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Investigation of Pu-238 Heat Source Modifications to Increase Power Output through (α,N) Reaction-Induced Fission

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Abstract : The objective of this study is to improve upon the current $^{238}PuO_2$ fuel technology for space and defense applications. Modern RTGs (radioisotope thermoelectric generators) utilize the heat generated from the radioactive decay of ^{238}Pu to create heat and electricity for long term and remote missions. Application of RTG technology is limited by the scarcity and expense of producing the isotope, as well as the power output which is limited to only a few hundred watts. The scarcity and expense make the efficient use of ^{238}Pu absolutely necessary. By utilizing the decay of ^{238}Pu, not only to produce heat directly but to also indirectly induce fission in ^{239}Pu (which is already present within currently used fuel), it is possible to see large increases in temperature which allows for a more efficient conversion to electricity and a higher power-to-weight ratio. This concept can reduce the quantity of ^{238}Pu necessary for these missions, potentially saving millions on investment, while yielding higher power output. Current work investigating radioisotope power systems have focused on improving efficiency of the thermoelectric components and replacing systems which produce heat by virtue of natural decay with fission reactors. The technical feasibility of utilizing (α,n) reactions to induce fission within current radioisotopic fuels has not been investigated in any appreciable detail, and our study aims to thoroughly investigate the performance of many such designs, develop those with highest capabilities, and facilitate experimental testing of these designs. In order to determine the specific design parameters that maximize power output and the efficient use of ^{238}Pu for future RTG units, MCNP6 simulations have been used to characterize the effects of modifying fuel composition, geometry, and porosity, as well as introducing neutron moderating, reflecting, and shielding materials to the system. Although this project is currently in the preliminary stages, the final deliverables will include sophisticated designs and simulation models that define all characteristics of multiple novel RTG fuels, detailed enough to allow immediate fabrication and testing. Preliminary work has consisted of developing a benchmark model to accurately represent the $^{238}PuO_2$ pellets currently in use by NASA; this model utilizes the alpha transport capabilities of MCNP6 and agrees well with experimental data. In addition, several models have been developed by varying specific parameters to investigate their effect on (α,n) and (n,fi ssion) reaction rates. Current practices in fuel processing are to exchange out the small portion of naturally occurring ^{18}O and ^{17}O to limit (α,n) reactions and avoid unnecessary neutron production. However, we have shown that enriching the oxide in ^{18}O introduces a sufficient (α,n) reaction rate to support significant fission rates. For example, subcritical fission rates above 10^8 f/cm^3-s are easily achievable in cylindrical $^{238}PuO_2$ fuel pellets with a ^{18}O enrichment of 100%, given an increase in size and a ^9Be clad. Many viable designs exist and our intent is to discuss current results and future endeavors on this project.

Keywords : radioisotope thermoelectric generators (RTG), Pu-238, subcritical reactors, (alpha,n) reactions
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