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Strategies for Rapid Implementation of Interstellar Missions: Precursors and Beyond (4)

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NUCLEAR ELECTRIC PROPULSION FOR FAST INTERSTELLAR PRECURSOR MISSIONS: PROBLEMS AND PROMISES

Abstract

Reaching "nearby" interstellar space has always been challenging due to the long distances and associated long travel times. Combinations of near-term, planned, large chemical rockets with multiple stages and planetary gravity assists can potentially double the solar system escape speed of Voyager 1 of 3.6 au/yr. The addition of orbital propellant "depots" and super heavy-lift launch vehicles (SHLLV) in the class of the Starship Super Heavy vehicle could potentially enable a Voyager-class scientific satellite to leave the solar system at an escape speed of up to 10 au/yr, but even that speed (47 km/s) falls short of some of the older notional goals of 20 au/yr. The latter was envisioned for, e.g., the Thousand AU (TAU) mission, with a goal of reaching a distance of 1,000 au from the Sun during a flight time of 50 years. Of the 20 Interstellar Probe studies and concepts articulated from 1960 through 2022, three have been based upon nuclear electric propulsion (NEP). Of these, only 2 "promised" flyout speeds 20 au/yr or greater, with the third providing an average speed of 13 au/yr to a distance of 200 au. The reactors considered in the two faster NEP-enabled studies ranged from power outputs of 500 kWe to 1 MWe with electric thruster operational times of 8 to 12 years with specific mass of the propulsion systems of 12 to 17 kg/kWe. These detailed NEP concepts were last considered over 35 years ago. Since that time many advances have been made in both gridded ion thrusters and Hall thrusters, as well as in more advanced deep-space electric propulsion systems. The latter include the solar electric propulsion (SEP) systems used on the Deep Space 1, Dawn, and ongoing Psyche missions, all using xenon for propellant. Masses and reliabilities for constituent parts for such SEP missions are now well known. Similar required advances in space nuclear reactors for NEP missions have, however, continued to lag. Questions of durability,

multi-year autonomous operation, and decade-long reactor lifetime and associated reactor and waste-heat rejection masses continue to remain a problem, although these problems were better defined in the course of the Project Prometheus pre-phase A study conducted by NASA almost 20 years ago. We reexamine the state of the art in enabling long-term NEP operation required for a rapid interstellar precursor mission as compared against more recent nuclear technologies and more recent implementation of such missions using chemical means.