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Space Nuclear Propulsion for Human Mars Exploration

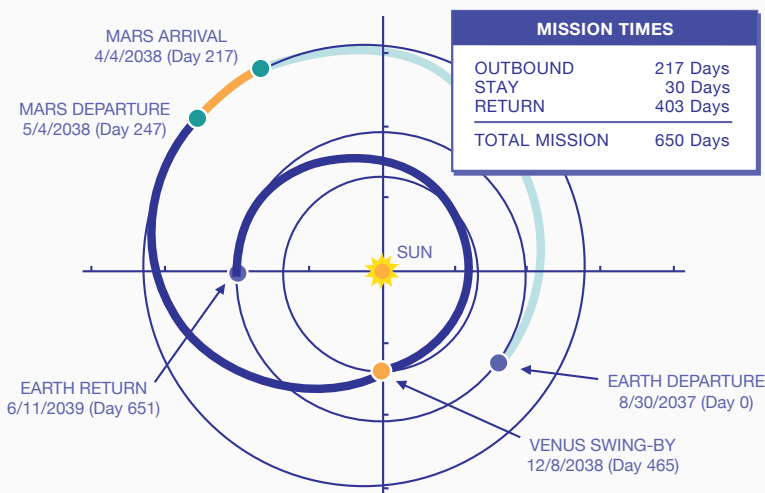


Safely transporting humans to and from Mars will require advances in spacecraft propulsion. Advanced nuclear propulsion systems, including Nuclear Thermal Propulsion (NTP) and Nuclear Electric Propulsion (NEP), have the potential to substantially reduce trip time, launch mass, and space radiation exposure for astronauts compared to non-nuclear approaches. Both NTP and NEP have unique advantages and limitations when applied to a crewed mission to Mars, and more research is needed to bring these technologies to fruition.

At the request of NASA, the Aeronautics and Space Engineering Board of the National Academies of Sciences, Engineering, and Medicine convened a committee of experts to evaluate the research needed to develop space nuclear propulsion systems to support a human exploration mission to Mars with a 2039 launch date. *Space Nuclear Propulsion for Human Mars Exploration* identifies key technical challenges and presents a development and demonstration roadmap for NTP and NEP systems.

Nuclear Propulsion for Human Mars Exploration identifies key technical challenges and presents a development and demonstration roadmap for NTP and NEP systems.

The committee finds that both NEP and NTP systems show great potential to facilitate the human exploration of Mars. Using either system to execute the baseline mission, however, will require an aggressive research and development program. Such an effort would need to begin with NASA making a significant set of architecture and investments decisions this year (2021). The multi-year research program would need to include subsystem development, prototype systems, ground testing, and cargo missions as a means of flight qualification prior to first crewed use. NASA should also develop consistent metrics and technical expertise to allow for an objective comparison of the ability of NEP and NTP systems to meet mission requirements.

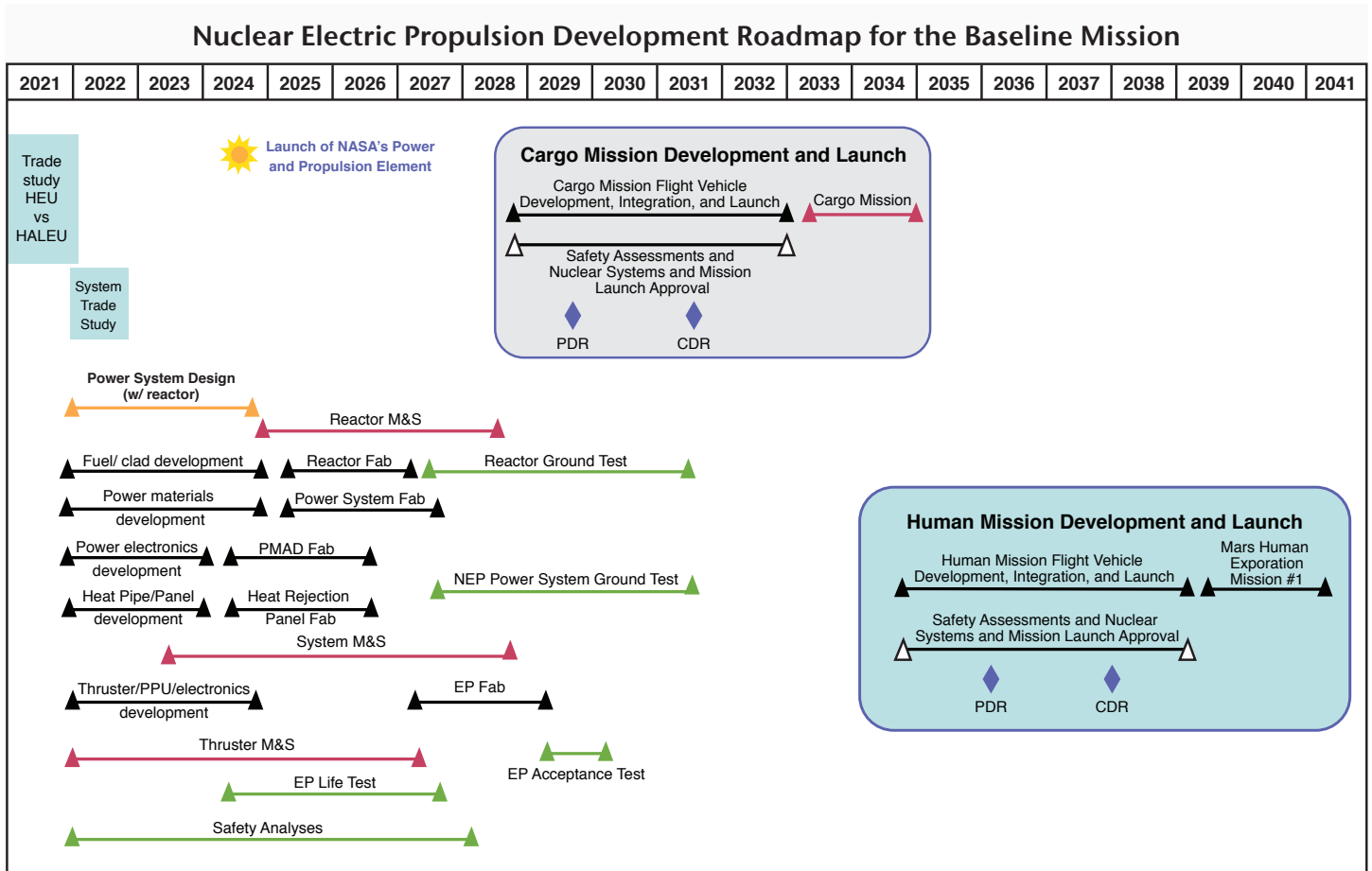


Trajectory and timeline for a typical “opposition-class” mission to Mars, the baseline mission considered in this report.

Due to the changing orbital positions of Earth and Mars, an opposition-class mission would involve a shorter stay on Mars (30 to 90 days) and a shorter total mission time (400 to 750 days) than the alternative “conjunction-class” mission. SOURCE: NASA, *Human Exploration of Mars, Design Reference 1045 Architecture 5.0*, p. 48.

RESEARCH CHALLENGES FOR NUCLEAR ELECTRIC PROPULSION (NEP) SYSTEMS

NEP systems convert the thermal energy from a nuclear reactor into electrical energy to power electric thrusters. 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. Other key challenges are assuring operational reliability over a period of years and the parallel development of a compatible large-scale chemical propulsion system to provide the primary thrust when departing Earth orbit and when entering and departing Mars orbit. *Because of the low and intermittent investment over the past several decades, it is unclear if even an aggressive program would be able to develop an NEP system capable of executing the baseline mission in 2039.*

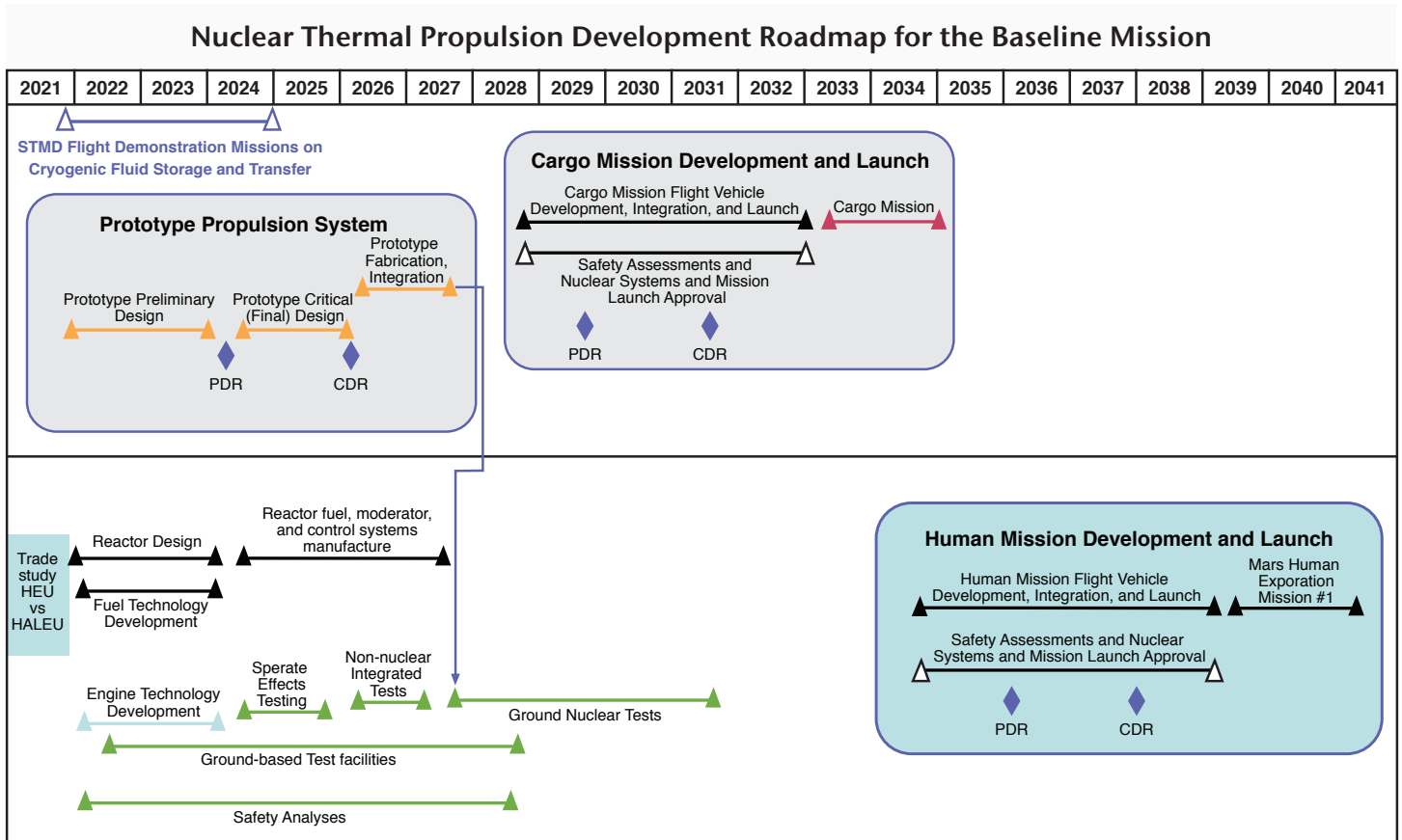


This roadmap shows key milestones and when they would need to be achieved to execute the baseline mission: launching a crewed mission to Mars in 2039 preceded by an initial cargo mission in 2033. As of the end of 2020, there are no NEP component, subsystem, or system development efforts under way. Developing and producing crew-ready flight NEP systems by 2039 would therefore require a significant and rapid ramp-up of component-level development and testing. It is essential that development efforts focus on the key design selections required to define the final NEP flight system.

The proposed program structure combines initial technology development of reactor fuels, materials, and designs for each of the subsystems and assumes concurrent modeling and simulation, ranging from the physics to system levels, to address the system complexity. The roadmap also includes time for lifetime demonstration and validation testing for all NEP subsystems. Additionally, the proposed roadmap uses an early Mars cargo mission, to be launched in 2033, as the first flight of the NEP system, rather than conducting a subscale flight test.

RESEARCH CHALLENGES FOR NUCLEAR THERMAL PROPULSION (NTP) SYSTEMS

NTP systems use the thermal energy from a nuclear reactor to heat rocket propellant and create thrust. For NTP systems, the fundamental challenge is to develop a system that can heat its propellant to approximately 2700 K, which is necessary to meet system performance requirements. Other key challenges are the long-term storage of liquid hydrogen in space with minimal loss, the lack of adequate ground-based test facilities, and the need to rapidly bring an NTP system to full operating temperature. *An aggressive program could overcome these challenges to achieve the baseline mission in 2039.*



This roadmap shows key milestones and when they would need to be achieved to execute the baseline mission: launching a crewed mission to Mars in 2039 preceded by an initial cargo mission in 2033. The development of an NTP system for the cargo and crewed elements of the baseline mission will require several program phases. These phases include the following:

- Development of technology and M&S capabilities for the NTP system and its subsystems and components,
- Ground testing of subsystems and components,
- Facility development and integrated testing of the NTP system,
- Development and launch of cargo missions, and
- Development and launch of the baseline mission for human exploration of Mars.

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This Consensus Study Report Highlights was prepared by the National Academies' Aeronautics and Space Engineering Board based on the report *Space Nuclear Propulsion for Human Mars Exploration* (2021). This study was sponsored by NASA's Space Technology Mission Directorate. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of the sponsors. Download the report at nap.edu/25977.

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