National Aeronautics and Space Administration

Nuclear Electric Propulsion

Space Technology Mission Directorate
Space Nuclear Propulsion
Dr. Kurt Polzin, SNP Chief Engineer | 9/5/2024

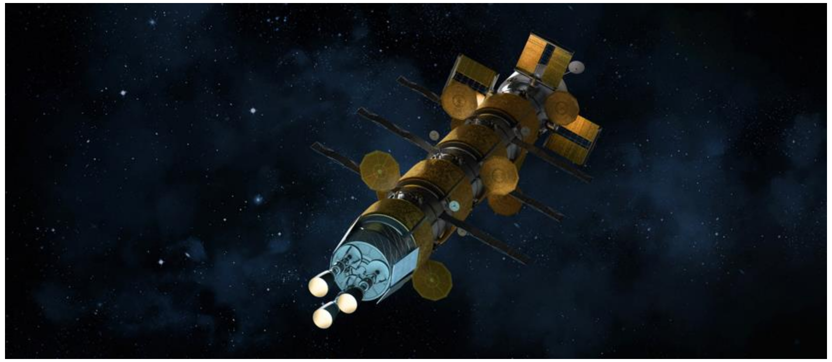
NASA Space Nuclear Propulsion (SNP)

Overview

Vision

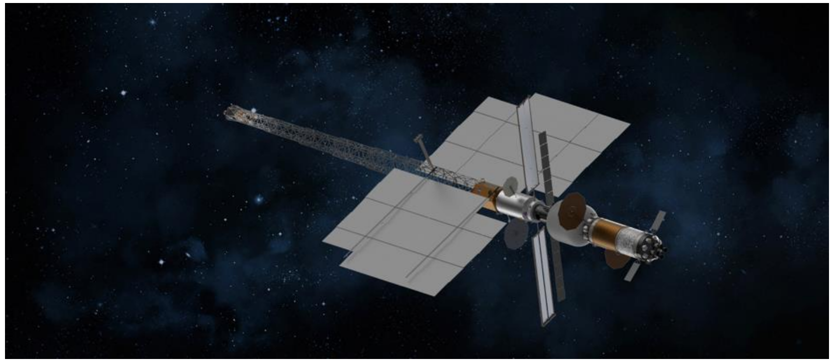
Robust and enduring access to destinations throughout the solar system

Space Nuclear Propulsion is an enabling capability



Nuclear Thermal Propulsion (NTP)

Nuclear Electric Propulsion (NEP)



Why Nuclear Propulsion?

Crewed Interplanetary Missions

- Reduced transit times and exposure to space hazards (space radiation, microgravity, prolonged confinement)
- Increased robustness: larger launch windows, more abort and contingency opportunities

Next-Generation Science Missions

- Maximize payload, enable more science at the destination
- Increased power capability to enabling more science
- Reduced mission times – achieve objectives sooner

Space Nuclear Propulsion Mission Spaces

Orbital Transfers, Loitering, and Maneuvering

Cis-Lunar Maneuvering and Transportation

Deep Space Exploration and Science

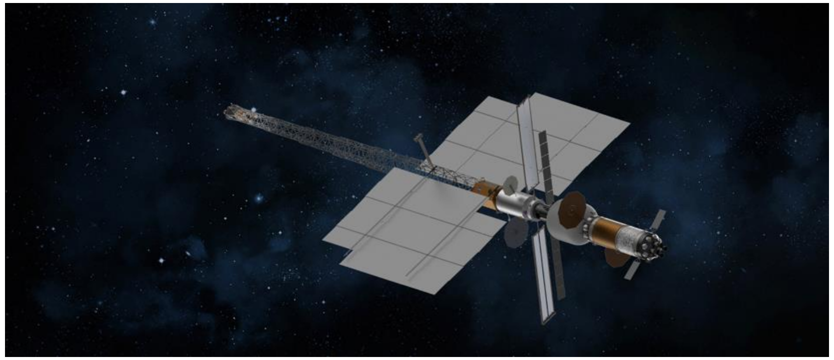
Mars Cargo and Crew Transit

Nuclear propulsion has great potential for a number of missions and applications

Challenges for Nuclear Electric Propulsion (NEP)

The need for coordinated, realistic technology maturation

For high-power NEP



NASA Engineering & Safety Center Findings[1]

- The majority of critical technologies for NEP systems are relatively immature.
- TRLs in the literature are often overestimated and a proper baseline assessment to gauge resources required for advancement has been a consistent issue.
- The majority of critical technologies are at a relatively high level of advancement degree of difficulty (AD2 > 4) for maturation, strongly suggesting use of a dual development approach.
- Non-advocate reviews should occur at the start of a technology program and at all key milestones.

National Academies of Science, Engineering, and Medicine Findings[2]

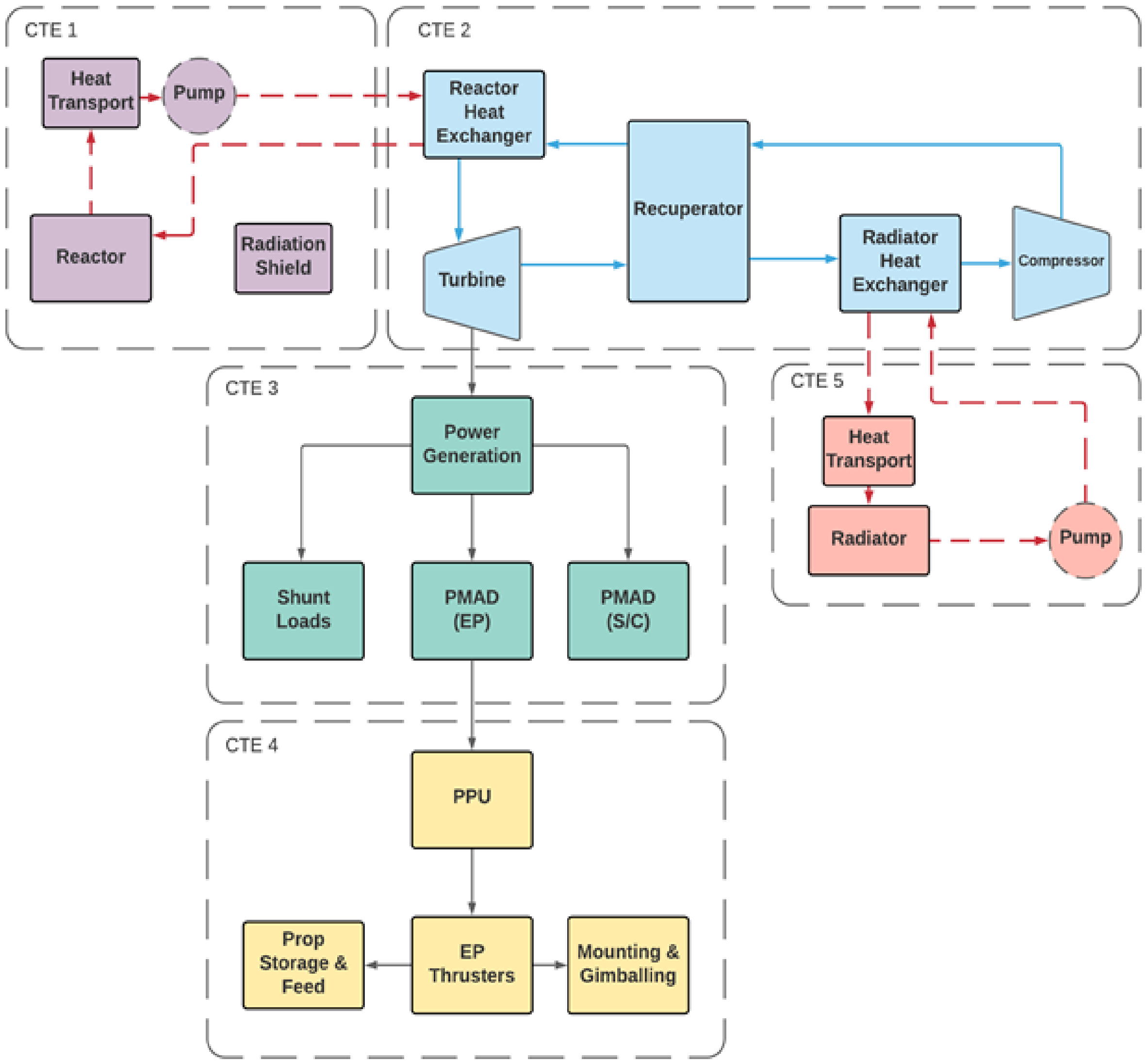
- For NEP systems, the fundamental challenge is to scale up the operating power of each NEP subsystem and to develop an integrated NEP system suitable for the baseline mission. This requires, for example, scaling power and thermal management systems to power levels orders of magnitude higher than have been achieved to date.
- There has been, low, intermittent, and unfocused investments over the past several decades
- Regarding Hall thrusters and scaling to 100 kW_e thrusters: "… although ground testing of high-power Hall thrusters has revealed that interactions between the test facility, the thruster, and its conducting plasma plume can impact the performance and lifetime measurements in ways that are not fully understood as of this writing."

[1] *Independent Assessment of the Technical Maturity of Nuclear Electric Propulsion (NEP) and Nuclear Thermal Propulsion (NTP) Systems*, NASA Engineering & Safety Center, 2020

[2] *Space Nuclear Propulsion for Human Mars Exploration*, National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., 2021. DOI: 10.17226/25977

There are recognized challenges to developing an NEP system

Nuclear Electric Propulsion (NEP) System



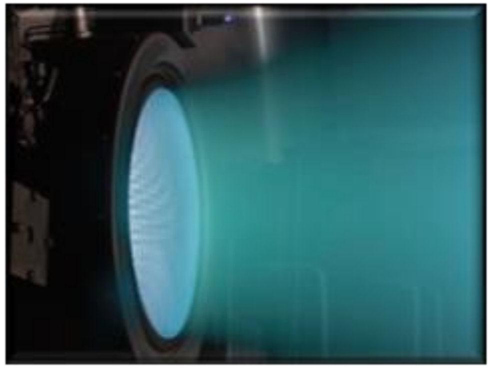
- NEP system separated into 5 subsystems or Critical Technology Elements (CTE)
- Subsystems can be developed separately and in parallel if interfaces are properly defined and controlled

Incremental Progress Possible

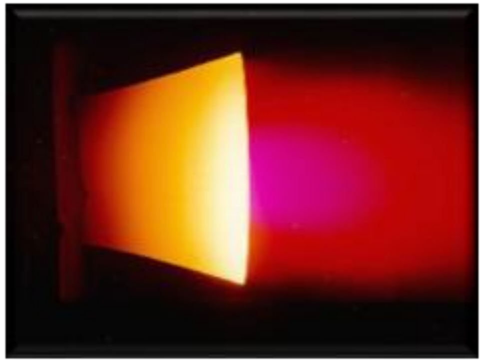
NEP Challenges
CTE-4 - *Electric Propulsion Subsystem*

<u>For Lower-Power NEP (10s of kW_e)</u>

- NASA has options previously developed by other programs
  - Hall thrusters for PPE on the Lunar Gateway (6 & 12.5 kW_e)
  - NEXT-C ion thruster (7 kW_e)
- High SNP interest in the performance of the PPE Hall thrusters



Low-Power options available. Some risk in clustered operations and being able to operate/ground test at high power



<u>For High-Power NEP (MW_e)</u>

- SNP investing in Li-fed MPD* (believed capable of up to 1 MW_e/thruster)
- Longest, highest power continuous operation of any EP thruster (500 hrs at 500 kW_e)
- Condensable propellant makes ground testing at full-scale possible
- Low-pressure solid/liquid storage – significant experience w/liquid Li handling/pumping in nuclear fusion community

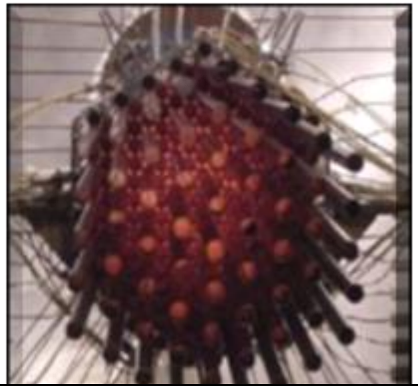
High-Power option. 500 hour/500 kW_e ground test existence proof.

* MPD - Magnetoplasmadynamic

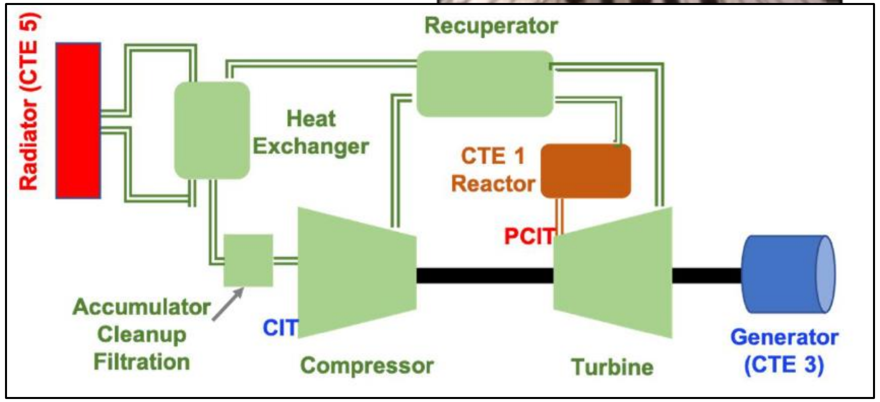
NEP Challenges

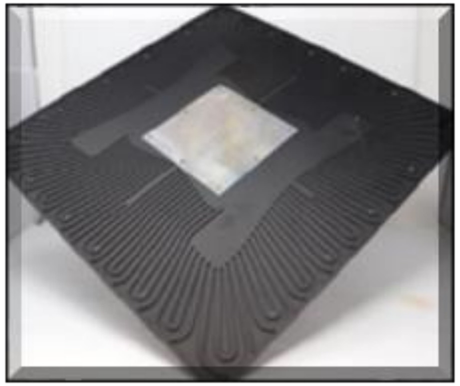
Other Critical Technology Elements

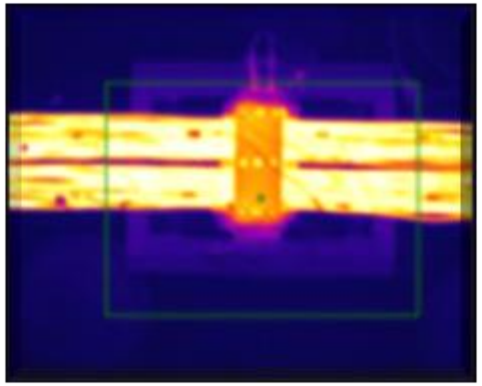
Primary challenges: high-temperature operation (→ lower specific mass), reliability, lifetime



- **CTE-1** – Reactor
  - Operating at high temperature (well above terrestrial power systems)
  - System/fuel lifetime
  - Heat extraction / heat transfer limitations
- **CTE-2** – Power Conversion
  - Operating at high temperature (from superalloys to more exotic materials)
  - Bearings & seals (lifetime / wear / high speeds)
  - Heat exchangers / recuperator (efficiency & creep)
- **CTE-3** – Power Management & Distribution
  - Power generator speed and operating temperature
  - Electromagnetic components (transformers, power converters)
  - Switching network components, interconnectivity, and isolation
- **CTE-5** – Radiative Heat Rejection
  - Heat transfer effectiveness at interfaces
  - Pumped and passive heat transport capability at high temperature
  - Overall structure size (deployment vs. in-space assembly)

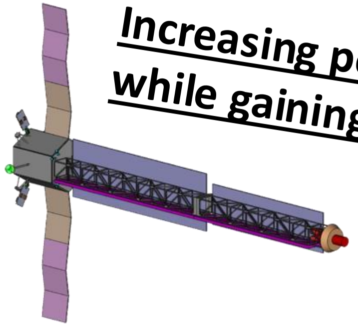






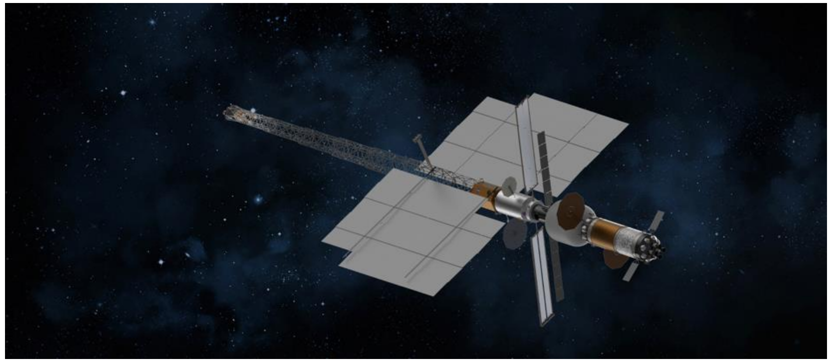
Development Plan for NEP

Incremental advancement to perform successively more difficult missions



Low-power (10's of kW_e) NEP Demo

Science mission-class NEP system (10's of kW_e)



Increasing power, lifetime, performance while gaining experience and identifying gaps

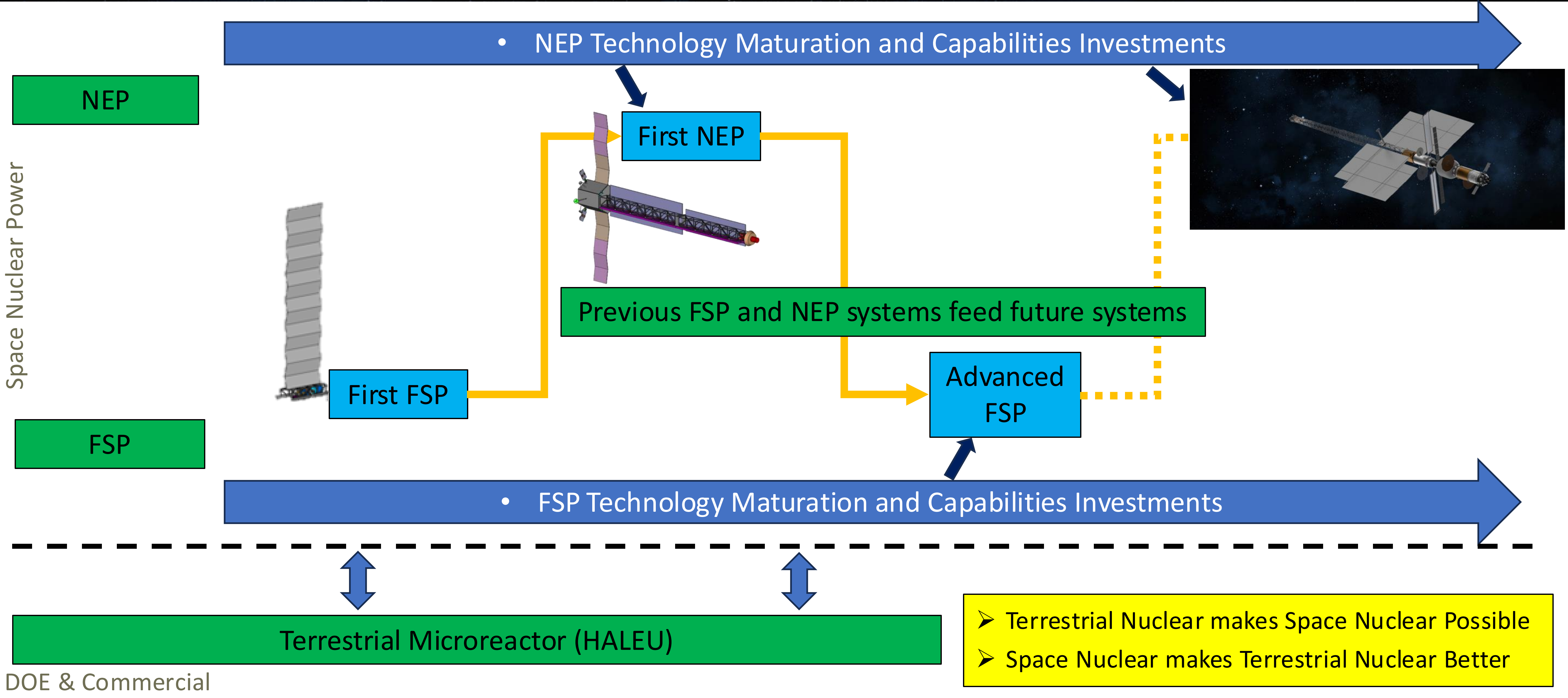
Mars Cargo (MW_e)

Human Mars (MW_e)

- Improving performance (specific mass), reliability/lifetime, and power capability
- Technology maturation, new technology development
- Stand-up of new test and evaluation capabilities

- Low-power provides a cost-effective path to understand integrated NEP systems and potential to expose gaps requiring added investments
- Low-power NEP offers a useful capability to Science missions and an endpoint that can strengthen interest and advocacy
- Develop and implement advances that also play forward for higher-power

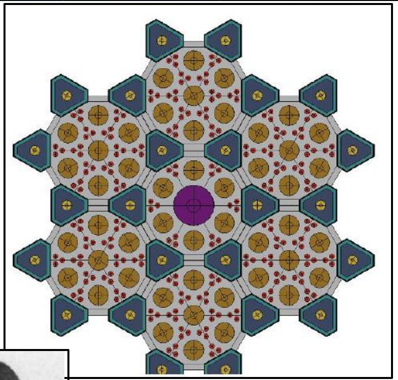
- Initial FSP Development and Investments Aid NEP
- NEP Development and Investments Aid Future FSP



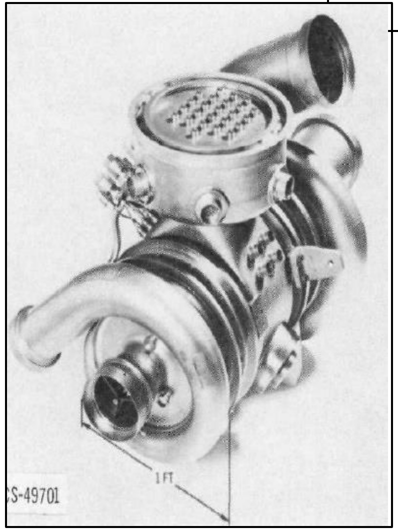
NEP Technology Maturation

Improve Both Low and High-Power Cases

National Academies of Science, Engineering, and Medicine Recommendation[2]



- Subscale in-space flight testing of NEP systems cannot address many of the risks and potential failure modes associated with the baseline mission NEP system. With sufficient M&S [modeling & simulation] and ground testing, **including modular subsystem tests at full scale and power**, flight qualification requirements can be met by the cargo missions that will precede the first crewed mission to Mars. Fully integrated ground testing may not be required." [emphasis added]



- NASA tech maturation plan developed to guide investments

  Key to plan is building and testing hardware **<u>at power and scale</u>**

  - High temperature reactor components/heat extraction methods (SNP-funded effort)
  - High temperature Brayton (FSP-funded effort)
  - High temperature-capable electrical generator (SNP-funded effort)
  - Pushing limits on radiator temperatures (Two SNP-funded efforts through SBIR Phase III's)

- Leveraging other investments
  - Electric aircraft (power handling), additive manufacturing (complex structures/heat exchangers), terrestrial microreactors (HALEU-fueled power reactor technology), NTP high-temperature nuclear materials (SNP-funded)

Funding tech maturation activities & leveraging other activities (FSP and others) to make progress through hardware fabrication and demonstration

Accelerating Space Science with Nuclear Technology: The Tempe Workshop[3] – an engagement example

- Space Nuclear Propulsion and Power Technologists, Space Science Principal Investigators, Level 1 STMD & SMD technologists
  - NASA, USSF, DOE labs, reactor & engine contractors, contributors to the 2023 Planetary Science & Astrobiology Decadal Strategy[4]

- Discussed
  - Present state and possible future capabilities provided by nuclear tech
  - Wants of the space science community
- **Wants**: Faster Trip Times, More Mission Opportunities, More Power
- High-I_{sp} (NEP) and high thrust (NTP) systems, used on their own or in conjunction may have great utility for deep space science missions (under further study)

Not working in a vacuum – engaging end-users of the technology to ensure it delivers capabilities those users want

[3] "Accelerating Space Science with Nuclear Technology: The Tempe Workshop", T. Reuter, R. Myers, P. Christensen, L. Dudzinski, and K. Polzin; Institute for Space Science and Development; December 2023. https://i-ssd.org
[4] *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032*, National Academies of Sciences, Engineering, and Medicine, The National Academies Press, Washington, D.C., 2023. DOI: 10.17226/26522

NEP Development Summary

- Space Nuclear Propulsion has great potential
- There are a number of recognized challenges to developing an NEP system
- NEP system is comprised of multiple CTEs, and incremental progress can be achieved separately and in parallel if interfaces are properly defined and controlled
- SNP is funding NEP tech maturation activities & leveraging other activities (FSP and others) to make progress through hardware fabrication and demonstration
- SNP is engaging with end-users (SMD, ESDMD/MAT) to ensure an NEP system delivers capabilities those users want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