Nuclear Electric Propulsion

National Aeronautics and Space Administration

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

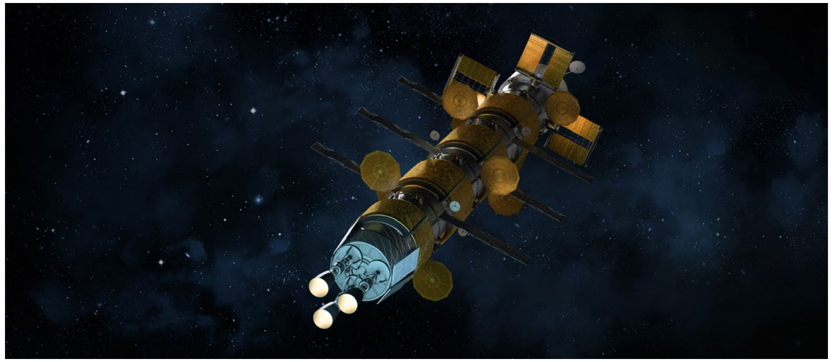
NASA Space Nuclear Propulsion (SNP)

Overview

Vision

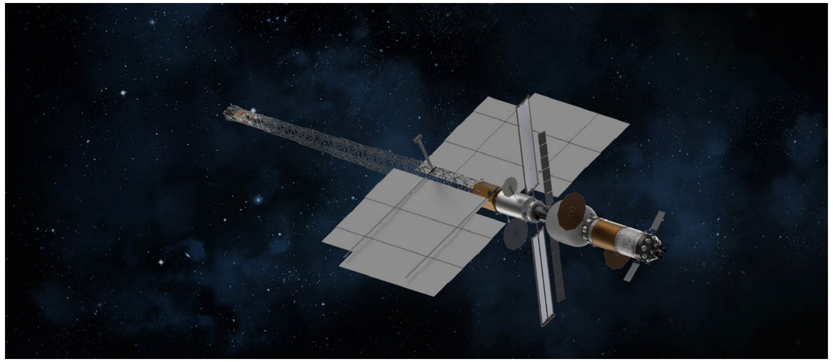
Robust and enduring access to destinations throughout the solar system

Space Nuclear Propulsion is an enabling capability



Nuclear Thermal Propulsion (NTP)

Nuclear Electric Propulsion (NEP)



Why Nuclear Propulsion?

Floor performance is 2X current chemical systems

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

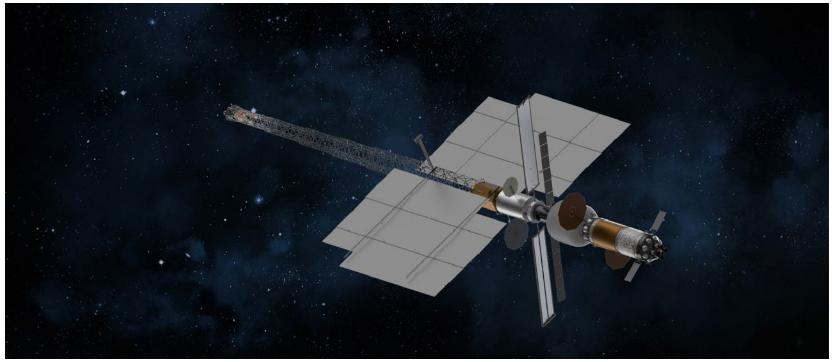
Deep Space Exploration and Science

Mars Cargo and Crew Transit

Challenges for Nuclear Electric Propulsion (NEP)

The need for coordinated, realistic technology maturation

For high-power NEP



NASA Engineering & Safety Center Findings[1]

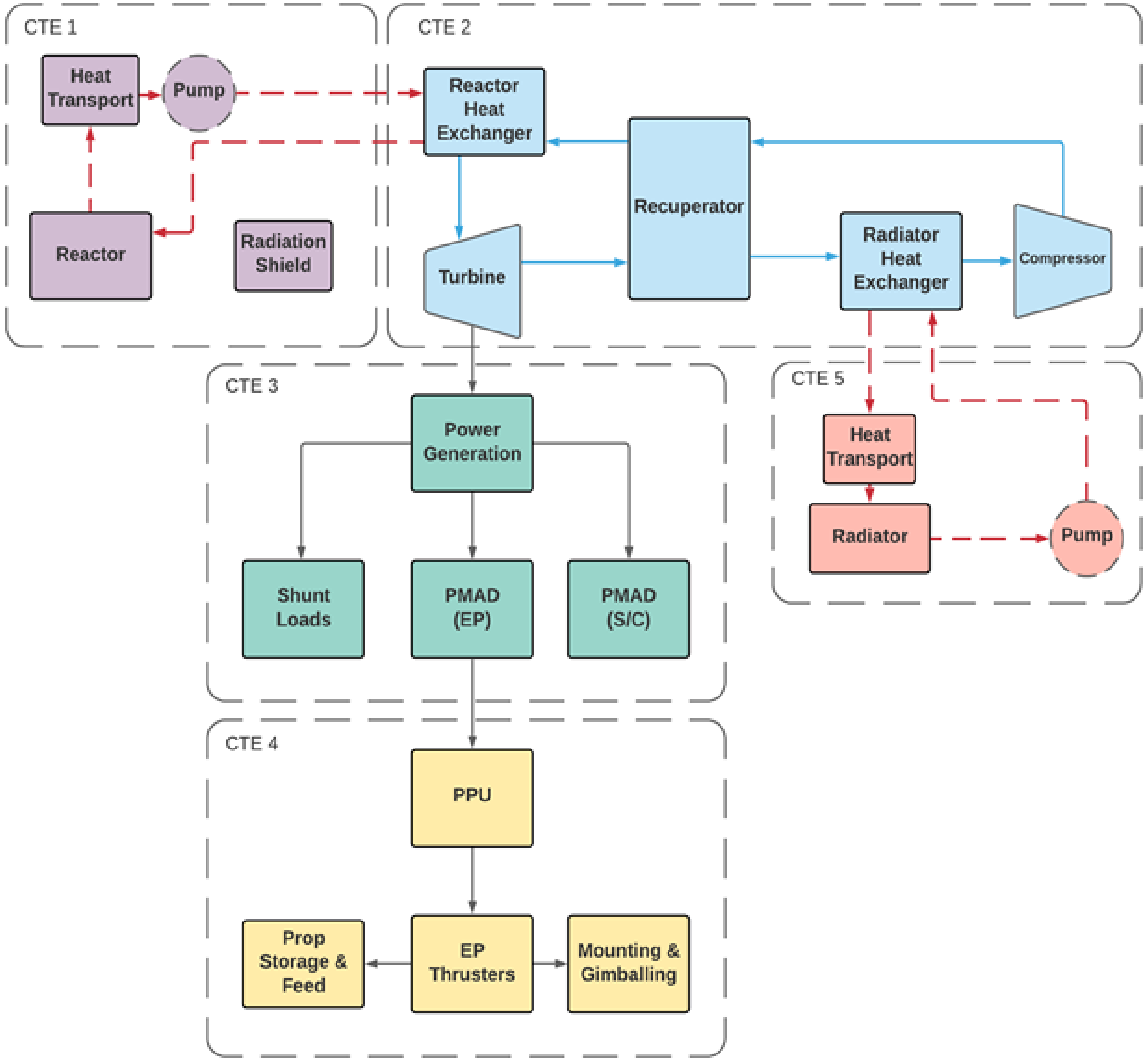
- The majority of critical technologies for NEP systems are relatively immature.
- TRLs in the literature are often overestimated and a proper baseline assessment to gauge resources required for advancement has been a consistent issue.
- The majority of critical technologies are at a relatively high 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

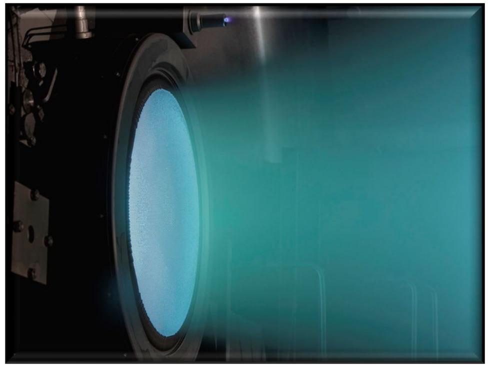
Nuclear Electric Propulsion (NEP) System



- NEP system separated into 5 subsystems or Critical Technology Elements (CTE)
- Each CTE is further divided into major assemblies and components as required for advancement
- System-level modeling – detailed models of various design options to determine the effects on mass and performance
- Subsystems can be developed separately if interfaces are properly defined and controlled

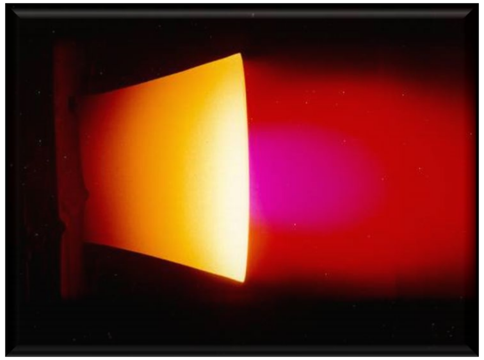
NEP Challenges

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
  - Recent GRC-hosted workshop for SNP on Hall thrusters
    - Discussed differences between on-ground and in-flight operations
    - Identified additional activities/data that could prove useful in understanding these differences and quantifying the risk associated scaling to higher-power and/or operating a greater number of clustered thrusters.



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

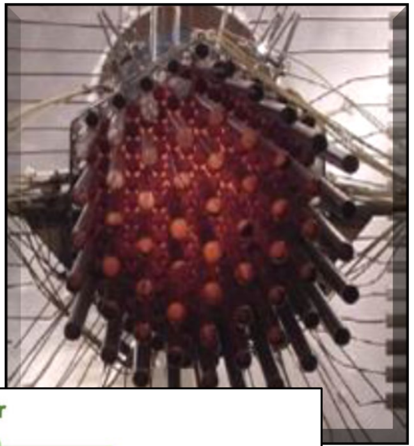
- SNP investing in Li-fed MPD* (believed capable of up to 1 MW_e/thruster)
- Longest, highest power continuous operation of any EP thruster (500 hrs at 500 kW_e – Russian test)
- Condensable propellant makes ground testing at full-scale possible
- Low-pressure solid/liquid storage – significant experience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

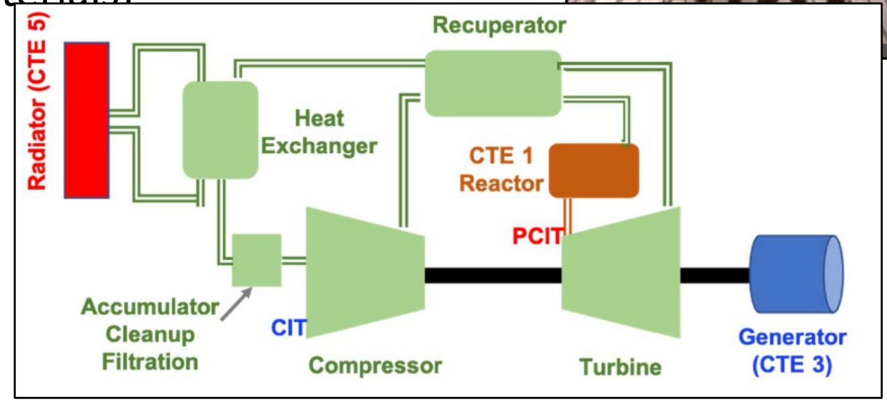
* MPD - Magnetoplasmadynamic

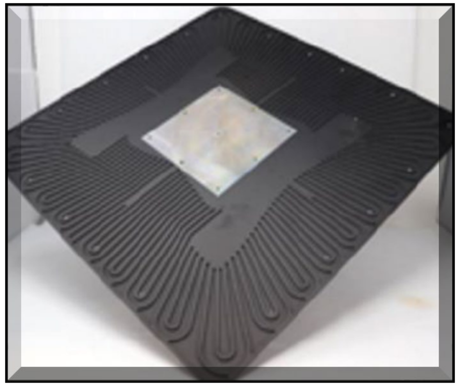
NEP Challenges

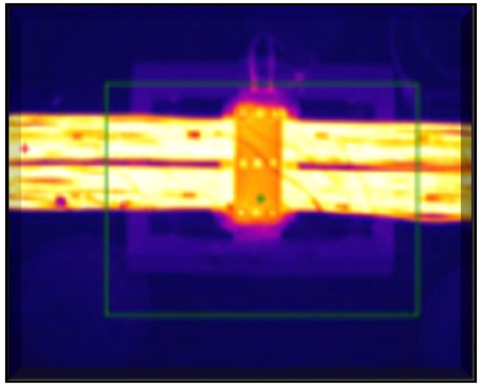
Other Critical Technology Elements

- **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)





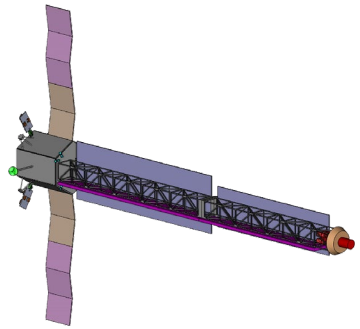




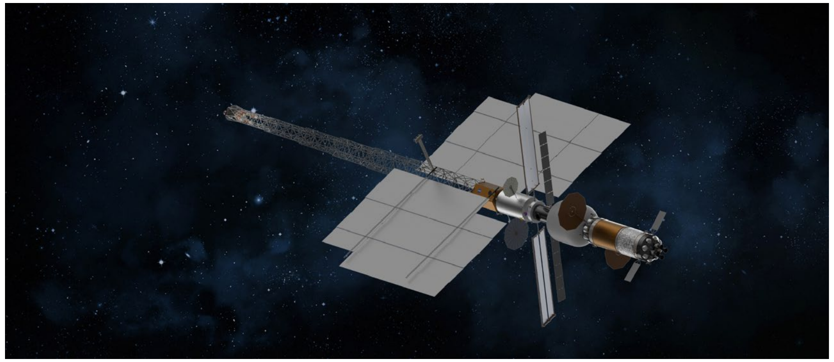
Development Plan for NEP

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)



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

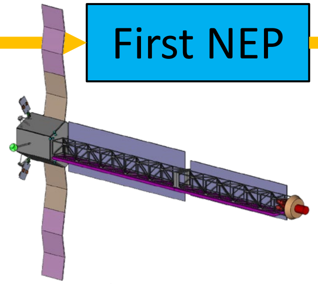
- Initial FSP Development and Investments Aid NEP
- NEP Development and Investments Aid Future FSP

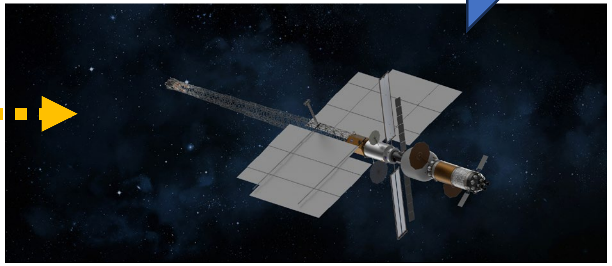
- NEP Technology Maturation and Capabilities Investments

NEP

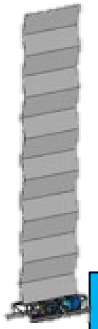
Space Nuclear Power

First NEP





▪ Previous FSP or NEP systems feeds future systems



First FSP

Advanced FSP

FSP

- FSP Technology Maturation and Capabilities Investments

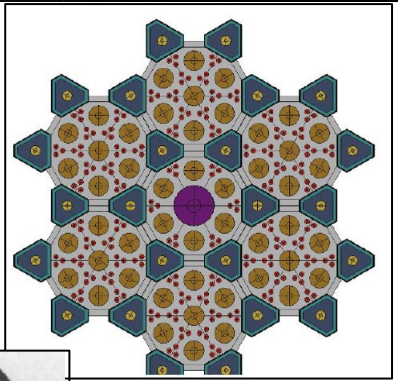
Terrestrial Microreactor (HALEU)

DOE & Commercial

➢ Terrestrial Nuclear makes Space Nuclear Possible
➢ Space Nuclear makes Terrestrial Nuclear Better

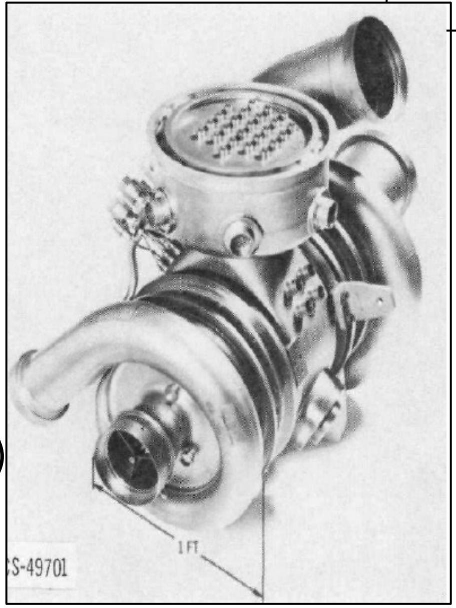
NEP Technology Maturation

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 for high-power systems

  Many also align with increasing the performance/capability/utility of lower power systems

  Key to plan is building and testing hardware **<u>at power and scale</u>**
  - High temperature reactor components/heat extraction methods (FSP ~~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)

[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

Accelerating Space Science with Nuclear Technology: The Tempe Workshop[3]

- 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
- **<u>Wants</u>**: Faster Trip Times, More Mission Opportunities, More Power
- High-I_{sp} (NEP) <u>and</u> high thrust (NTP) systems, used on their own or in conjunction may have great utility for deep space science missions (under further study)

[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

- Multiple non-advocate reviews rated the subsystems required for high-power NEP as relatively immature with TRLs often overstated in the literature – recommended focused investments to test hardware at power and scale, supported by the development of predictive modeling & sim capabilities

- SNP's notional first demo using a low-power NEP system will benefit from flying the first FSP system and will incorporate additional advances achieved through tech maturation investments.
  - FY25 goal to develop a demo mission design and requirements

- Many tech maturation investments improve the low-power NEP system and have a big lever arm in improving the high-power NEP system (improve = reduced power system specific mass [kg/kW_e of power generated])

- SNP is actively working to leverage investments by other programs and organizations that may be applicable to developing and fielding NEP systems (FSP, JETSON, Electric Aircraft, etc.) and building relationships with end-users of these systems.

Fielding an NEP system will be a national effort likely requiring partnerships every step along the way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