Space Nuclear Power and Propulsion (SNPP)

STMD Space Nuclear Technologies Portfolio, September 1, 2020

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Space Nuclear Technology Overview

The NASA STMD Space Nuclear Technology portfolio within the Technology Demonstration Mission program focuses on advancing nuclear fission technology and system capabilities to meet space exploration missions needs

- Design, build, and demonstrate a space-rated fission surface power system that enables a sustained lunar presence and is directly extensible to future planetary surface missions
- Advance a deep-space, nuclear-propulsion capability through the maturation of key, high-risk technologies that lead to the design, build, and demonstration of a human rated propulsion system
- Establish collaborative, working relationships with other government agencies and organizations that share common, synergistic technology needs such as the DoD and DoE
- Catalyze industry and academic interest and support to enable broad spectrum of innovative and economic technology approaches and solutions

Space Nuclear Technology (SNT) Portfolio Projects

THE SPACE NUCLEAR TECHNOLOGY PORTFOLIO WITHIN MSFC-LED TDM PROGRAM CONSISTS OF TWO MAJOR FISSION TECHNOLOGY INVESTMENT AREAS

Fission Surface Power (FSP)

Solar independent, continuous power production

- Enable sustained, long-duration lunar operations
- Demonstrate operational extensibility to Mars mission

Space Nuclear Propulsion (SNP)

Enable opposition-class, short-duration Mars mission

- Focus for NTP is on fuel and reactor technology maturation
- Identify NEP subsystem capability gaps and needs
- Advance critical CFM technologies needed for SNP

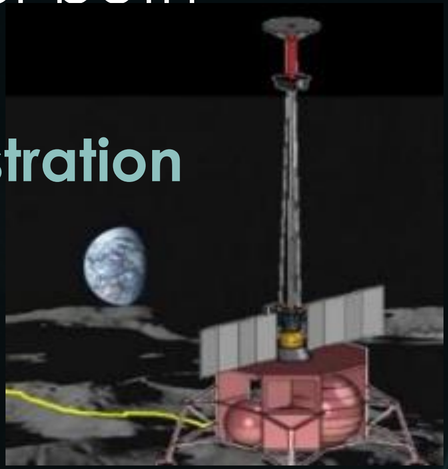
Prioritize lunar surface power while continuing to advance nuclear propulsion capabilities to support future human missions to Mars

Space Nuclear Technology Projects

The Agency is currently engaged in advancing technologies for both propulsion and power fission systems with DOE support

Investment is focused on two Projects within the Technology Demonstration Program managed by Marshall Space Flight Center

- **Fission Surface Power (Todd Tofil, Prj Mngr, GRC)**
  - Low weight reactor with 10 kW dynamic power conversion system
  - Requires near term reactor fuels and materials development
  - Open design and trade space will define 'what' the government needs, design and test qualification identified by industry



Government Reference Design

- **Space Nuclear Propulsion (Mike Kynard, Prj Mngr, MSFC)**
  - High temperature, 500 MW thermal reactor drives high Isp engine
  - Support for a common NASA/DOE/DOD fuel production capability
  - Pursuing a DOE industry solicitation for reactor designs

NTP vehicle concept

Agency reference configuration for Mars architecture is NEP

NASA/DOE MOU Energy-related Civil Space Activities

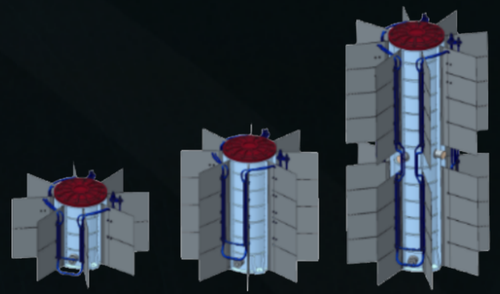
Kick-off at the Mars 2020 Perseverance launch, MOU supersedes a 1992 agreement and establishes interagency Working Groups on Strategic and Innovative Collaborations, Space Nuclear Power and Propulsion (SNPP), and Crewed Lunar Surface Environments

SNPP Working Group provides a forum to collaborate on nuclear research and development areas of mutual benefit and reinvigorate US commercial nuclear industry

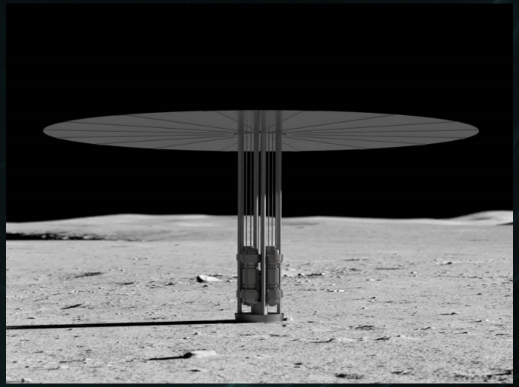
Current NASA/DOE SNPP collaborations fall under an existing 2016 MOU that establishes nuclear safety framework including indemnification

Potential opportunities for collaborative research and development with commercial partners that could benefit the space and terrestrial nuclear systems include:

- ➢ Reactor fuel and materials research and development
- ➢ Additive/advanced manufacturing methods and processes
- ➢ Test and demonstration infrastructure capabilities



Advanced RPS



Fission Surface Power

Fission Surface Power (FSP)

Fission Surface Power (FSP)

"The United States will…**establish a sustainable human presence on the Moon by 2028, and chart a future path for Mars exploration**.

White House Fact Sheet, 26 Mar 2019

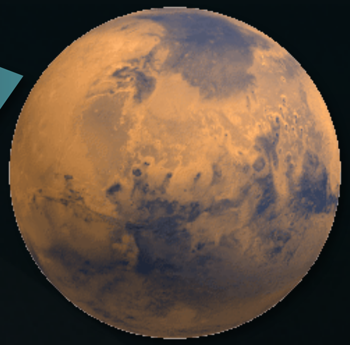
FSP Government Reference Design

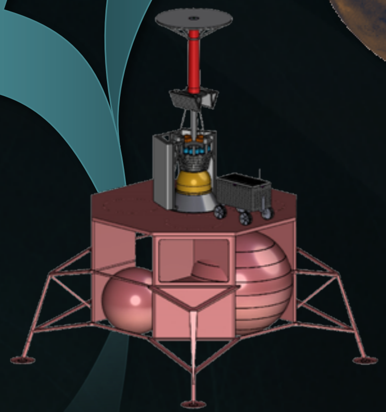
NASA and DOE are collaborating on the development of a 10 kWe-class fission power system for a flight demonstration to the Moon by 2027, with extensibility to human Mars missions.

Fission surface power is the Agency's top nuclear priority

- Enabling capability for lunar sustainable presence and crewed Mars exploration
- 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
- DOE identified moderated HALEU FSP reactors and recently released an RFI for Industry Designs

FSP Integration Story





Lunar Surface Fission Power Demonstration

- Design, fabricate and qualify a launch ready 10 kWe FSP flight unit by late 2020’s
- Flight qualified hardware needed for reactor, power conversion and heat rejection

Lunar Surface Sustainability

- System design to provide dissimilar redundant power for sustained operation
- Concept of operation includes power management system, power cable, cable cart, and avionics

Mars Surface Power Needs

- Nominal 10 kWe power source meets current Mars surface power needs
- Lunar operational needs and performance metrics feed forward to lunar demonstration

DOE reactor study completed in March 2020 identified LEU reactor solutions in same mass class as HEU system

- These are moderated reactors with lower technology maturity but potential alignment with industry

Fission Surface Power Lunar Demonstration

Fission Surface Power System Design

- Power: 10kWe
- Life: 10 year design life
- Modularity: Multi-unit interconnectivity to accommodate higher power
- Distribution: 1km cable cart + conditioning box
- Radiation: ~5 rem/yr @ 1 km (fission source) requires cable cart

Fission Surface Power Project Status

- Current government reference design calls for a moderated LEU reactor with a Stirling power conversion system has an estimated launch readiness date in 2028
  - Risk reduction activities are needed for moderated reactor and a 1 kWe space-rated Stirling power conversion unit
- Request for Information issued on July 23rd in partnership with DOE seeking industry designs for a FSP full system
  - DOE led acquisition provides security, safety, and indemnification framework
  - Mass of cable could be traded against source radiation exposure
  - Upper mass limit may be traded with higher power output range
  - Still considering opportunity for cost sharing with industry

Industry FSP System Design Solicitation

Provides opportunity to explore Innovative design approaches for FSP system

- ➢ Leverage industry approaches to design and operational reliability
- ➢ Identify path leading to a test qualified flight unit by December 31, 2026
- ➢ Identify technology maturation needs, development risks, subsystem tradeoffs
- ➢ Identify approach to ground testing and nuclear safety
- ➢ Forum for partnering relationships between aerospace and nuclear industries

Industry Day was held August 20, 2020 (virtual)

- ➢ Included talks from James Reuter (STMD), Dr. Rita Baranwal, (DOE), Aaron Miles (OSTP), and Ryan Whitley (NSpCI)
- ➢ Open Discussion and One-on-One Industry /Government Sessions

- ✓ Over 180 online participants
- ✓ Extended open discussion
- ✓ Setting up web site for partnering

- ✓ Twelve industry 1-on-1 sessions
- ✓ BWXT, GA, Lockheed, TerraPower, Blue Origin, Aerojet Rocketdyne, etc.

- ➢ **Phase 1 RFP release October 2020 → Preliminary Designs by December 2021**
- ➢ **Phase 2 RFP release January 2022 → Flight unit design, test and launch ready by 2027**

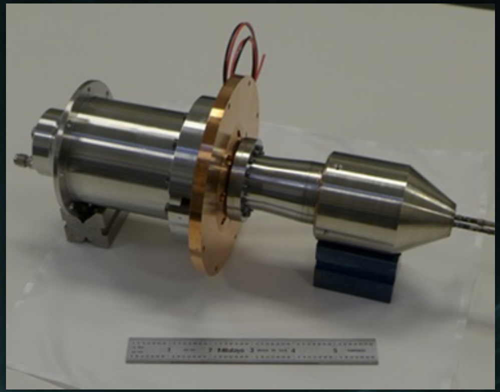
FSP Technology Maturation Initiatives

- Advance moderated HALEU reactor design TRL (3/4-6)
  - Technology developments are related to the moderator life testing and qualification

- Advance Non-nuclear reactor sub-system assembly TRL's (3-5)
  - Design, test and qualify central shutdown rod mechanism
  - Develop thermal and mechanical core-to-heat pipe bonding
  - Design, fabricate and qualify neutron and gamma shield;
  - Design, fabricate, and qualify multi-layer insulation

- Advance Stirling converter/controller TRL 4–6:
  - Development of a 1 kW class converter and controller focused on robustness

1,000 watt Stirling

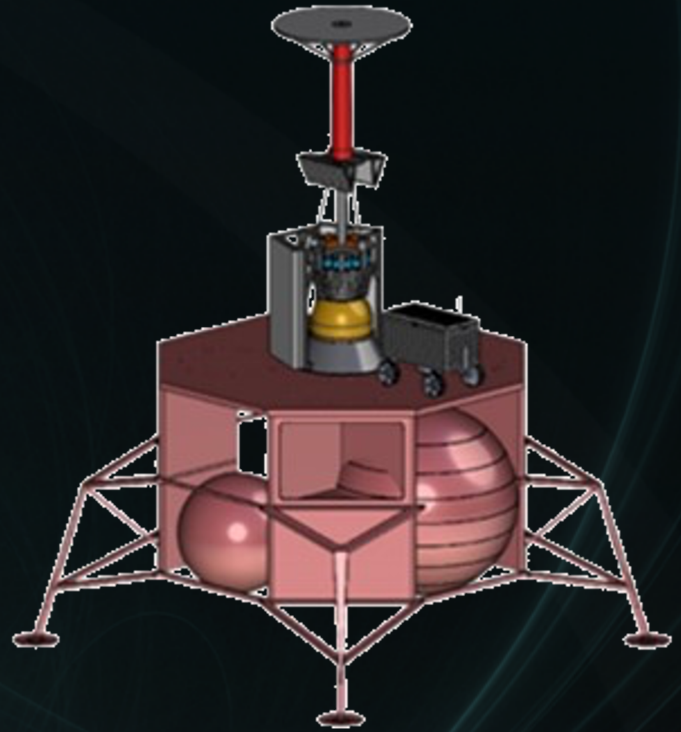


Modified 80 W Stirling convertor with electric heater

FSP Technical and Programmatic Challenges

Challenges

- Commercial alignment of industry
- Integration/alignment with government design
- Secure funding profiles needed to support flight unit development, design, and build
- Definition of human reliance rating for system operational reliability
- Commonality/synergy with future, higher power fission power system needed for ISRU and NEP/Chem
- Coordination of design capability/flexibility and extended lunar concept of operations



FSP concept on a Blue Moon Lander

Space Nuclear Propulsion (SNP)

Space Nuclear Propulsion

STMD current nuclear propulsion technology investment remains focused on NTP, and planning meetings are examining NEP subsystem maturation requirements.

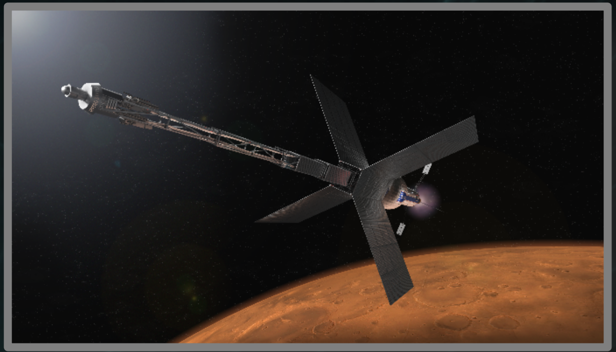
Nuclear Thermal Propulsion System

- Isp estimates are driving reactor temperature to exceed 2900 K
- Primary focus is fuel and reactor technology maturation
- Leveraging common NASA/DOE/DOD fuel production capability
- Strong DOE collaboration with SME and testing support
- Engaged with industry and current solicitation for reactor support
- Advance CFM capabilities needed for NTP systems

NTP vehicle concept

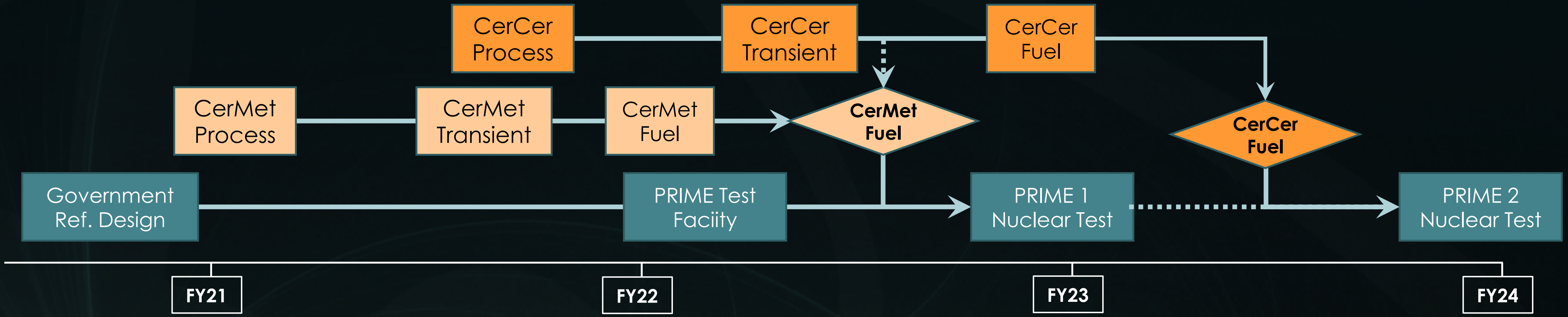
Nuclear Electric Propulsion System

- Current Agency reference configuration for Mars architecture
- Coordinating FY20-21 strategy and planning meetings to identify technology requirement leading to an implementation plan

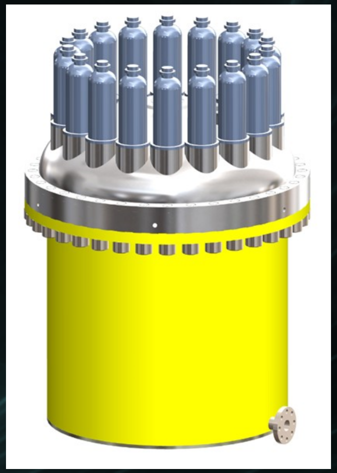


NEP vehicle concept

NTP Fuel and Reactor Development



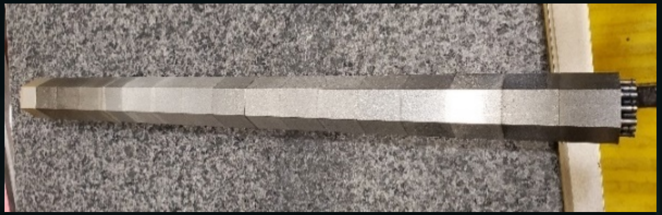
- Project primary focus for the next three years is to develop a high-temperature HA-LEU fuel form moderator-block reactor design
  - Moderator block accommodates UN to UC fuel transition plans and has flight with the Russian Topaz reactor
  - Building-block strategy to fuel development is key to maturing critical technology path
    - Optimizes ability to advance fuel fabrication capability and reactor design simultaneously
    - Primary development of 900 sec Isp refractory metal fuel (CerMet) with later transition to >950 Sec Isp ceramic (CerCer) fuel
    - Baseline chemistry is UN with concurrent, accelerated development of carbide chemistry



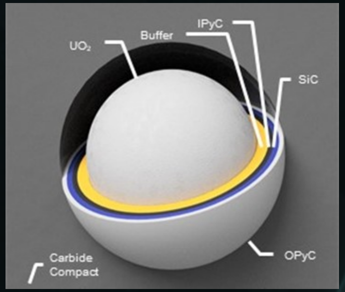
HALEU Reactor Concept

Nuclear Thermal Propulsion Development Status

- Baseline government reference reactor design is a moderator block using a sintered solid-core fuel column
  - Design approach uses spark-plasm sintering to obtain a solid core fuel wafer and has shown to ability retain kernel coating structure
  - Thermal testing in March 2020 and July 2020 demonstrates robust fuel form and fuel column manufacturing methods for 900 sec Isp system
- NASA/DOD-SCO fuel production partnership awarded to BWXT
  - Accommodates AGR TRISO and coated-carbide particle fuel production
  - Kick-off meeting was held in July 2020 and first fuel production is planned for early FY22
- Flight Demonstration Study for 900 sec Isp reactor designs completed in July 2020
  - Eight week extension narrowed design revisions to NASA MSFC engine balance requirements
  - Reactor designs provided by BWXT, USNC, X-Energy, and General Atomics ranged from moderator block to Rover/NERVA design approaches
  - Independent review team assessed strengths, weaknesses, opportunities, and risks for each design



Successful fuel column test specimen



Coated particle fission fuel

Nuclear Thermal Propulsion Industry Solicitation

- The proposed reactor designs will use high assay low-enriched uranium and produce a hydrogen propellant outlet temperature of at least 900 seconds Isp for a 12,500 lbf subscale engine
- Draft RFP was released through DOE/INL on 8/7/2020 and comment period closed on 8/21/2020
- Final RFP is expected to be released before the end of September 2020
- Industry analyses and data products need to demonstrate proposed design will meet performance requirements, and must identify quality assurance requirements that will be applied during fabrication and testing of the reactor system

Base **2-4 Contracts**	**Option 1** **1-2 Contracts**	**Option 2** **1 Contract**
Reactor Preliminary Design (30% Design Review)	Reactor Detailed Design (90% Design Review)	Reactor Final Design (Fabrication, Build, and Integration)
CY 2021-22	**2022-2026**	

Fuel Development Nuclear Testing with Idaho National Laboratory

Nuclear Transient Test - 2
UN cermet & UC cercer
Currently running at INL

Purpose: Investigate impacts of temperature ramp rate and operating temperature on CerMet and CerCer fuel

Specimen Geometry: Single hexagonal wafer, angular uncoated fuel, 19 flow channels, no flow tubes

Environment: Static safe gas

Nuclear Transient Test – 3
UN cermet
July, 2021

Purpose: Investigate impacts of temperature ramp rate and operating temperature on subscale fuel column

Specimen Geometry: subscale fuel column length, unbonded circular wafers, uncoated angular fuel kernels, 7 flow channels, unbonded Mo flow tubes

Environment: Static safe gas

PRIME – 1
UN cermet, flowing hydrogen
July, 2022

Purpose: Investigate interactions of fuel and moderator in flowing hydrogen

Specimen Geometry: half-scale unbonded circular wafers in prototypic reactor fuel column with moderator and thermal management materials, CerMet coated spherical fuel kernels, 7 flow channels, bonded Mo flow tubes

Environment: Flowing hydrogen

PRIME –2
UN cercer, flowing hydrogen
July, 2023

Purpose: Investigate integrity of fuel + moderator unit cell in flowing hydrogen

Specimen Geometry: half-scale fuel column with un-bonded circular wafers in prototypic reactor fuel column with moderator and thermal management materials, CerCer coated spherical fuel kernels, 19 flow channels, bonded Mo flow tubes

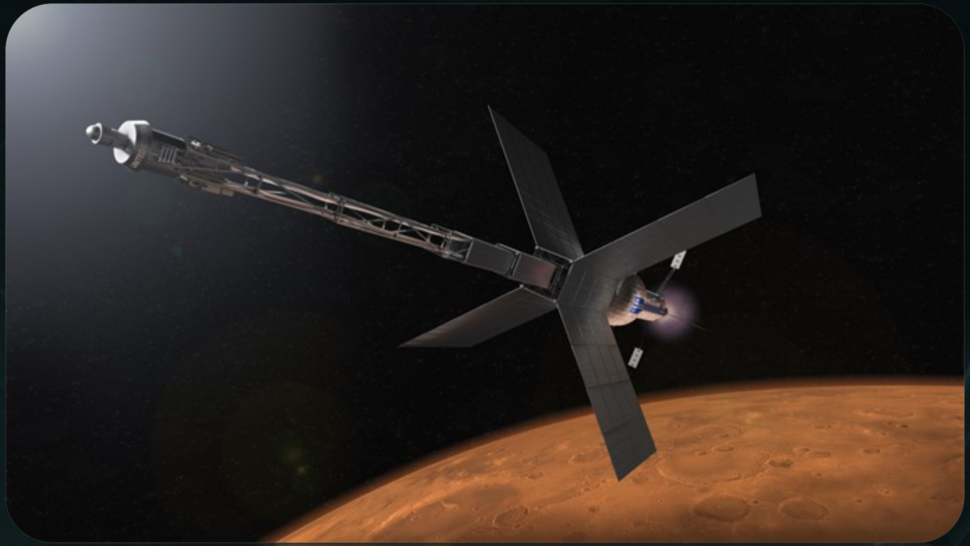
Environment: Flowing hydrogen

NASA funding and teaming with INL to add flowing hydrogen capability to the TREAT reactor for the Prime 1 & 2 test series

[redacted]

Nuclear Electric Propulsion

- In conjunction with MTAS and Agency NEP reference configuration for Mars architecture, SNP project office will coordinate an effort to identify state of the art for key subsystems, technology gaps, infrastructure needs, programmatic schedule and risks from a project implementation perspective
- Key implementation considerations include:
  - Reactor
  - Power Conversion
  - Heat Rejection
  - High-output Hall Thruster Development
  - Methane Engine Development
  - Infrastructure (testing, propellant production, etc.)



- Goal is to deliver a draft project development plan (scope, cost, schedule) consistent with accomplishing the NEP/Chemical Stage combination vehicle by mid FY21
- SNP project office is planning a "state of things" meeting in September 2020

NESC Review NTP and NEP Final Report

- Performed an independent assessment of the technical maturity and gaps for NTP and NEP/Chem propulsion systems
- Mission-agnostic assessment provided system and component evaluations that are independent of specific architectures
- Assessment focused on in-space, orbit-to-orbit transportation elements with a grounding assumption that technology must be qualified and launch ready by 2035
- Evaluations included Technology Readiness Level (TRL), Advancement Degree of Difficulty (AD2), Schedule Stoplight (G,Y,R), and binned Cost Metrics
- Four primary technology groups were evaluated
  - NTP/NEP Reactors and Fuels, NEP Auxiliary Systems, Cross-Cutting Technologies
- Majority of critical technologies for both propulsion systems are immature and at a high level of advancement difficulty
- Most of the assessed technologies could be matured to support launch readiness by 2035 given a dedicated, highly focused, and robust funded program

Mars Transportation Architecture Study (MTAS)

Foster an objective understanding of in-space nuclear propulsion systems as it relates to mission performance and assess capabilities essential to the development of system advancements that can be used to guide both policy and technology investment decisions

- MTAS 1.1 (2035 opposition class mission, NRHO staging, 2 SLS launches/year)
  - Nuclear fuel and reactor development for both NTP and NEP/Chem are the most challenging technologies with the long lead-times
  - Long-term cryogenic fluid management and storage is a critical technology development, particularly for NTP which requires liquid hydrogen
  - NEP/Chem requires fewest launches and is considered feasible but challenging
  - NRHO is not an optimal staging condition for the higher thrust NTP system and drives up Isp requirement
  - NEP system is complex and subsystem integration needs successful demonstration
- MTAS 1.2
  - Determine architecture needs consistent with technical capabilities for each system

National Academy of Sciences Assessment of NTP & NEP

- **A committee convened by the National Academy of Sciences will assess both NTP and NEP with respect to:**
  - Key technical and programmatic merits, challenges, and risks
  - Top-level development and demonstration roadmap with key milestones
  - Space exploration missions that could be enabled
- **Study timeline:**
  - A series of 13 weekly or biweekly 3-hour meetings; 5 meetings with public sessions)
  - 1st meeting: May 18; Last meeting: Sep 21
  - Report released Spring 2021
- **Speakers at public sessions:**
  - NASA
  - Idaho National Laboratory
  - Los Alamos National Laboratory
  - Aerojet Rocketdyne
  - Aerospace Corp
  - GA Tech
  - BWX Technologies
  - Ultra Safe Nuclear Technologies
- **Committee membership**
  - Roger Myers, R Myers Consulting **(co-chair)**
  - Robert Braun, JPL **(co-chair)**
  - Shannon Bragg-Sitton, INL
  - Jonathan Cirtain, BWX Technologies
  - Tabitha Dodson, DARPA
  - Alec Gallimore, U Michigan
  - James Gilland, Ohio Aerospace Institute
  - Bhavya Lal, IDA/Science and Tech. Policy Institute
  - Parviz Moin, Stanford
  - Joseph Sholtis Jr, Sholtis Eng & Safety Consulting
  - Steven Zinkle, U Tennessee Knoxville

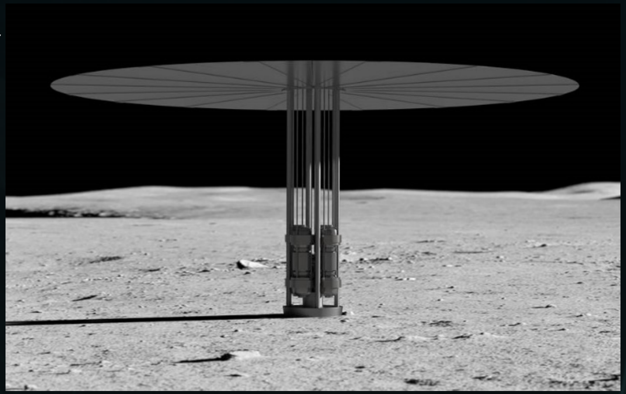
SNP Technical and Programmatic Concerns

Challenges

- Fabrication and testing of high temperature composite fuel columns and reactor materials looking at UN/W-Mo cermet system and UC/ZrC cercer system to meet operational temperature (Isp) and neutronic requirements
- Focus is on developing a subscale (12,500 lbf) engine that can be ground or flight tested
- Both propulsion and power projects are working together to identify safety, licensing, and regulatory requirements
- PRIME test series will provide confidence high temperature requirements can be met, however, a cost-effective means to perform a full systems test through a ground or flight demonstration remains a near-term, critical need
- Schedule for NTP - NEP/Chem trade studies and decision on path forward has the potential to delay test demonstration

Summary

The NASA STMD Space Nuclear Technology portfolio has made good progress in FY 2020 to align investments for nuclear power and propulsion with implementable plans possessing achievable goals within realistic timeframes to meet NASA mission needs



- FSP is actively seeking innovative industry solutions for a fission power capability that can align with commercial interests and can meet a launch readiness date as early as 2027 for a lunar surface demonstration mission
- SNP will engage industry reactor designers as a integrated team members critical to advancing the design, build, and demonstration of a engineering-relevant subscale NTP engine
- SNP is supporting ongoing Mars transportation architecture studies, the NEP reference configuration for Mars, and will adjust as necessary to accommodate Agency priorities
- SNT portfolio projects have working relationships with DARPA, DOE, and DOD and are identifying investment areas of common interest