EXPLORESPACE TECH

TECHNOLOGY DRIVES EXPLORATION

NASA Advisory Council Technology, Innovation, and Engineering (NAC TI&E) Committee

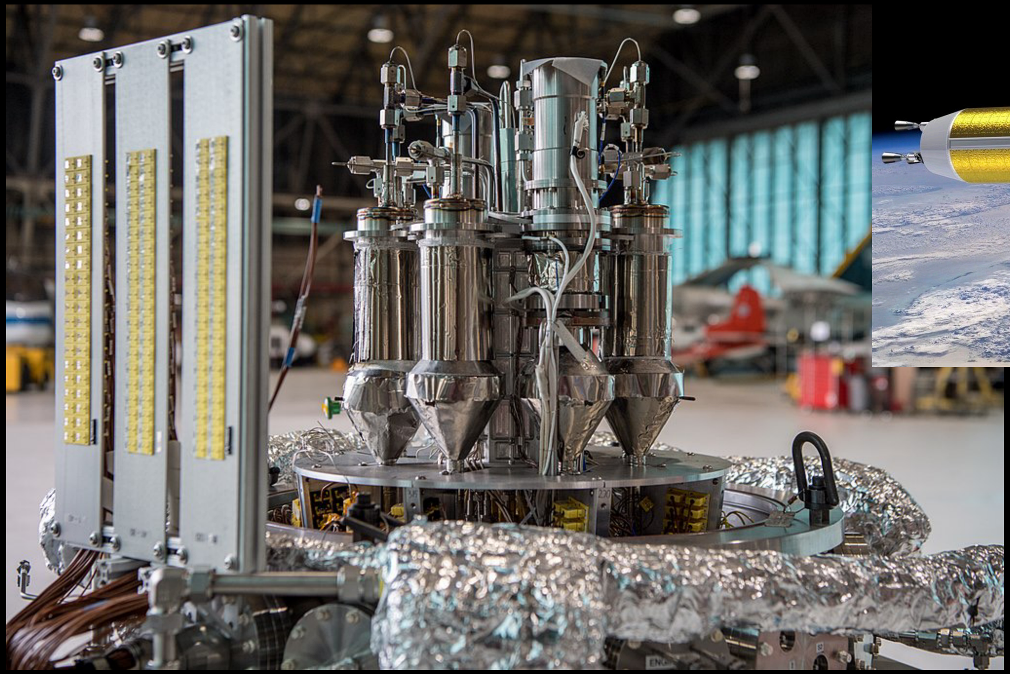
Dr. Anthony Calomino | Space Nuclear Technology Portfolio Manager | December 14, 2021

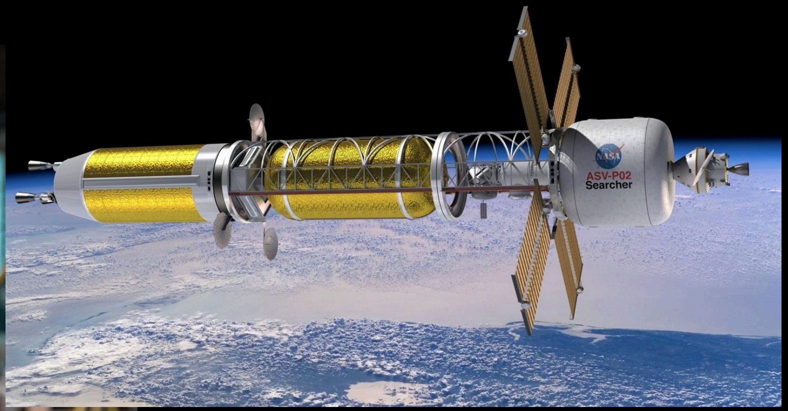
Space Nuclear Technologies

- Reliable energy production is essential to human and scientific exploration missions
- Nuclear enables higher energy systems that operate continuously in extreme environments
- NASA seeks synergy and collaboration with industry, other government agencies, and academia

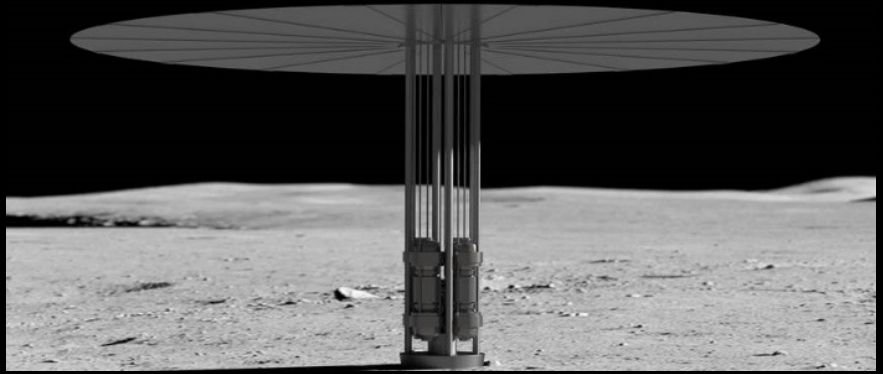
Benefits:

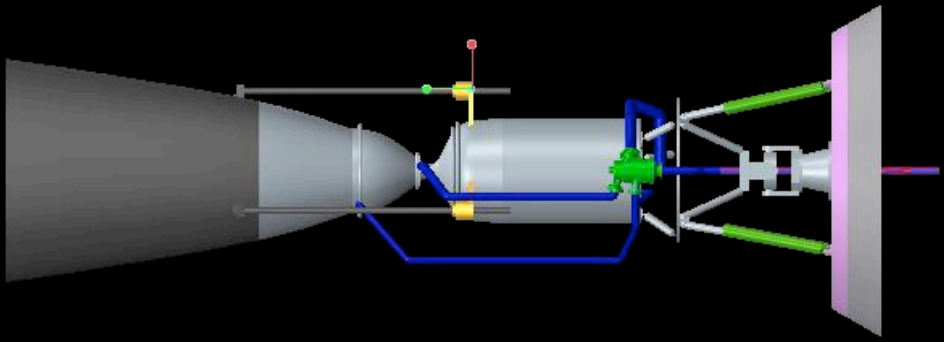
- ✓ Space Leadership
- ✓ National Security
- ✓ Global Competition
- ✓ Domestic Economy
- ✓ Green Energy





Space Nuclear Fission Technology Portfolio





- **Fission surface power**
  - Enable sustained, long-duration lunar operations
  - Establish an evolvable system for the Moon and Mars
- **Space nuclear propulsion**
  - Advance a fast transit, in-space, nuclear propulsion capability
  - Evaluating nuclear thermal and electric propulsion options

NASA's priority is surface fission power for lunar operations

NASA and DOE are working together to develop low-enriched uranium solutions

Mission Comparison of NEP and NTP Capabilities

NESC conducted a mission-agnostic assessment of critical technology maturities and gaps

- Key sub-system capability needs for both NEP/Chem and NTP were assessed to have comparatively equal levels of technology maturity and difficulty of advancement

Mars Transportation Architecture Study for a 2039 mission

- NEP architecture requires less mass and significantly fewer flight assembly launches and is the preferred technology pathway for NASA

National Academy Study on Systems Capability for a 2039 mission

- Majority of the technologies needed for both systems need aggressive development to meet a 2039 Mars mission, and reactor development considered most challenging

NEP is the Agency baseline propulsion system for the Mars human exploration architecture

National Academy of Science, Engineering, and Medicine

Finding 1: A significant amount of characterization of reactor core materials, including fuels, remains to be done before NASA and DOE will have sufficient information for a reactor core design

> **Agree:** NASA, DOE and DOD are actively pursuing a multidisciplined approach to fuel and moderator development to realize a suitable high-temperature fuel that operates at the required temperatures

Finding 2: Long-term liquid hydrogen storage is required at 20 K for NTP baseline missions

> **Agree:** NASA is making significant investments in key technologies including insulators, coatings, and high-capacity cryocoolers capable of refrigeration at 20 K and 90 K to enable two-stage, broad-area cooing to minimize boil-off

Finding 3&4: Modeling & Simulation, Ground and Flight Testing: Subscale in-space flight testing cannot replace full-scale ground testing; with sufficient M&S *and fully integrated system ground testing*, flight qualification requirements could be met by cargo missions

> **Agree:** Mars architectures leverage cargo missions as integrated system demonstrations supported by modeling, simulations, and ground testing. NASA believes extensive ground and flight testing will be required for any for any human-rated system

National Academy of Science, Engineering, and Medicine

Finding 5: NTP program success - an aggressive program could develop an NTP system capable of executing a baseline mission by 2039

Agree: NASA is pursuing solutions to technology challenges for reactor development, hydrogen propellant storage, ground testing, and reactor modeling and simulation

Finding 6: Developing a MWe class NEP system requires orders of engineering scale increase, due to low historical investment, it is unclear if even an aggressive program will be able to develop an NEP system capable of executing baseline mission by 2039

Agree: Significant advancement of the readiness for key technologies has not been completed and recent plans for initiating a maturation effort are being formulated that will leverage existing SEP capabilities, and advance investment within the government and industry to buy down risk and schedule

Finding 7: Apples-to-apples trade studies comparing NEP and NTP systems for a crewed Mars mission in general, particularly the 2039 baseline mission, do not exist

Agree: NASA is completing a report on Mars Transportation Architecture Study that compared mission requirements for both systems, but disparity in NEP technology investment increases the uncertainty in the projected capability and efforts are needed to align with the fidelity for NTP

National Academy of Science, Engineering, and Medicine

Finding 8: Given NEP/NTP key commonalities for significant technology maturation – development work can proceed independently of the selection of a particular space nuclear propulsion system

Agree: Though operating conditions differ for NEP & NTP, both can leverage current investments to advance fission fuel, moderator materials, manufacturing methods, shielding, testing, and modeling

Finding 9: Enrichment of Nuclear Fuels - a comprehensive assessment of HA-LEU vs HEU for NTP and NEP systems

Disagree: NASA's goal is to have the industry engagement and commercial support offered by a LEU technology approach, and recent National policy changes provided in NSPM-20 and SPD-6 impose significant approval requirements on the use of HEU that clearly limit the application of HEU

Finding 10: Synergies with Terrestrial and National Defense Nuclear Systems

Agree: Significant commonalities exist between SNP and compact terrestrial systems (DOD SCO's "Pele" and some industry concepts) and the DARPA DRACO program; NASA's close coordination and collaboration with key agency partners can benefit both NEP and NTP system development

Interagency Engagements

DOD/SCO – Pele' Mobile Terrestrial Power Plant

Partnership to establish commercial source for coated fission fuel and participation in reactor design activity

DARPA – DRACO NTP Flight Demonstration

Integrated teams support proposal evaluations, contract management with leveraged investment in cryogenic fluid management, reactor technology, and turbine machinery

USSF – Space Nuclear Systems Capabilities

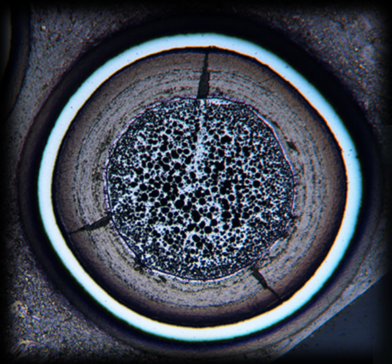
Hold joint meetings to identify technology synergies and investment opportunities

DIU – Low Kilowatt In Space Nuclear Power

Support for evaluation of nuclear electric propulsion proposals with low power reactor investments

DOE – Nuclear Authorities and Technology Expertise

Integrated teams to mature HA-LEU reactor technology, database development, modeling, and advanced testing



Federal Policy and Processes

NSPM-20
Updates launch approval process and establishes quantified risk levels

SPD-6
Defines national strategy for use of space nuclear power and propulsion systems

Nuclear Regulatory Commission

Department Of Transportation

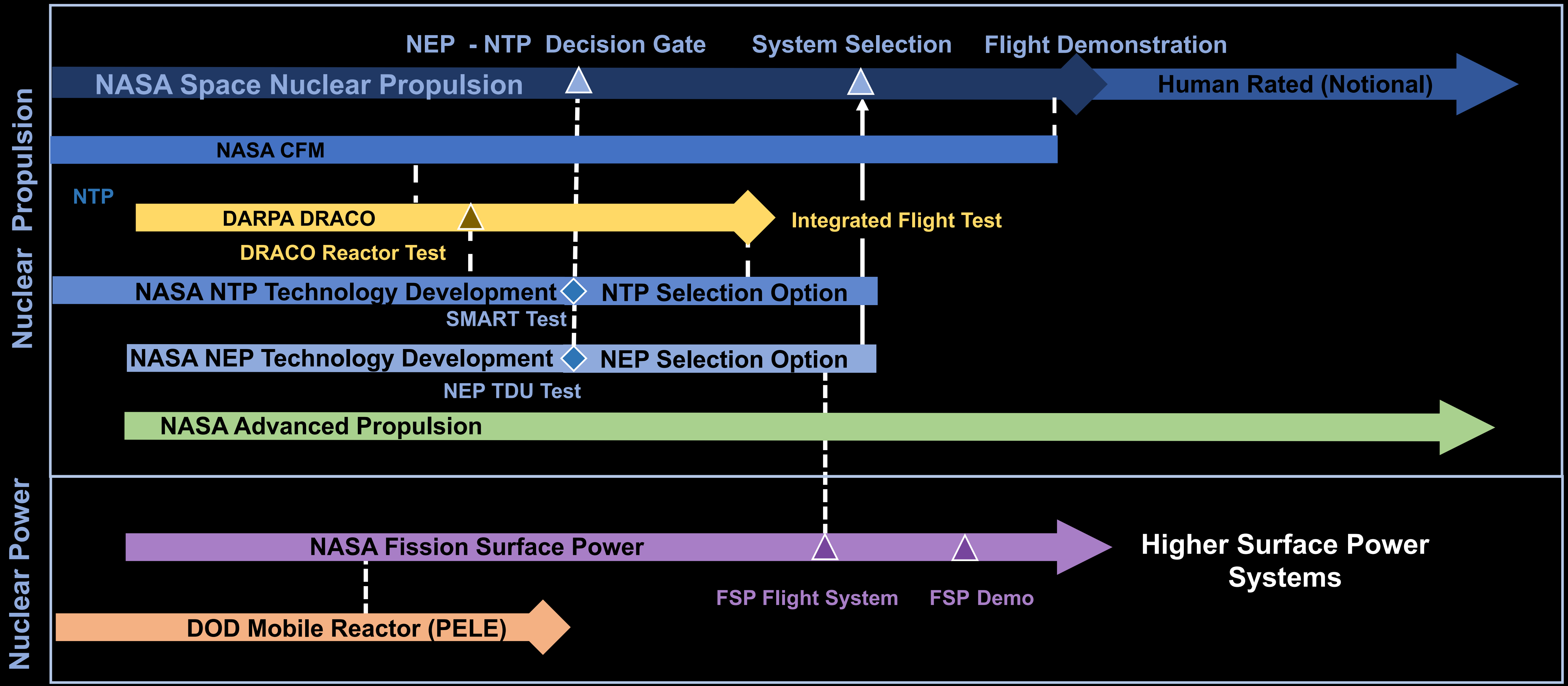
OSTP/NSTC
Integrated implementation of SPD-6 and EO 13972 with integrated interagency roadmap

Defines:

- ✓ Agency launch authority
- ✓ Interagency reviews (INSRB)
- ✓ Use of HEU for SNPP
- ✓ Commercial launch process
- ✓ Process for interagency roadmap

EO 13972
Directs NASA to utilize **common nuclear systems for exploration missions through 2040**

Preliminary Space Nuclear Fission Systems Roadmap

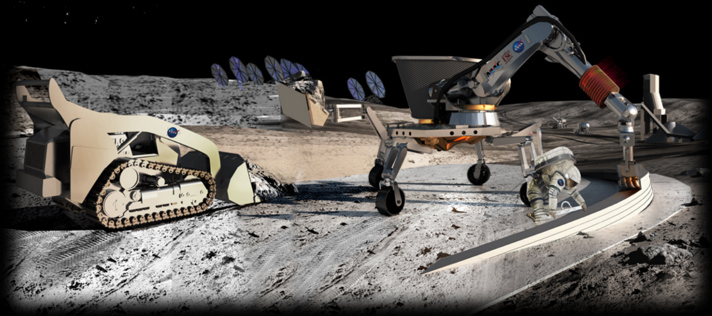


Plan enactment requires sustained commitment and substantial investment over the next 10-20 years

Fission Surface Power

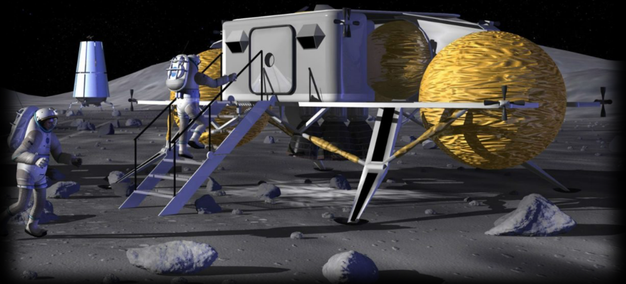
- Power: 40 kWe with technology extensible to higher power
- Mobility: Capable of being transported on a rover
- Size: Capable of fitting on a large lander
- Mass: Capable of fitting on a large lander

Surface Operations



ISRU Operations

Habitat Operations



FSP industry solicitation released November 18, 2021
Two phase acquisition strategy for industry solutions:

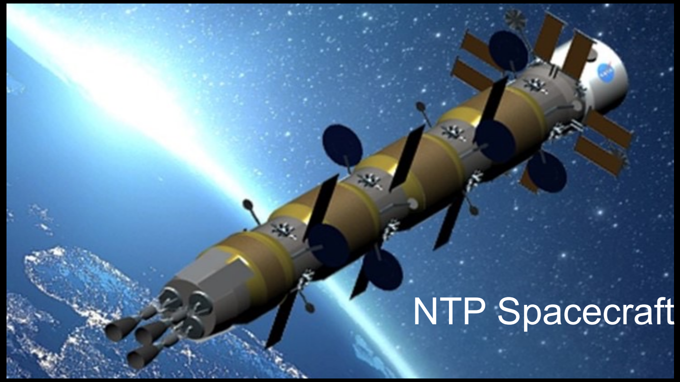
- Phase 1: Three 12-month efforts for a preliminary design
- Phase 2: System design, build, test, and delivery

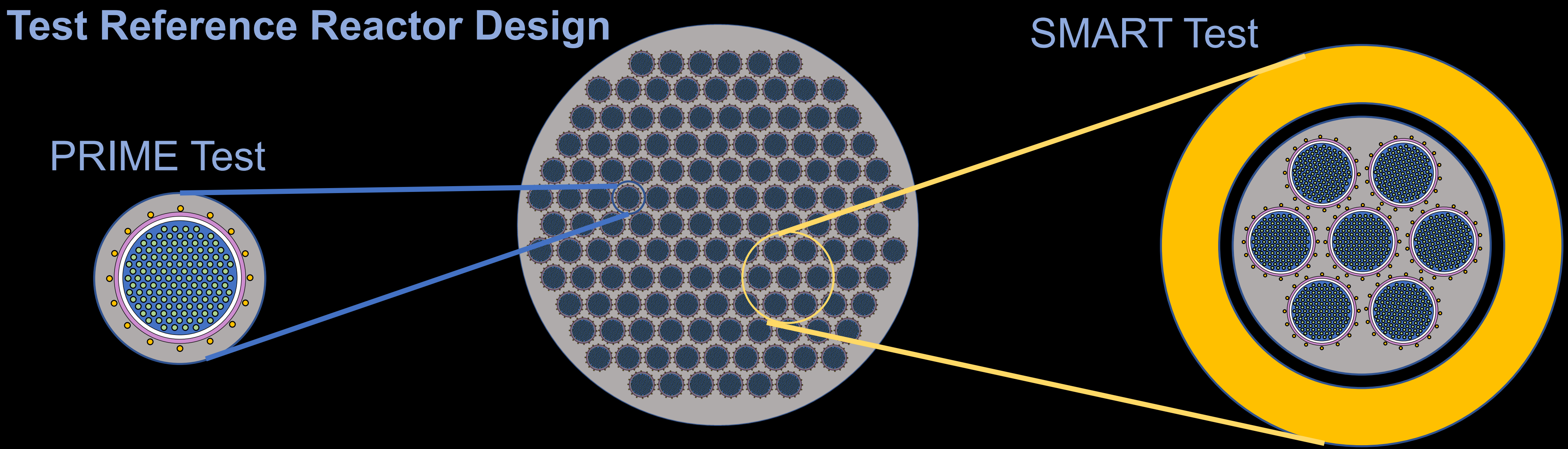
Nuclear Thermal Propulsion

Nuclear reactor provides high propellant efficiency (900 sec Isp) high thrust (25,000 lb)

NTP technology maturation plan considerations

- Multi 100-megawatt, high-assay, low enriched uranium reactor
- Extreme temperature HA-LEU reactor designs
- Reactor fuel, materials, and manufacturing
- Integrated engine design, build and demonstration





Fuel and Reactor Maturation Testing

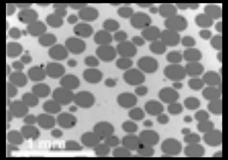
- Design-independent reactor risks identified and addressed with government Test Reference Design concept and test assessments capabilities

1) Fuel and Moderator Development

Assess performance at prototypic conditions during steady--state operation and start-up transient characterized to satisfy reactor mission lifetime

Coated Kernels

Solid Core Fuel



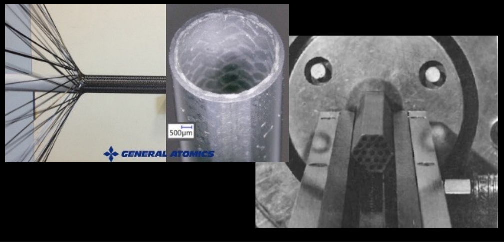
Moderator

2) Manufacturing Demonstration

Demonstrate new manufacturing processes proposed to enable a reactor through fabrication of representative design elements

Fuel Wafers

Flow Tubes and Fuel Elements



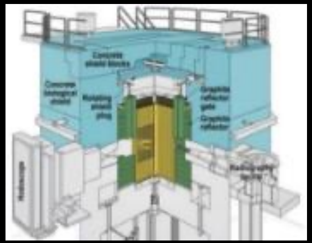
3) Nominal and Off-nominal Reactor Operation

Demonstrate the engineering functionality of representative design elements through combined thermal and nuclear loads testing to increase confidence

CFEET

NTREES

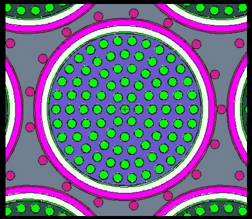
TREAT



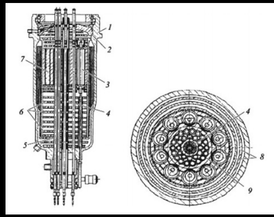
4) New Test Methods and Facilities

Modify existing facilities to enhance prototypical test capabilities and identify new, high-value test facilities that may be needed to reduce design risks

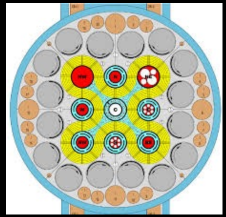
Representative Unit



Flowing Hydrogen/TREAT



SMART



Nuclear Thermal Propulsion Reactor Design

NASA selected three industry reactor preliminary design efforts in August 2021

- ✓ Preliminary design of a 12,500 lb, 900 sec Isp, HA-LEU powered reactor with a mass of less than 3500 kg
- ✓ Demonstrate design feasibility, manufacturability, and scalability

BWXT
BWX Technologies, Inc.

BWXT joined with Lockheed Martin, and Aerojet Rocketdyne are pursuing a metal hydride moderator block design with cercer fuel

USNC
ULTRA•SAFE•NUCLEAR

USNC partnered with Blue Origin, General Electric and Framatone are designing a beryllium moderator block reactor using cercer fuel

GENERAL ATOMICS
ELECTROMAGNETICS

General Atomics teamed with X-Energy and Aerojet Rocketdyne propose to design a ggraphite stabilized fuel particle reactor that builds on Project Rover

Space Nuclear Technology Accomplishments

Fission Surface Power

- Established a HA-LEU government reference design to guide technology and design decisions
- Completed power conversion system and power transmission studies
- Released Phase I request for proposal to industry for industry-led designs
- Completed power conversion technology maturation SOW with planned release in December 2021

Space Nuclear Propulsion

- Successfully fabricated and tested cermet fuel element feature design
- Awarded three Phase I industry design awards with kick-off in September 2021
- Completed critical design to integrate flowing hydrogen in the INL TREAT facility
- Completed ground site studies for potential modified open-air test of subscale engine