NUCLEAR ELECTRIC PROPULSION FOR THE EXPLORATION OF THE OUTER PLANETS

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Introduction: New power and propulsion technology efforts such as the DS-1 ion propulsion system demonstration and renewed interest in space nuclear power sources call for a reassessment of the mission benefits of Nuclear Electric Propulsion (NEP) [1]. In this study, a large emphasis has been placed in defining the NEP vehicle configuration and corresponding subsystem elements in order to produce an estimate of the vehicle's payload delivery capability which is as credible as possible. Both a 100-kWe and a 1-MWe system are defined. Various Outer Planet missions are evaluated using NEP: a Pluto Orbiter, a Europa Lander and Sample Return, a Titan/Saturn Sample Return and a Neptune Orbiter.

Vehicle Configuration: The overall NEP vehicle configuration assumes the use of an ion propulsion system [2]. In this configuration, a long boom separates the power and propulsion systems from the other subsystems of the spacecraft. The boom also serves as a structural attachment for the deployable radiators. Every element of the vehicle other than the reactor is located in the reactor shield's shadow. The power conversion system, propulsion system fuel tanks, feed system, power processing and thrusters are mounted next to the shield. The very large deployed radiators are unfolded along each side of the main boom. In stowed configuration, the spacecraft fits within a Delta IV launch fairing (5-m diameter by about 14 m long).

Systems: A careful examination of all NEP vehicle subsystems was performed, leading to a 100-kWe and 1-MWe NEP vehicle dry mass respectively of about 3200 kg and 7500 kg.

Power. The 100-kWe system is the result of a detailed trade study in which a variety of reactor concepts and conversion systems were evaluated. The baseline system has a NASA/Marshall Space Flight Center (MSFC) SAFE-300 UO_2 fueled, heat-pipe-cooled reactor with a Brayton cycle power conversion system [3]. The 100-kWe system produces 102.4 kWe power and approximately 320 kWth power.

The 1-MWe power system is based on a direct gas-cooled concept, particularly attractive for its lighter weight at these thermal power levels. A Brayton power conversion cycle is also used for the 1-MWe system. The turbine speed and the size were increased over the 360-kWe design point of the study. This system has the potential to scale to at least the 10-MWe class of power.

Propulsion. The 100-kW ion propulsion system (IPS) is composed of 60-cm diameter ion engines that can process 25 kW of electric power and use krypton rather than xenon as propellant. The thruster has an estimated efficiency of 0.67 at a specific impulse (Isp) of 5000 s, and 0.77 at 15000 s. The propellant throughput capability of each engine was estimated to be 500 kg, by scaling the capability of the existing, flight qualified 2.3-kW engine.

The 1-MW ion propulsion system is composed of two 480-kW ion engines. Each ion engine includes eight 60-cm diameter, 60-kW ion sources plus one redundant engine. This approach is called a "segmented ion engine" in which multiple discrete ion sources are integrated together to form a single large ion engine with a large effective total grid area. A significant advantage of such a design is in the ground testing and facilities (pumping requirements significantly relaxed). The 60-kW ion sources are essentially the same design as the previously described 25-kW engines.

Other subsystems. The Thermal, Attitude Control, Structures (long boom…), Mechanisms and Cabling subsystems are also defined.

Mission results and conclusion: It is found that the 100 kWe power and ion propulsion systems are applicable for a 9-12 year Pluto rendezvous, a 10-13 year Titan/Saturn Sample Return and a 3-4 year Europa Lander mission. Net delivered masses varies between 500 and 2000 kg. The 1-MWe class NEP vehicle also shows a Titan/Saturn Sample Return mission in 10-12 years on the Delta IV Heavy. This conclusion is an artifact of the constraint in Isp to 16000 s. A higher Isp (30,000 - 40,000 s) would increase the net delivered mass compared to the 100-kW vehicle. However, a 0.5-1-MWe class vehicle enabled a Europa Sample Return in 5-6 years. Since the total dry mass of both NEP vehicles is quite large, the benefit of NEP only shows for a Delta IV Heavy (or equivalent) launch vehicle. All robotic mission trajectories started from a slightly positive C3. The NEP vehicle specific mass (not including tank mass that varies with the trajectory) for the 100-kWe and 1-MWe vehicle is respectively 31.7 kg/kW and 7.5 kg/kW. This analysis shows that NEP is especially applicable for short trip time and very high-energy missions (40-60 km/s).

References:

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