INTRODUCTION

The elemental concentrations of Pu and U in spent nuclear fuel (SNF) can be determined via non-destructive analysis (NDA) by detecting self-induced x-ray fluorescence (XRF). However, during conventional spectroscopy, the characteristic x-ray peaks of interest lie beneath background and require extended exposure times.

Quartz-crystal spectrometers allow x-rays of selected energies, obeying Bragg’s law for coherent scattering of incident photons, to be focused directly onto a detector. This provides a higher signal with less background by decreasing the possible Compton interaction in the detector.

SPECTROMETER DESIGN

The spectrometer and collimator designs were optimized by simulating the system in MCNP. Also, the quartz crystal parameters were finalized by optimizing the probability of the diffraction of the x-ray energies of interest. Previous experiments investigating wavelength-dispersive spectrometers were performed at much lower energies (<50 keV) and were not for nuclear forensics applications.

Wavelength-Dispersive Spectrometers

Wavelength-dispersive spectroscopy uses a crystal of known properties to diffract x-rays according to Bragg’s Law:

\[ n\lambda = 2d \sin \theta \]  

where \( \lambda \) is the photon wavelength, \( d \) is the crystal’s interplanar spacing, \( \theta \) is the Bragg angle of diffraction and \( n \) is a positive integer. Thus, an array of x-ray energies and their corresponding wavelengths will each have a unique, first-order Bragg angle. This allows for a detector to be positioned specifically for the detection of a desired photon energy.

Spectrometer Design

The transmission-type crystal spectrometer design was chosen after investigating multiple spectrometer styles and diffraction modes. The proposed spectrometer design uses a unique collimation system to block high energy photons from reaching the detector and contributing to background contamination.

Collimator Design

Due to the proposed transmission-type crystal spectrometer design, the diffracted X-rays were expected to be emitted conically from the quartz crystal (Fig. 1). Also, as the X-ray energies of interest were in the 80-130 keV range, the expected angles of diffraction could be calculated using Eq. (1). Using these values, basic geometry was used to design a useable conic collimator that was centered in front of the quartz crystal.

MCNP source definitions simulating SNF were used to simulate the U and Pu K X-rays. Lead (Pb) and tungsten (W) collimators of increasing lengths were simulated to determine the ability to decrease the background radiation in the detector.

RESULTS

Currently, the proposed crystal spectrometer design parameters are being used to obtain a quartz crystal from a manufacturer so that experiments can be performed. From the MCNP results, it was found that the 6 cm and 8 cm long Pb and the W conic collimators sufficiently attenuated the high energy background radiation, primarily from the \(^{137}\text{Cs}\) gamma-rays. Additional figures and quantitative results will be presented at the conference.

REFERENCES