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COMPUTATIONAL ANALYSIS OF NUCLEAR THERMAL PROPULSION ROCKET (NTPR) BIMODALITY, FUEL, AND PROSPECTIVE COATING

Abstract

Space transportation systems have been advancing to meet the goals of long-distance space travel and long-term space habitation since the beginning of the space race, and one contender from the 1950s still has a lot to offer with some new designs and analyses employed to solve old technical challenges and new mission needs. The nuclear thermal propulsion rocket (NTPR) can double the specific impulse of modern chemical rockets and be designed to generate both electricity and propulsion. This modular reactor functions by introducing a separate but simultaneous thermodynamic loop to the existing high-temperature hydrogen loop. Using heat pipes within the structural tie-tube elements, extra heat is transferred from the reactor to a power conversion system. This functionality is dependent on reducing the mass loss in fuel elements due to chemical and mechanical interactions with the high-temperature hydrogen that was observed in the NTPR program's experiments, NERVA, which tested both niobium carbide and zirconium carbide coatings before its abrupt cancellation. Test samples with other coatings were fabricated but never tested, warranting this investigation into optimal coatings based on minimal hydrogen diffusion, high thermal conductivity, thermal expansion coefficient which matches that of the fuel elements, and no impedance to the surrounding nuclear reactions. This paper presents a model of an NTPR reactor in the Monte Carlo N-Particle Transport Code (MCNP). The fuel coatings and composition are varied, first to compare against the experimental NERVA results, and then the newer coatings and compositions are analyzed. The goal of this modeling is to determine the axial and radial distributions of neutron flux throughout the reactor core and the energy deposition per unit mass. The energy deposition is used in determining the temperature distribution throughout the reactor core, which can affect the degradation of the fuel and therefore be adjusted to reduce such fuel losses. In addition, the hydrogen propellant content within the fuel elements of the MCNP model is reduced and the control drums rotated for compensation in order to demonstrate bimodality of the reactor from complete propulsion through complete electricity generation. A DOE-developed heat pipe analysis code is used to evaluate the electrical power potential of the NTPR and the functionality of the reactor with reduced moderation and surface area exposed to coolant.