

NASEM Consensus Study: “Space Nuclear Propulsion For Human Mars Exploration”

- Focus: Nuclear thermal propulsion (NTP) and nuclear electric propulsion (NEP) systems for the human exploration of Mars
- Considered a very challenging 2039 crewed opposition-class mission to ensure system would be capable of many launch opportunities
- Identify:
 - Primary technical and programmatic challenges, merits, and risks
 - Key milestones and a top-level development and demonstration roadmap
 - Missions that could be enabled by each technology

Full report available for free download from NASEM website

System Requirements and Characteristics for Human Mars Mission

NTP

Isp: 900 s

Thrust: up to 100,000 lbf with up to 25,000lbf/engine

Total operational lifetime: 4 h
(intermittent operation: 6 to 8 restarts)

Reactor thermal power: ~500 MWth

Temperature of propellant at reactor exit: ~2700 K

Propellant

LH₂ stored at 20 K for 2-3 years

NEP

Isp \geq 2,000 s

Electrical power: 1 to 2 MWe

Specific mass: \leq 20 kg/kWe

Operational lifetime (continuous operation):
4 years for power generation, 1 to 2 years for thrust

Reactor thermal power: ~3 to 10 MWth

Reactor coolant outlet temperature: ~1200 K

Propellant options:

- argon (stored as a cryogen liquid at 90 K), xenon, krypton (gases), lithium (solid)

Supplemental chemical propulsion system

Fuel: Liquid methane (110 K) and liquid oxygen (90 K)

Isp: 360 s

Thrust: 25,000 lbf

Major Development Challenges for NTP and NEP

Category	NTP	NEP
Reactor Core Fuel and Materials	<ul style="list-style-type: none"> High reactor fuel operating temperature (>2700 K) 	
System Operational Parameters	<ul style="list-style-type: none"> Rapid system startup to full operating power and temperature (preferably in 1 min or less) 	<ul style="list-style-type: none"> Long system operational reliability (4 years for power generation, 1 to 2 years for thrust)
Scale		<ul style="list-style-type: none"> Power conversion and thermal subsystem tests conducted to date have been at power levels orders of magnitude below that required for baseline mission Limited full scale, short duration electric propulsion subsystem testing at power levels an order of magnitude below that required for baseline mission
Ground-Based Testing	<ul style="list-style-type: none"> Need for full-scale and thrust ground testing to support crewed system qualification Need to capture and process engine exhaust (resulting in high cost) Facility preparation time (stresses baseline schedule) Little integrated system testing experience; none of it recent Last relevant-scale tests were nearly 50 years ago 	<ul style="list-style-type: none"> No fully integrated system testing experience at relevant power levels Could be tested using a modular approach with carefully managed interfaces
In-space Propulsion Technology Needs	<ul style="list-style-type: none"> Long-term storage of liquid hydrogen in space at 20 K with minimal loss 	<ul style="list-style-type: none"> Parallel development of a chemical propulsion systems
System Complexity		<ul style="list-style-type: none"> Highly complex: six NEP subsystems and a chemical propulsion system

Space Science Applications Workshop

- “*Accelerating Space Science with Nuclear Technologies*” workshop held 12/6-7/2023 at Arizona State University
- Attended by ~20 leading space scientists from JPL, APL, SwRI and leading universities, along with ~20 space nuclear technologists and program leaders.
- Goals:
 - Create new, more integrated community with open communications
 - Update space science community on rapidly developing programs in space nuclear systems and their planned capabilities
 - Get feedback from space scientists on priorities and key technology attributes for their missions
 - Identify next steps to advance technology and mission opportunities
- Considered NTP, NEP and FSP systems using DRACO, JETSON and FSP program status as baseline

**Full report available for free download from the
Institute for Space Science and Development website (i-ssd.org)**

WORKSHOP CONCLUSIONS

1

Nuclear propulsion and power could accelerate space science for missions across the solar system by enabling new, higher capability orbiters and landers as well as potentially enabling the goal of “sample return from anywhere in the Solar System.” The effectiveness of nuclear propulsion and power for these missions will be driven by the success in achieving key technology performance and mass objectives.

2

Reducing the trip time to high ΔV destinations (both inner and outer solar system) is a high priority that enables significantly faster science return following launch. Space nuclear technologies could reduce trip times and increase launch window flexibility by reducing or eliminating the need for gravity assists. The combination of larger launch windows and reduced trip times would enable a larger number of missions within a space scientist’s career and permits learning from one mission to the next.

3

For missions to high radiation environments, increases in delivered payload mass may be used to increase radiation shielding, which could enable dramatically longer science acquisition activities at those destinations. Increased delivered mass would also be beneficial to increase maneuverability at the destination, including, for example, to orbit multiple moons or change the orbit inclination.

4

Increased power availability may best be used to dramatically increase communication rates, which currently limit science obtained from deep space destinations. Additional uses for increased power include the use of high-power instruments. An example is the use of ground penetrating radar systems at the icy moons with enough power to measure and quantify the subsurface ice/liquid interface.

5

Increased science instrument mass is not a high priority (due to instrument cost), but enabling the delivery and landing of capable vehicles on the ocean worlds (Enceladus in particular) is a priority to support the search for life.

6

Nuclear systems should be designed for mission lifetimes of 10 - 20 years to ensure ample opportunities for science, even for the fast trip times to the outer planets. Nuclear architectures may enable missions to reach multiple destinations, though the long-term funding needs for such missions must be addressed.

Nuclear propulsion and power systems planned for the next 10 years could enable new science missions

Technical Insights

- NEP power levels should be higher than 10kW to provide real benefit to space science missions – the sample return missions examined 20-40kW, and initial high-level optimization showed 40kW provided significant improvements in trip time and delivered mass.
- Maximizing commonality between FSP and NEP subsystems (where possible), will help control costs and enable more rapid applications
- NTP may provide key speed benefits to outer planet missions if the full potential of the system (900s Isp) is achieved. If NTP is only used for Earth departure to reduce trip time then the new commercial launch capabilities may eliminate the need for long-term cryo storage of liquid hydrogen, but if deep space burns are required, this technology will also be required.
- Additional mass is a benefit NOT for additional science (instruments are too expensive), but for additional shielding and maneuverability, where it might be VERY important for high radiation environments, landers and sample return missions.

Space Science needs can directly impact technology maturation plans and priorities