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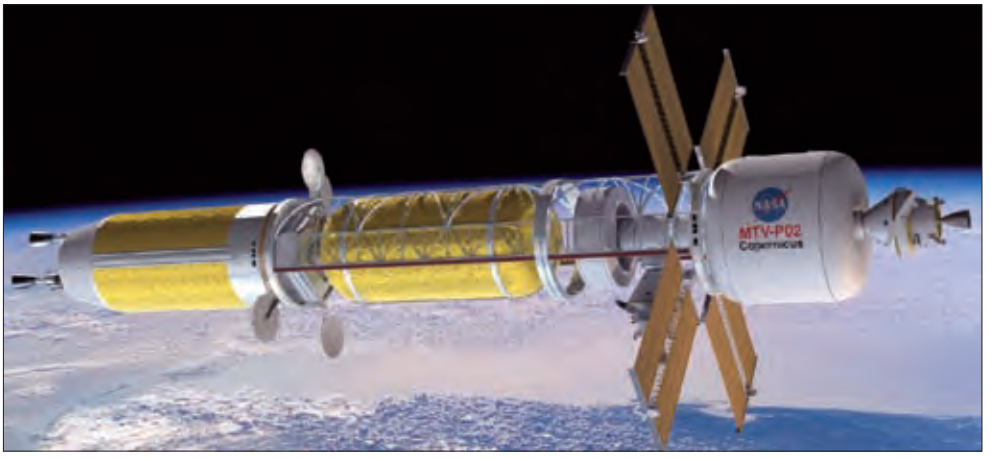
Nuclear and future flight propulsion

Atmospheric mining in the outer solar system was investigated as a means of fuel production for high-energy propulsion and power. A nuclear fusion fuel, Helium 3 (3He), can be wrested from the atmospheres of Uranus and Neptune and used in situ for energy production and/or propulsion.

Five teams from the Case Western Reserve University Dept. of Mechanical and Aerospace Engineering participated with NASA Glenn Research Center in the study. Four teams addressed cruiser-based and balloon-based 3He mining vehicles, and one focused on 3He mining on an outer planet moon.



A nuclear rocket could deliver the crew to the orbiting Mars Transfer Vehicle prior to Earth departure.

Team 1 created a conceptual 3He mining cruiser for Uranus. An inertial-electrostatic confinement (IEC) nuclear fusion reactor was used for propulsion, operating as an air-breathing engine during subsonic cruise in the atmosphere and operating on stored liquid hydrogen as propellant during ascent to orbit. The overall vehicle dry mass was approximately 40,000 kg. The mass was estimated based on past designs and estimates of the IEC engine from Robert Bussard's research. The overall mission delta-V to climb from the low mining altitude to the 5,000-km altitude was 16.23 km/sec. The engine specific impulse was approximately 6,000 sec. The mining time was 28.3 days.

In NASA's recently completed Mars DRA (design reference architecture) 5.0, payload and transportation system options for a human Mars mission after 2030 were examined. Recent work detailed the analysis of a nuclear thermal rocket (NTR) that will reduce the number of Ares V heavy-lift launchers. The NTR was selected over chemical propulsion for in-space transportation because of its higher specific impulse, increased tolerance to payload growth, and lower initial mass in LEO, which is important for reducing the number of heavy lifters.

All three NTR vehicles use a common core propulsion module with three 25,000-lb-thrust "composite fuel" NERVA (nuclear engine for rocket vehicle applications) -derived engines to perform all primary mission maneuvers. NERVA-derived engine features include an exit temperature of roughly 2,700 K, chamber pressure of about 1,000 psia, specific impulse of around 900 sec, and engine thrust-to-weight ratio of about 3.43.) Two cargo flights, using minimum energy paths, deliver a cargo lander to the surface and a habitat lander into a 24-hr elliptical parking orbit where it remains until the arrival of the crew during the next mission opportunity (about 26 months later). The cargo elements aerocapture into Mars orbit and are enclosed within a large triconic aeroshell, which is a payload shroud during launch, then an aerobrake and heat shield during Mars orbit capture and in entry, descent, and landing on Mars.

The gasdynamic mirror (GDM) is a magnetic device where fusion plasmas are heated to ignition by the reaction products resulting from the "at-rest" annihilation of antiprotons in uranium 238. Unlike terrestrial fusion power systems, where large Q values (ratio of fusion power to injected power) are required, only modest Q values are needed for spaceflight. Recent work at the University of Michigan focused on a bimodal fusion propulsion system in which Q values near unity are used and the GDM serves as a neutron source. Fusion reactions are neutron rich but energy poor, while fission reactions are energy rich but neutron poor. This fact led to a system in which the GDM device serves as a fast neutron source surrounded by a blanket of thorium 232, which is used to breed uranium 233 and simultaneously burned to produce energy.

For a reasonable blanket size and deuterium-tritium plasma density, size, and temperature, the hybrid system can produce tens of gigawatts of thermal power per centimeter. When heating hydrogen fuel, a 7-m-long engine can generate a specific impulse of about 59,000 sec at a thrust of about 8 MN at a fuel flow rate of about 130 kg/sec.

by **Bryan Palaszewski** and the **AIAA Nuclear and Future Flight Propulsion Technical Committee**