Advancing NMA of TRISO-fueled pebbles using fast and accurate gamma-ray spectroscopy

PI: Dr. Daniel Becker – University of Colorado
Program: FC-3, Material Protection, Accounting and Control Technology

Collaborators: Dr. Mike Dion and Dr. Jianwei Hu – Oak Ridge National Laboratory. Dr. Joel Ullom – National Institute of Standards and Technology. Mr. Mark Croce – Los Alamos National Laboratory.

ABSTRACT:

Pebble-Bed Reactors (PBR) are an emerging nuclear energy technology that has recently received significant funding from the U.S. Department of Energy's Advanced Reactor Demonstration Program. For fuel, these reactors use Tristructural-Isotropic (TRISO) uranium-oxide or uranium-oxycarbide particles mixed into a carbon matrix and compacted to form 60 mm diameter "pebbles", combining moderator and fissile material in one package. A typical reactor design contains hundreds of thousands of pebbles, each of which is cycled through the system multiple times at roughly 1-year intervals.

PBRs require a new approach for Nuclear Material Accountancy (NMA) because each individual pebble contains only a small amount of nuclear material (~ 1 g U-235 per pebble prior to irradiation, ~ 0.25 g Pu at full burnup), but large numbers of pebbles are continually cycled through and eventually removed from the PBR. Upon removal, each pebble must be inspected for mechanical integrity and burnup, and a decision made as to whether to cycle the pebble through the reactor again, or whether to remove the pebble from the reactor entirely. Furthermore, to close accounting gaps throughout the entire fuel cycle and meet safeguards requirements, the actinide content of each "retired" pebble must be accurately quantified prior to disposal or reprocessing.

Prior work has explored using gamma-ray spectroscopy with high-purity germanium detectors to perform burnup measurements on irradiated pebbles. Microcalorimeter spectrometers, which can achieve energy resolutions 10x better than HPGe at energies below 250 keV, have recently emerged as a valuable tool for improving Nuclear Materials Accountancy (NMA), and have potential to improve NMA and Non-Destructive Analysis (NDA) techniques for TRISO-fueled pebbles because of their ability to resolve closely spaced spectral features and improve peak-to-background ratios in NMA measurements.

We propose to extend existing research on gamma-ray spectroscopy of nuclear fuel by carrying out a simulation and modelling program with the aim of determining the capabilities of microcalorimeter and HPGe spectrometers for TRISO-fueled pebbles to determine 1) initial enrichment for input accountancy, 2) burnup with rapid measurements as pebbles are cycled through the reactor, and 3) detailed quantification of actinide content of discharged pebbles. Special emphasis will be placed on quantification of achievable uncertainties in a given measurement time. Our modelling will allow us to define an optimized measurement system that best leverages the strengths of each technology. To aid in validation of our simulations, we will make gamma-ray spectral measurements of irradiated cylindrical TRISO compacts at Oak Ridge National Laboratory (ORNL) with both a microcalorimeter spectrometer and HPGe detectors.

The outcome of this proposal will be new NDA techniques for NMA of TRISO-fueled pebbles using gamma-ray spectroscopy. We will create a detailed measurement plan to monitor burnup and actinide content throughout the fuel cycle. A further outcome of our program will be an evaluation of what technological advances may be required in order to ensure that these measurements can be made in an optimal and time-effective manner, allowing us to develop specific requirements for NMA sensor technology and identify opportunities for focused technology development to meet these requirements.