Improved Delayed-Neutron Spectroscopy Using Trapped Ions

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ABSTRACT:

The neutrons emitted following the b decay of fission fragments (known as delayed neutrons because they are emitted after fission on a timescale of the b-decay half-lives) play a crucial role in reactor performance and control. Reviews of delayed-neutron properties highlight the need to obtain high-quality data for a wide variety of delayed-neutron emitters as these properties are essential for a detailed understanding of reactor kinetics needed for reactor safety and to understand the behavior of these reactors under various accident and component failure scenarios. With improved nuclear data, the delayed-neutron flux and energy spectrum could be calculated and thus accurately modeled for any fuel-cycle concept, actinide mix, or irradiation history. Trapped radioactive ions suspended in vacuum allow an innovative new way to measure delayed-neutron properties by inferring the neutron energy from the large momentum kick it imparts. When a radioactive ion decays in the trap, the recoil-daughter nucleus emerges from the ~1-mm3 trap volume without scattering and the recoil energy can be measured. The energy of the emitted neutron can be easily and precisely reconstructed from this recoil by conservation of energy/momentum. This ability to measure the nuclear recoil unperturbed enables a novel way to perform delayed-neutron spectroscopy with high efficiency, few backgrounds, and improved energy resolution – avoiding all the well-known challenges associated with detecting neutrons. This recoil-ion technique has recently been successfully demonstrated using the Beta-decay Paul Trap (BPT) equipped with a modest detector array. The research performed under this proposal will focus on collecting high-quality data for the light-mass fission fragments $^{100\text{-}103}$Y and ^{88}As, which have been identified as being particularly important for reactor studies, and demonstrating an advanced measurement technique that can be applied to improve the quality of delayed-neutron data for all the fission products. With the beams just now becoming available from the Californium Rare Ion Breeder Upgrade (CARIBU) facility at Argonne National Laboratory, and an optimized ion trap with a highly-efficient detector array, high-quality measurements of the delayed-neutron branching ratios and energy spectra for these isotopes can be performed. By using fast plastic scintillator detectors for b detection and MCP detectors for recoil-ion detection, the recoil energy will be determined simply from the time-of-flight of and the distance travelled by the daughter nucleus. The high b-ion rates will yield the statistics for a 1% neutron-emission branching ratio and will allow detailed studies of systematic effects and the neutron energy spectrum.