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Nuclear Thermal Propulsion for Mars Exploration - Overview

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1. Background

The global space sector has entered the ‘New Space’ era, where private companies and emerging nations play a growing role alongside traditional government agencies. This shift has accelerated innovation and intensified geopolitical competition [1]. The United States is leading with the Artemis program, which aims to return astronauts to the Moon by 2025 as a step toward Mars missions. In addition, the United States Space Force was officially established in December 2019. Meanwhile, China and Russia are planning the International Lunar Research Station (ILRS), targeting a crewed lunar landing by 2030 and a permanent base by 2035. These global developments show that space is no longer only about science—it has become a critical field of strategic and security interest. South Korea has also recognized this trend, launching the Korea Aerospace Administration (KASA) in 2023 to strengthen national space governance.

2. Mars Exploration

Mars exploration carries both scientific and strategic significance. Scientifically, it provides a unique chance to search for evidence of past or present life and to study planetary evolution through Mars’ geology, atmosphere, and climate history. Strategically, it showcases national technological capability, enhances prestige in the global space race, and supports future economic opportunities through innovation and potential resource utilization. Moreover, Mars is the most promising candidate for long-term human settlement, making it central to humanity′s vision for survival and expansion beyond Earth [2-4].

NASA’s Mars exploration roadmap, framed within its Moon to Mars strategy, uses the Moon as a testing ground for technologies and systems needed for deep space missions. The roadmap emphasizes three goals: searching for signs of life, understanding Mars’ climate and geology, and preparing for human exploration. Near-term efforts focus on the Mars Sample Return campaign and follow-on robotic missions, while the long-term objective is to enable crewed missions to Mars in the 2030s through incremental system validation, international cooperation, and commercial partnerships [5].

South Korea has set a national goal of landing a probe on Mars by 2045, supported by large-scale investment and intermediate milestones such as a successful lunar landing in 2032 [6].

3. Nuclear Thermal Propulsion - Potential

Nuclear Thermal Propulsion (NTP) is regarded as a game-changing enabler for deep space missions. Unlike chemical rockets, whose energy density is constrained by combustion limits, NTP harnesses the thermal output of nuclear fission to superheat hydrogen propellant, thereby achieving significantly higher efficiency. Current chemical propulsion requires 6–9 months for a one-way Mars trip, exposing crews to prolonged cosmic radiation. By contrast, NTP can deliver two to three times higher specific impulse (I_{sp}), enabling shorter travel times, reduced radiation exposure, and greater payload capacity [7-10].

This is why the United States stated that the ability to use space nuclear power and propulsion systems safely, securely, and sustainably is vital to maintaining and advancing U. S. dominance and strategic leadership in space [11]. Recent initiatives reflect growing international momentum. NASA and DARPA are jointly developing the ‘DRACO’ project, which aims to demonstrate an operational NTP system in orbit. Similarly, the European Space Agency (ESA) launched its ‘ALUMNI’ nuclear propulsion program [1,7].

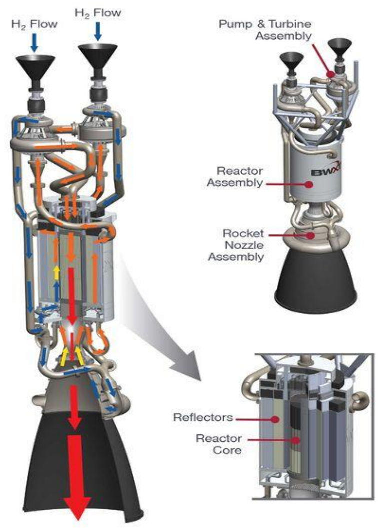

Fig. Rocket using Nuclear thermal propulsion (from BWXT)

4. Policy Implications

For South Korea, achieving the 2045 Mars landing goal requires independent and intensive development of NTP capabilities, because the NTP technology is highly restricted in terms of international collaboration and technology transfer.

To ensure the success of future space missions, it is essential to strengthen the integration between the aerospace and nuclear sectors. Nuclear propulsion technology should be explicitly defined as a core technology within the national space strategy. A clear national roadmap should be established, for example, detailing milestones from ground testing in the mid-2030s, orbital demonstrations in the early 2040s, and a full-scale NTP Mars vehicle by 2045. In parallel, the relevant safety regulations and rocket launch authorization framework should be reviewed.

5. Conclusions

NTP represents a critical future technology for realizing Mars exploration. Its adoption could drastically reduce mission duration, improve crew safety, and expand scientific payload capacity—making it indispensable for deep space missions. For South Korea, achieving its 2045 Mars goal depends on early investment in NTP, stronger coordination between aerospace and nuclear sectors, and the establishment of a clear national strategy. By doing so, Korea can position itself as both a leader in New Space and a contributor to humanity's next step into the solar system.

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