National Aeronautics and Space Administration

Integrated Development Strategy for Space Nuclear Propulsion
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Space Technology Mission Directorate

Space Nuclear Propulsion Office

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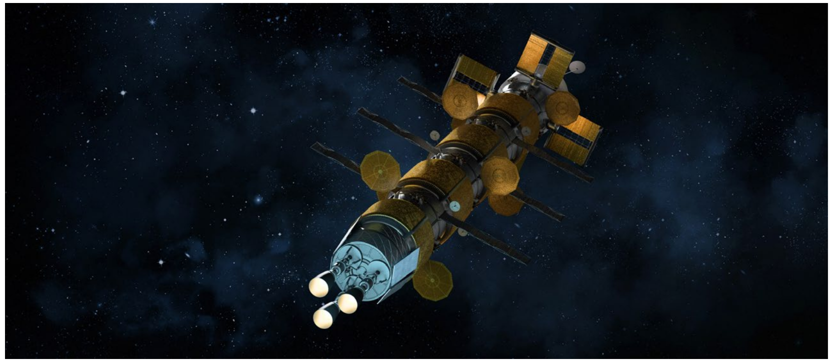
NASA Space Nuclear Propulsion (SNP)

Overview

Vision

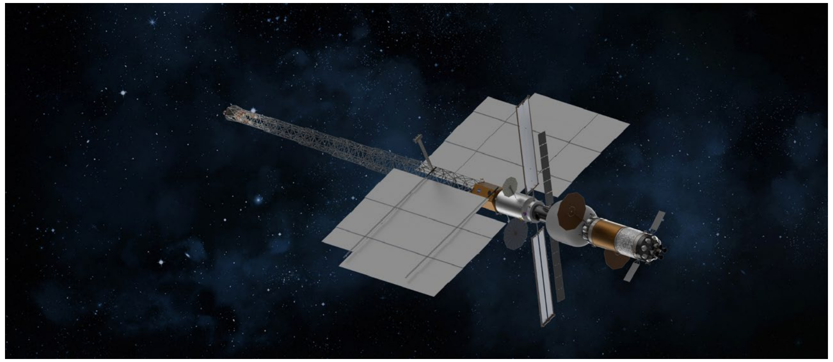
Robust and enduring access to destinations throughout the solar system

Space Nuclear Propulsion is an enabling capability



Nuclear Thermal Propulsion (NTP)

Nuclear Electric Propulsion (NEP)



“Whole of Government Solutions Required”

Arati Prabhakar, Ph.D. – Past-Director OSTP

Space Nuclear Propulsion provides the Nation with a transformative transportation capability applicable to multiple mission spaces

Cis-Lunar Maneuvering and Transportation

Deep Space Exploration and Science

Mars Cargo and Crew Transit

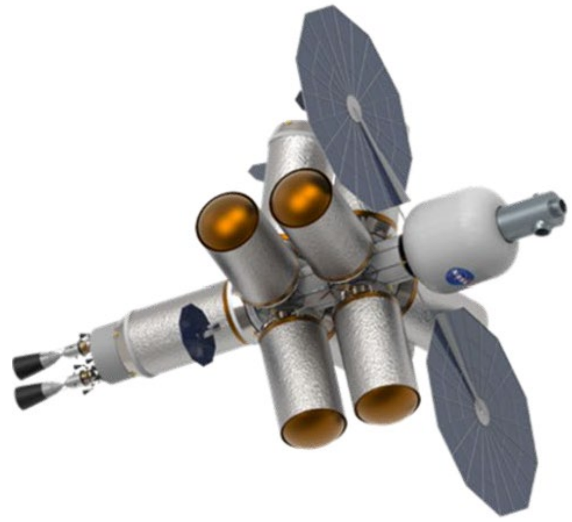
Stepwise, Generational Nuclear Propulsion Development

	Initial Demo Experiment	Cislunar / NEO	Deep Space	Mars
	Flight Experiments	**Operational Demo**	**Operational Cislunar / Deep Space Applications**	**Crewed and Large Cargo Systems**
NTP	**Generation 0: DRACO** Flight Experiment (lowest power)	**Generation 1** Operational Demo (low power, more capable than Gen 0)	**Generation 2** Operational System (low power, higher delta-V utility)	**Generation 3** Crewed & Large Cargo (high power, highest delta-V utility)
NEP	**Low-Power Demo** Flight Experiment (10's of kW_e NEP Demo)	**Operational Low-Power** Operational Demo (science mission-class NEP system)	**High-Power Demo** Demonstration System (MW_e class)	**Operational High-Power** Crewed & Large Cargo (MW_e class)

Improved engine specific mass, propulsive functionality (thrust, I_{sp}, Δv capability), lifetime & reliability, and reusability

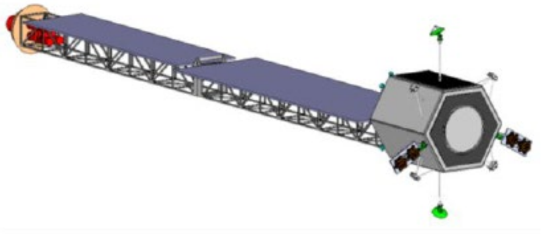
Generational NTP Development

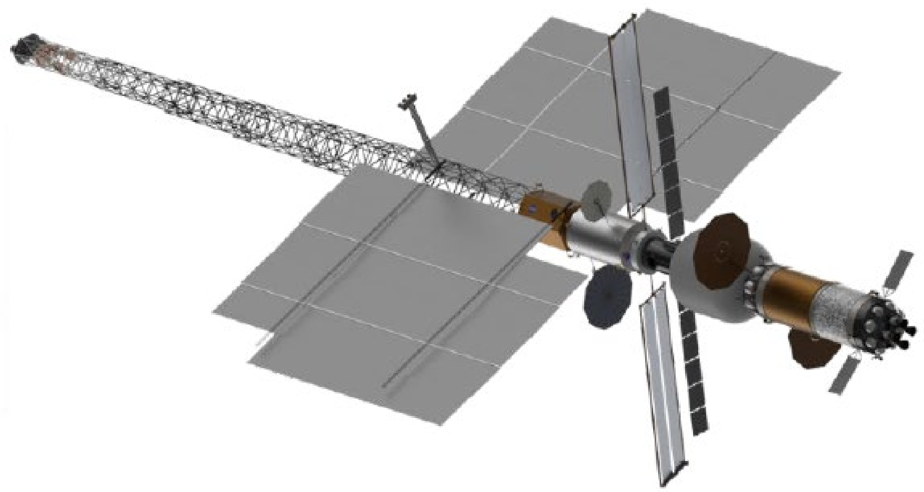
NTP Generation	Development Objectives
Gen 0	First-of-a-kind NTP system demonstrated in space. Pathfinder for clearing the regulatory and nuclear launch approval process. Nominal startup, steady-state operation, and shutdown in space.
Gen 1	Operational NTP system. Able to demonstrate fully controlled operations and maneuvers. Capabilities beyond those of Gen 0. Demonstrate closed-loop engine control, materials compatibility, and lifetime at high-temperature for longer-duration missions and multiple restarts. Gaps in national nuclear test and evaluation capabilities partially closed to support system development.
Gen 2	Operational system with longer life and higher overall Δv capability compared to Gen 1 system. Potential for reusability or to boost payloads from Earth orbit with a high escape velocity. Additional potential use for orbit capture at the destination. Gaps in national nuclear test and evaluation capabilities fully closed to support system development.
Gen 3	Higher thrust/power compared to Gen 1 and 2 systems. Support long-duration applications requiring high thrust to minimize trip time, such as Mars human and cargo missions. Capability to boost very large deep space science missions out of Earth orbit with a high escape velocity.



Generational NEP Development

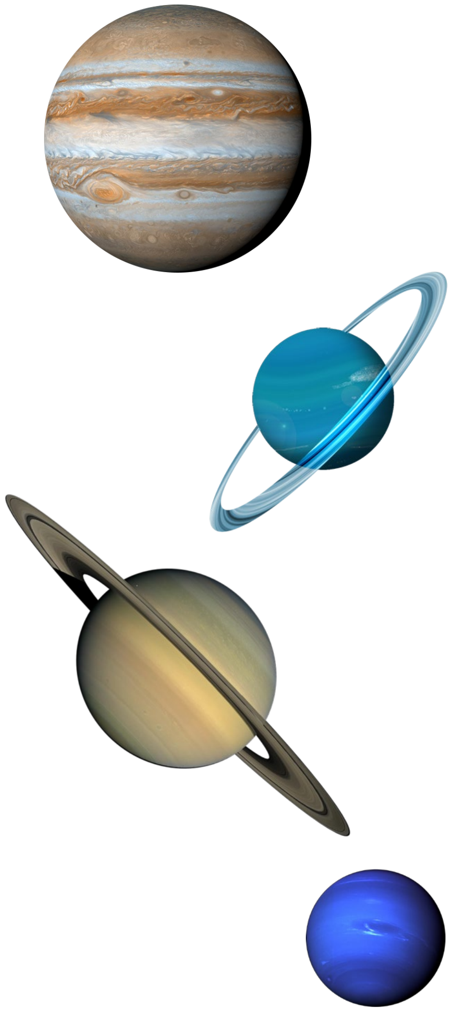
NEP Generation	Development Objectives
Gen 0 (low-power NEP demo)	Low power (10s of kW_e) NEP demo. Using aspects of the first fission surface power (FSP) system and infusing additional technology maturation for a lower system specific mass.
Gen 1 (low-power operational NEP)	Low power (10-50 of kW_e) operational NEP system. Improved system lifetime and lower specific mass relative to the Gen 0 system. Able to support the interplanetary needs of long-duration deep space science missions, including the continued production of power at the destination.
Gen 2 / 3 (high-power demo and operational NEP)	High power (100s-1,000s of kW_e) NEP operational systems. Able to support missions delivering heavy payloads (e.g. Mars human and cargo missions, very large deep space science missions). Potential to produce very high on-demand power in-space at any location.





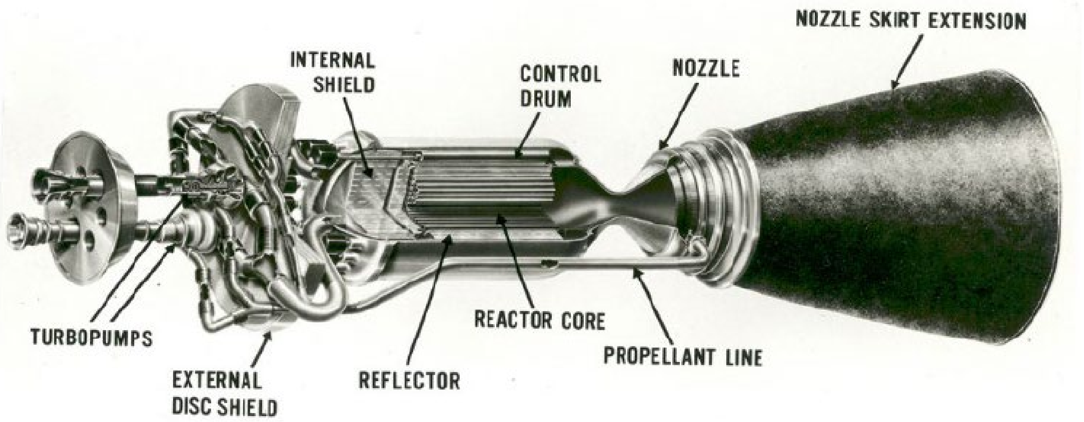
Challenges for Space Nuclear Propulsion

- Gen 0 flight
  - No recovery, post test inspection. Limited prop load.
  - Melding aerospace and nuclear processes. Launch approval. Gap identification.
- Materials – higher temps, survive nuclear/chemical/thermal env
- Nuclear test and evaluation capabilities
- Modeling & Sim (w/sufficient data for model creation / validation)
- Nuclear Regulatory / Safety – for launch, transport, integration, testing
- National Strategic Challenges
  - Nuclear fuel supply (HALEU, < 20% ^{235}U enriched)
  - Nuclear grade non-fuel materials / components
  - Workforce (design and build nuclear systems for aerospace applications)



Transition the space nuclear field from designing ‘paper reactors’ to fielding ‘practical reactors’

Near-Term NTP Developments



- Historical: Rover/NERVA (1950s-1970s), SNTP (1990s)
- SNP Program: Fuel & Moderator Development Program
- Insulators, flow channels/coatings
- Engine components
  - Compatible w/nuclear environments, different mode of operation
- Material and component nuclear and non-nuclear test and evaluation

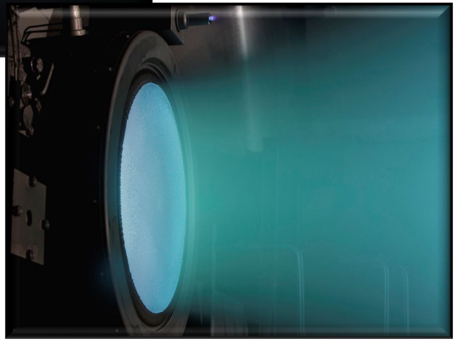
<u>Future Planning</u>

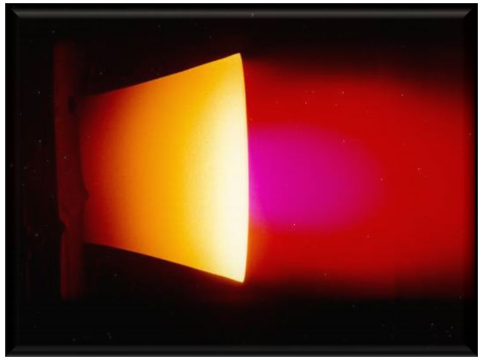
- Design of facilities for future test and evaluation
  - Nuclear testing, full-flow, thermal-vac, vibe, full-engine
- Instrumentation & Control systems
- Modeling and Simulation: predictive capability for design and evaluation, interpretation of data

Near-Term NEP Developments

- Investments in maturing NEP Critical Technology Elements (CTEs)
  - Capability to manufacture specific, long-lived, and low mass hardware
  - Testing hardware under conditions expected for an NEP system
  - Leverage low-power opportunities to test tech for high-power systems

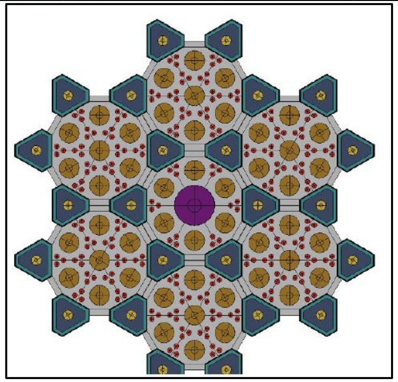
- High-temperature Li heat pipes
- High-temperature power generator
- Design & analysis of components for high-temperature Brayton systems
- High-power field-effect transistors (FETs) for nuclear rad environment
- High-temperature radiator panels
- Large radiator assembly using ISAM methods
- Li-fed magnetoplasmadynamic thrusters for MW_e applications





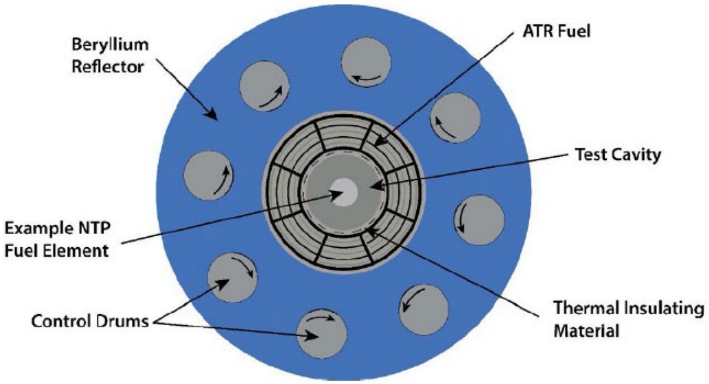
Terrestial Nuclear Developments

- Small modular reactors (SMRs or microreactors)
    - Common fuel type (HALEU)
    - Processes and manufacturing techniques developed for the terrestrial application can be leveraged for in-space reactors.
    - Expanding workforce and capabilities for engineering and production
    - Business case for fuel at this enrichment level
- Space nuclear reactors: mass is a driver
    - Terrestrial nuclear makes space nuclear possible
    - Space nuclear makes terrestrial nuclear better



Nuclear Test and Evaluation Capabilities

- Test Reactor for in-pile experiments
  - Test components in combined environment matching ‘most’ conditions



- NTP Engine Test Facility
  - Integrated ground engine testing <u>with exhaust capture and scrubbing</u>
  - Full combined conditions, post-test tear-down and inspection
- Nuclear Power Reactor Test Capability
  - Long-duration testing (possibly multiple options/designs, in-parallel)
  - Post-test tear-down and inspection

- Irradiated Nuclear Test Article Disassembly Facility
  - Once a test is completed, ‘Hot’ reactor needs disassembled for inspection, measurements, and PIE
  - NTP and NEP systems too large (or too much moderator material) for existing hot tear down locations

Support fielding ‘fleets’ of space nuclear systems, not ‘one-offs’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