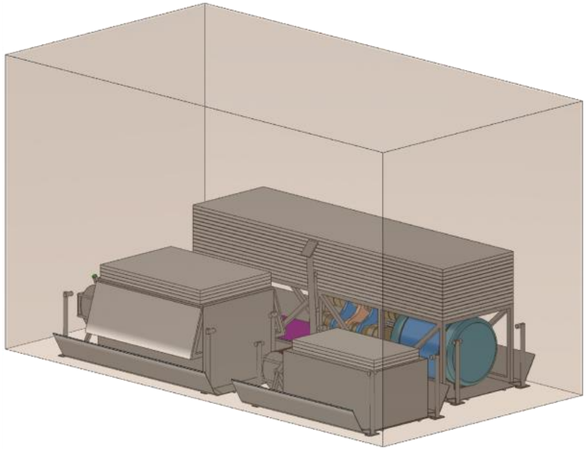


Reactor Pallet:

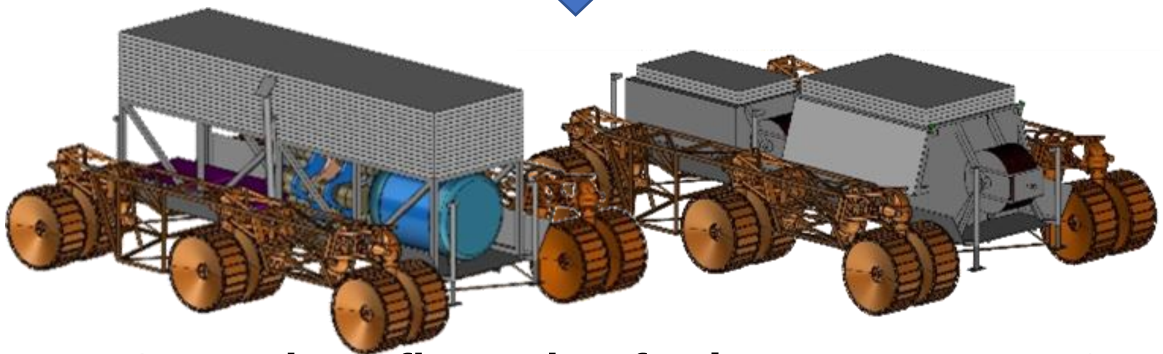
- A horizontal HALEU-moderated reactor is the reference
  - Shielded controllers and sensors for the reactor
- Power conversion consists of four, 6 kWe Stirling pairs
- Deployable radiators are sized for polar operations
  - Equatorial radiators are much larger
- Shielded Ka-Band link for communications to Earth

NASA's Technical Concept

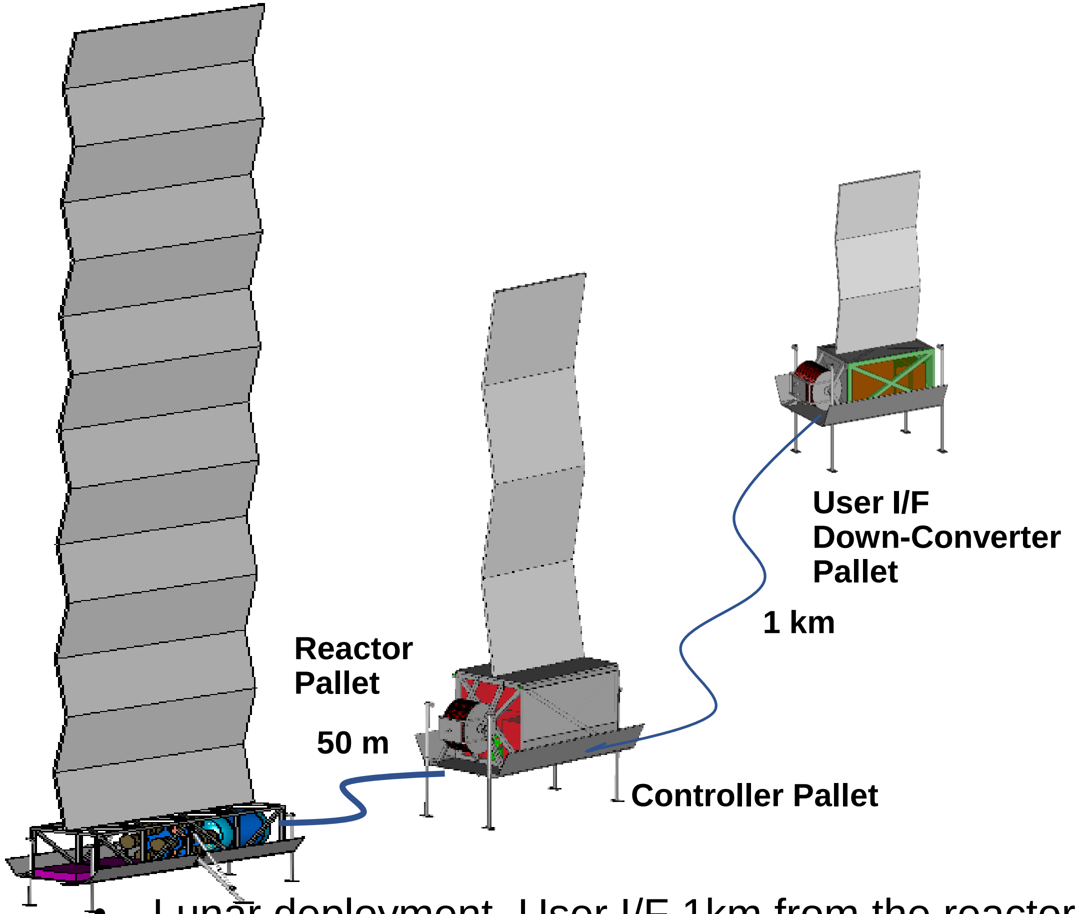
40 kWe, Transportable Fission Power System



Stowed configuration on a lander



Stowed configuration for lunar transport, 3 pallets



- Lunar deployment. User I/F 1km from the reactor

Deployed configuration

Nuclear Reactor Government Reference Design

Nuclear reactor Design Assessments

- A design assessment is underway to revise previous DOE assessments to the 40 kWe power level
- Concepts being analyzed include
  - KRUSTY derived HALEU UMo Fast Metal HP Reactor
  - Yttrium Hydride Moderated Ceramic Fuel HP Reactor
  - Yttrium Hydride Moderated Ceramic Fuel HeXe Gas-Cooled Reactor
- Ceramic fuel forms include sintered pellets and coated fuel particles
- Power conversion systems include Stirling and Brayton systems

Objectives of the design assessments

- Identify Technology and/or Materials Gaps. Develop a multi-year technology maturation strategy to achieve mission infusion readiness
  - Reconcile with industry findings
- Perform shielding and concept-of-operation analyses
  - Enable decisions related to location of deployment and ground-based reactor control
- Smart-Buyer for Phase-2 RFP
  - Independent nuclear design assessment with accompanying uncertainty/risk characterization
  - Fuse information from industry designs
  - Develop Phase-2 requirements
- Host Technology Interchange Meetings
  - Share data widely with the industry teams

Fission Surface Power Reactor Status Update

Assessment of Design Alternatives

Space Power Yttrium Dihydride Epi-thermal Reactor

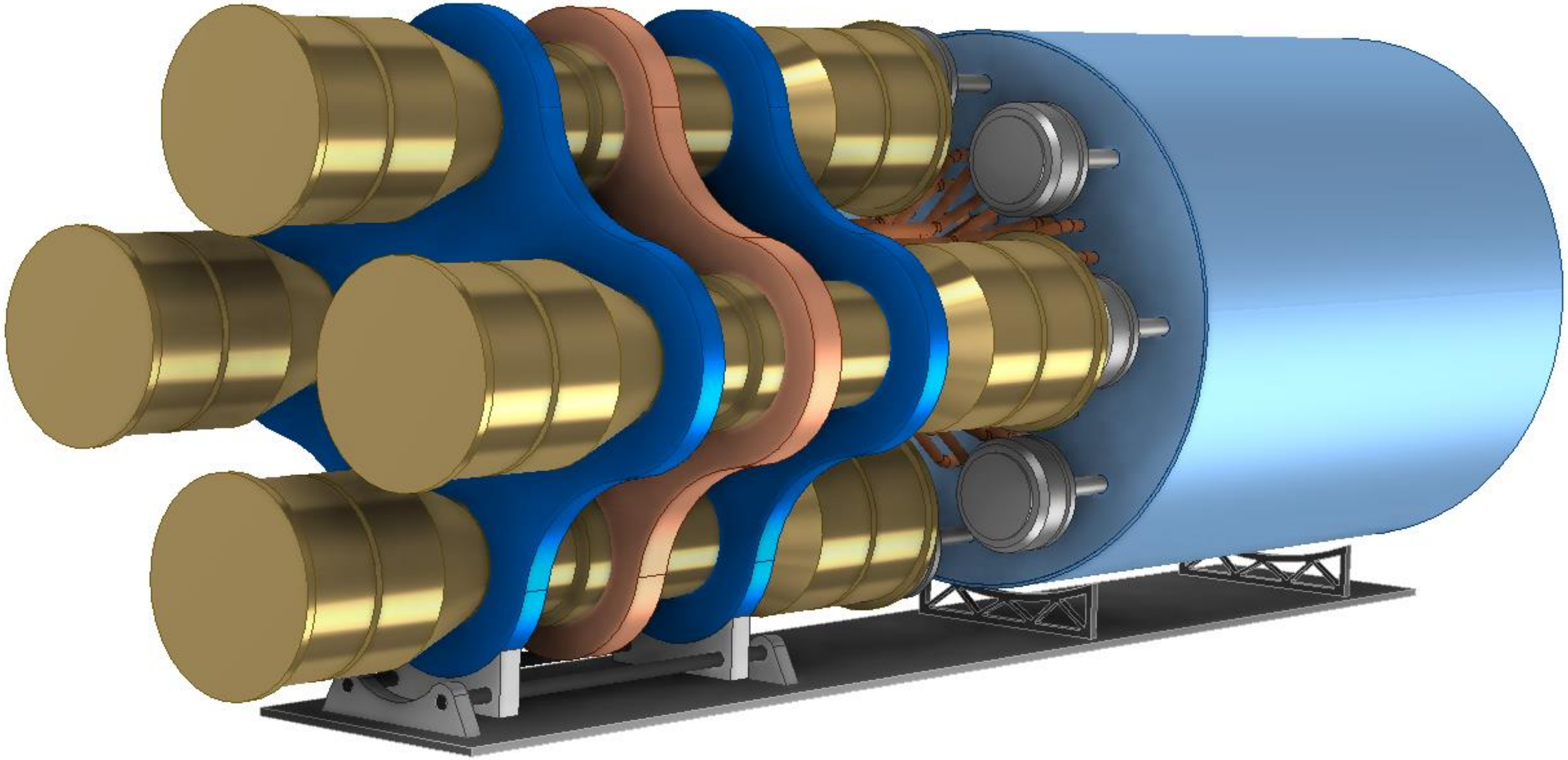
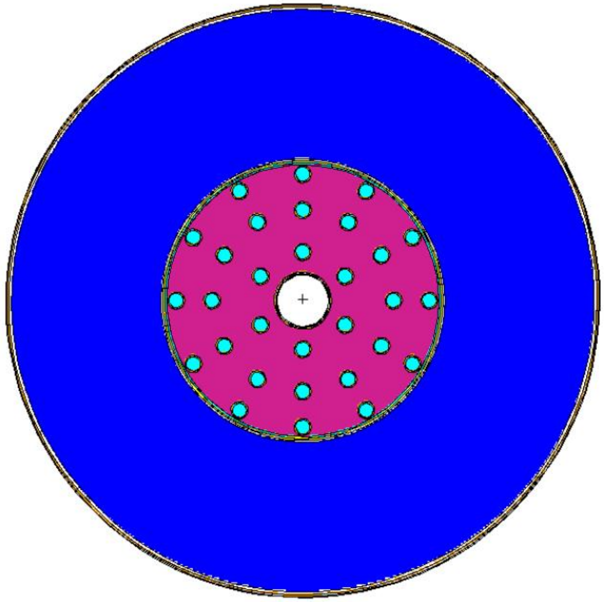


Illustration is a heat-pipe reactor with 8 x 6-kW Stirlings

Overview of Reactor Concepts

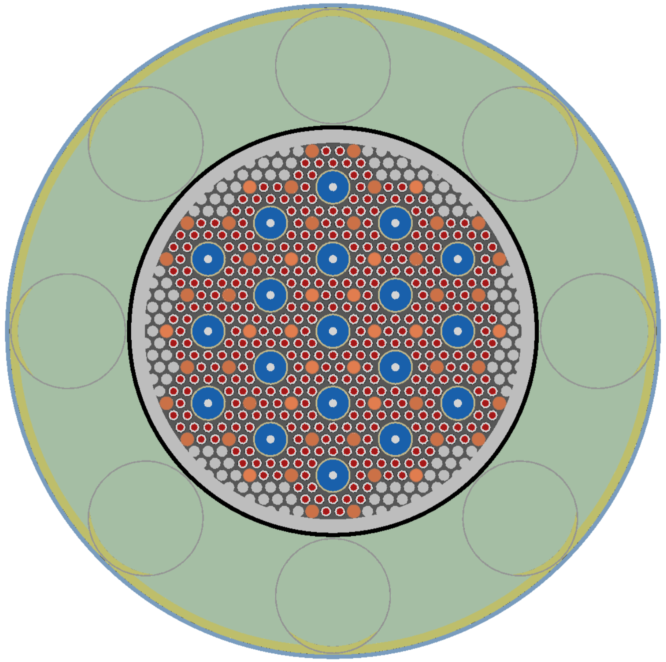
UMo fueled Fast-Spectrum Heat Pipe Reactor

KRUSTY Derived with HALEU Fuel
Mass: 1100 kg (Reactor); UMO (500 kg)
26 sodium heat pipes @ 1073 K
Tech Mat*: UMo-to-HP bonding, I&C



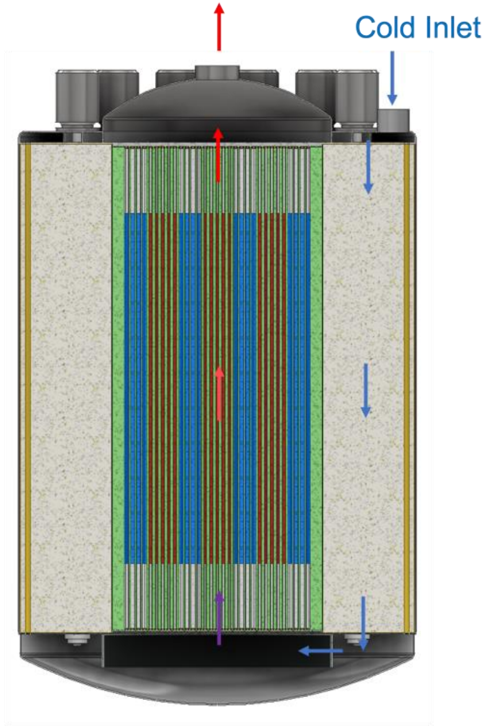
UN fueled YH/BeO-Moderated Heat Pipe Reactor

Graphite and C-C_f composite block
Mass: 1050 kg (Reactor); UN (160 kg)
54 sodium heat pipes @ 1100 K
Tech Mat: YH Moderator, and I&C



UN fueled YH/BeO-Moderated Gas-Cooled Reactor

Be-BeO composite block
Mass: 1250 kg (Reactor); UN (170 kg)
HeXe Gas at 1.5 MPa and 1100 K
Tech Mat: YH Moderator; Vessel; I&C



*Technology Maturation Necessary to Achieve TRL-5.

FSP Reactor GRD-1: 'Baseline Heat Pipe Stirling Design'

Power: 250 kW-thermal (nominal operating power) operating at 1073 K (nominal)

Estimated weight: 1050 kg + plus shield

Core: Graphite and Be-BeO (cermet) block with pre-drilled holes for fuel, moderator and heat pipes

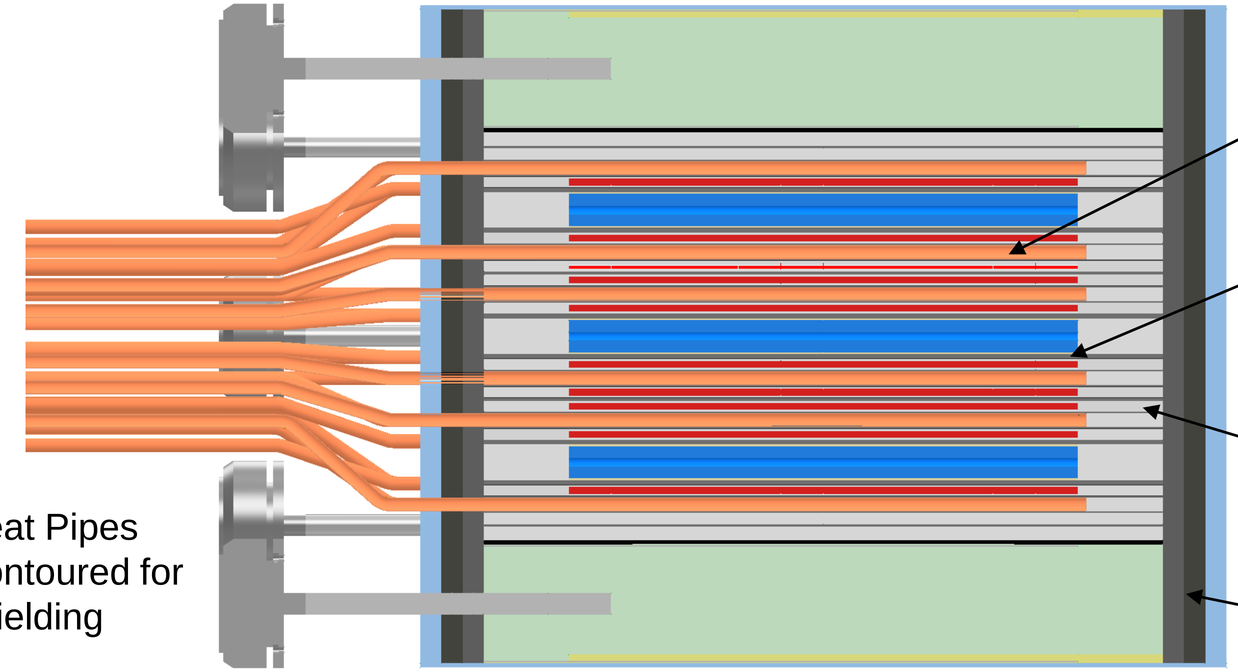
Fuel: HALEU Uranium Nitride Pellets (160 kg) in hermetically sealed C-C_f cladding with TZM liner

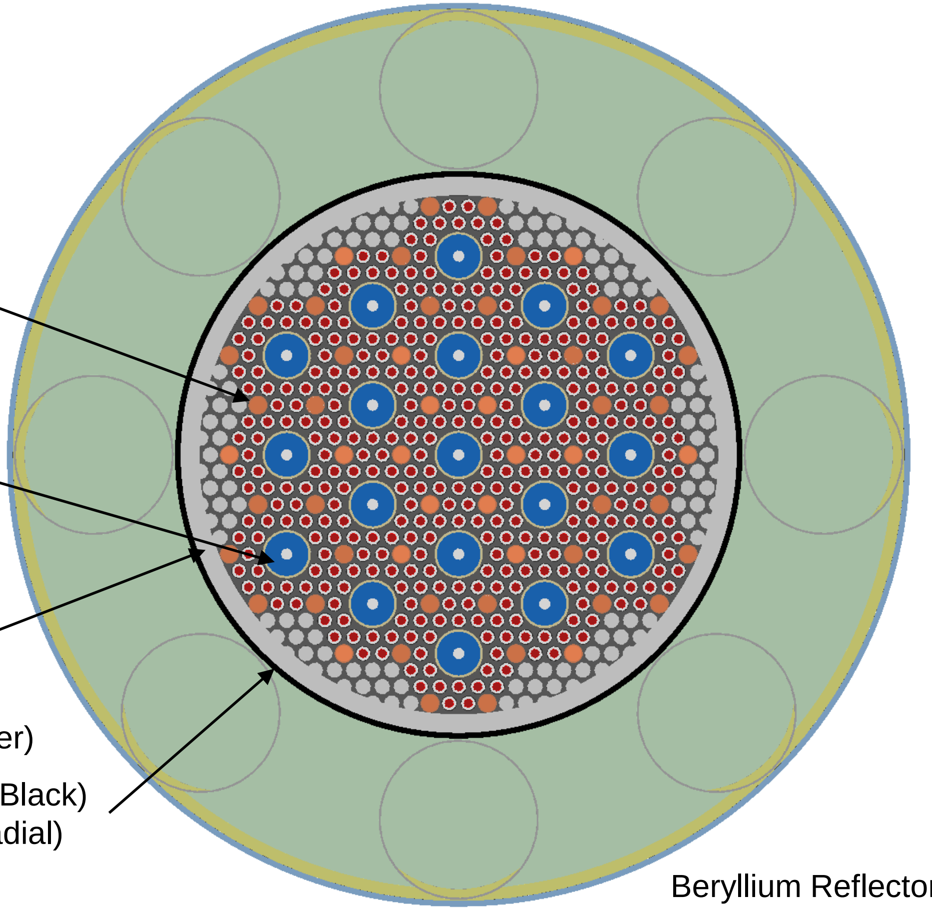
Moderator: Yttrium Hydride, $YH_{1.8}$, (50 kg) clad in a hydrogen barrier (Tungsten coated TZM 'can')

Heat Pipe: TZM walled 2.5 m long Sodium Heat Pipe

Reflector: 10-cm thick BeO (Axial); and BeO and Beryllium (Radial)

Vessel: Tungsten Molybdenum Alloy (serves also as gamma shield)





FSP Reactor GRD-1: ‘Baseline Direct He-Xe Brayton Design’

Power: 250 kW-thermal (nominal operating power) operating at 1073 K (nominal)

Core: Graphite and Be-BeO (cermet) block with pre-drilled holes for fuel, moderator and heat pipes

Fuel: Annular Uranium Nitride Pellets (180 kg) with lined central hole for gas flow

Moderator: Yttrium Hydride, $YH_{1.8}$, (50 kg) clad in a hydrogen barrier (Tungsten coated TZM ‘can’)

Heat Pipe: TZM walled 2.5 m long Sodium Heat Pipe

Reflector: BeO (Axial); and BeO and Beryllium (Radial)

Operating Pressure: 1.5 MPa

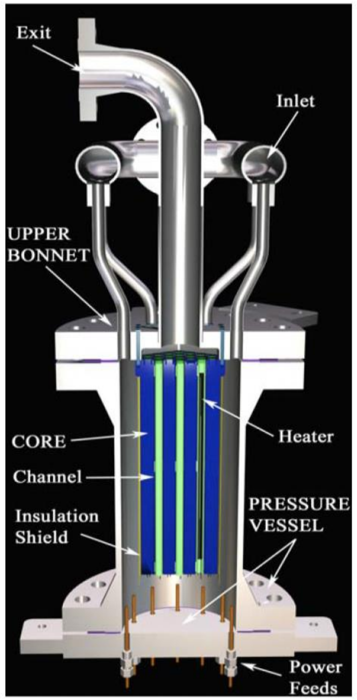
Maximum Fuel Temperature: 1100 K

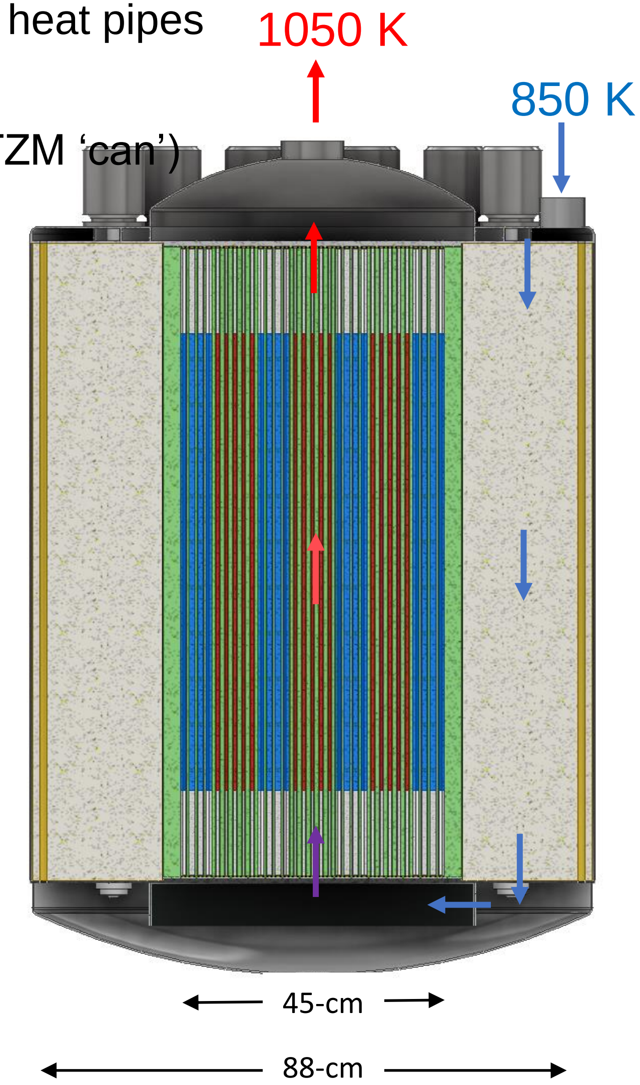
Gas Temperature: 850 K (Inlet) and 1050 K Outlet

Vessel: 316-L Steel Vessel (ASME BPV Compliant)

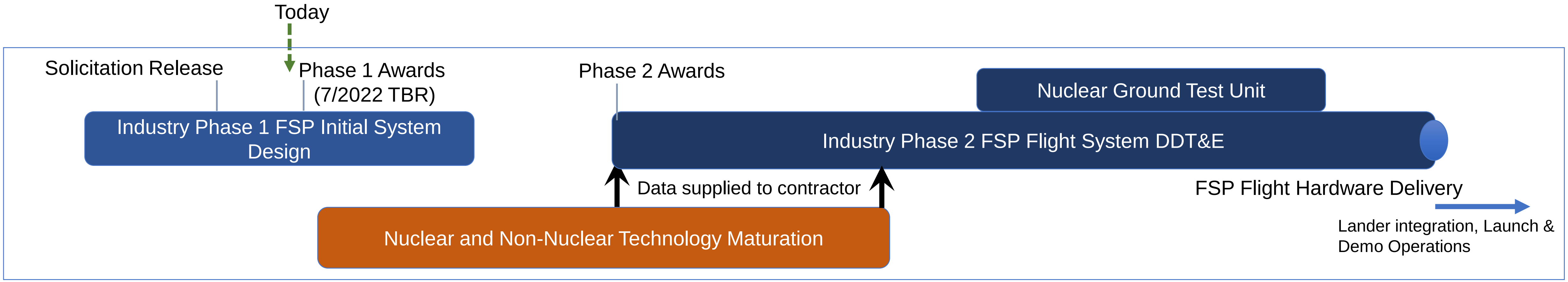
Estimated weight: 1050 kg + plus shield

Legacy EDU





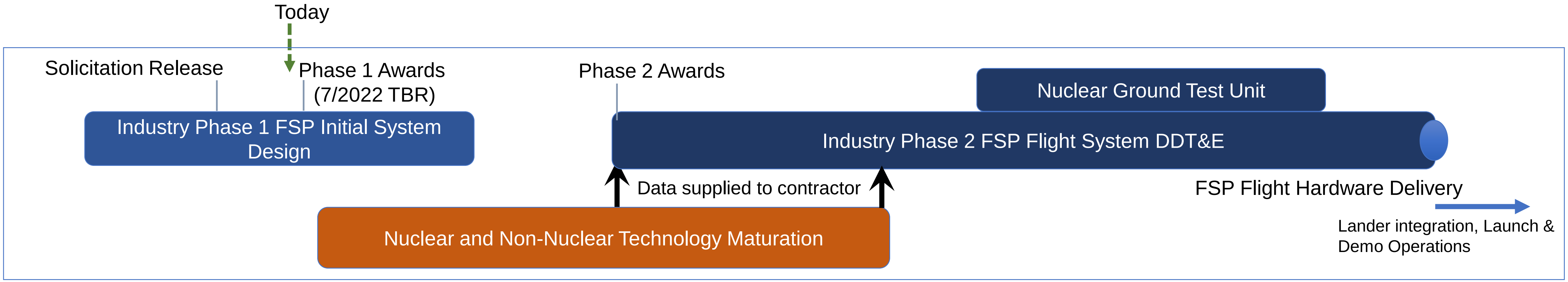
Fission Surface Power System Acquisition Approach 1/2



Two-phase acquisition strategy for development of the space-flight hardware

- <u>Phase 1</u>
  - Selected three contractors; will award three, 12-month efforts for an initial design, $5M each
    - **Lockheed Martin** – partnering with BWXT and Creare
    - **Westinghouse** – partnering with Aerojet Rocketdyne
    - **IX**, a joint venture of **Intuitive Machines and X-Energy** – partnering with Maxar and Boeing
  - Purpose is to show there are viable design options and inform the Phase 2 procurement
  - Planning 3 kick-off meetings,bi-weekly status meetings, interim review, final review, final data package
  - Deliverables include: Design Document, System and Subsystem Requirements and Verification, Interface Requirements, Mass Properties Report, System and Subsystem Drawing Package, Technology Readiness Assessment, Cost and Schedule Estimates for Phase 2

Fission Surface Power System Acquisition Approach 2/2



- <u>Phase 2</u>
  - An independent proposal solicitation, evaluation, and selection process to cover DDT&E, a separate nuclear ground test unit and payload delivery by December 2029
  - There's potential for two contracts with a down-select to one
  - Design & build development H/W and flight unit
  - Approximately 5-year contract for all Phase 2 products
  - The contracts will be managed by INL, with NASA participation
  - Culminates in a flight system delivered to the launch site

Near-term Project Milestones

PROJECT MILESTONE	TARGET DATE	COMMENTS
Award (3) Phase 1 Contracts FSP System Designs	08/2022	3 Contractors selected and publicly announced
Start Nuclear Technology Maturations	08/2022	DOE/INL Plan has been received
Start AMA Tasks	10/2022	
Award Brayton PCS Technology Maturation contract	02/2023 (TBR)	
Receive Interim Reviews from Phase 1 Contracts	04/2023 (TBR)	
Complete (3) Phase 1 Contracts	08/2023 (TBR)	
MCR / SRR	10/2023 (TBR)	Required before the release of the Phase 2 RFP
ASM	12/2023 (TBR)	Required before the release of the Phase 2 RFP
Release Phase 2 RFP - FSP System Development	1/2024 (TBR)	
Award Phase 2 Contract - FSP System Development	10/2024 (TBR)	
Flight Unit Ready for Shipment to Launch Site	**12/2029**	

DOE's MARVEL Reactor
20 kWe Microreactor

- Held informational meeting with the PM for the Microreactor Applications Research Validation and Evaluation (MARVEL) project
- It's a nuclear platform to support development and demonstration of the integration of end use technologies with a small-scale nuclear microreactor
- Idaho National lab started designing and modeling the MARVEL reactor project in June 2020
- The MARVEL design is a HALEU fueled, sodium-potassium cooled microreactor with Stirling engines that will produce 100 kWth being built at Idaho National Laboratory
- MARVEL will be used to: test microreactor applications, develop regulatory approval processes, systems for remote monitoring, and autonomous control technologies
- Its design is primarily based on existing technology and will be built using off-the-shelf components allowing for faster construction
- Project started in 2020; expected to be operational by Dec 2023
- DOE plans connected the reactor to the world's first nuclear microgrid at INL by 2024
    - MARVEL will test and demonstrate the reactor system's capability to manage grid demand and reactor power supply

Comparison of FSP and MARVEL

	Fission Surface Power	Marvel
Thermal Power	240 KW_{th}	100 KW_{th}
Electrical Power	40 KW_{e}	20 KW_{e}
Reactor Cooling	Sodium Heat Pipes	Sodium Potassium
Power Conversion	Stirling	Stirling
Reactor	HALEU, moderated	HALEU, moderated. UZrH
Control	Autonomous, remote	Manual, hardwired
Operational Environment	Lunar Surface	INL Test Facility
Planned Operational Date	> 2030 (TBD)	Dec 2023

Fission Surface Power Summary

- NASA is working with the Department of Energy and their federally funded laboratories to establish a lunar fission surface power system
- NASA's focus is on designing, building, and demonstrating a low enriched uranium fission surface power system that is directly applicable for Moon and Mars, scalable to higher power levels
- NASA will continue to be closely engaged with industry to seek innovative, unique design approached for fission surface power systems

Questions?

Thank-you!