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Neutron spectrometry for nondestructive assay of UF_6 in storage cylinders

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INTRODUCTION

Safeguards activities at uranium enrichment facilities require accurate, independent, and preferably unattended measurements of uranium enrichment and mass for each UF_6 cylinder with contents that are either a process input or output. Current technology relies upon low energy gamma measurements [1] that are effective only to UF_6 mass within few centimeters from the wall of the storage cylinder. Sandia is investigating the use neutron spectrometry to augment the measurement capabilities surrounding UF_6 cylinder verification.

In this work we investigate the use of neutron spectrometry and analysis techniques to augment the unattended and passive measurement capabilities for verification of declared UF_6 enrichment. There are three major contributions to the UF_6 fast neutron energy spectrum in the MeV range: 1) spontaneous fission (SF) neutrons from ^{238}U that extend to about 10 MeV energy, 2) neutrons produced by nuclear reaction of alpha particles emitted by ^{234}U with Fluorine atoms, $^{19}F(\alpha, n)^{22}Na$, with a mean energy of ~1 MeV and maximum of about 2.5 MeV, and 3) induced fission neutrons that may range up to 10 MeV. Figure 1 shows neutron spectra from 1 and 2 mentioned above.

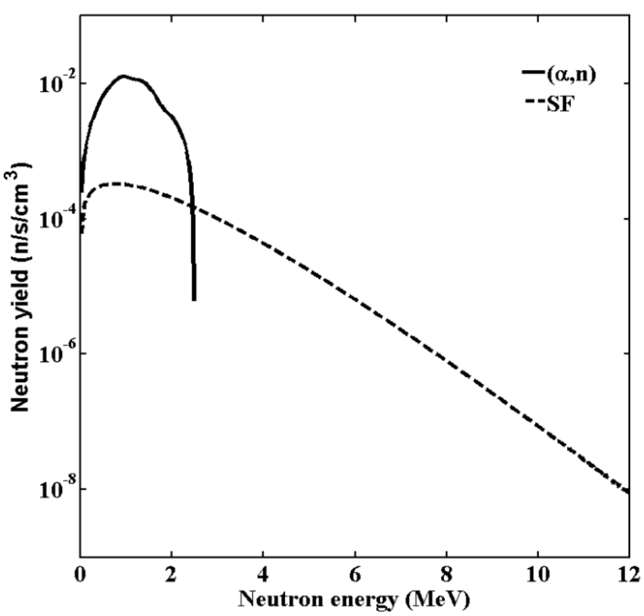

Figure 1. The neutron spectrum components for 5% enriched UF_6.

METHODS

The Sandia developed neutron scatter camera (NSC) was used to measure neutron spectrum from combined AmF and Cf-252 sources that emulate the UF_6 neutron spectrum in 30B storage cylinders. Source arrangements and setups were made to enable the imitation of varying enrichments in the UF_6 spectra. Source measurement validation was made using MCNP5 simulations.

a) Neutron spectrum measurement

The NSC, shown in Figure 2, with the double scatter technique has previously been used for solar neutrons and neutron generator measurements [2]. The NSC has been designed to be sensitive to fission energy sources between 1 and 10 MeV and consists of 32 EJ-309 liquid scintillator cells arranged in two planar arrays of each with 16 cells. Each cylindrical cell is optically coupled to a single photomultiplier tube (PMT). A key to the operation of the NSC for neutron detection is the ability to discriminate between neutrons and gammas (and muons etc). This is achieved by a combination of pulse shape discrimination (PSD) and time-of-flight (TOF) discrimination between coincident events.

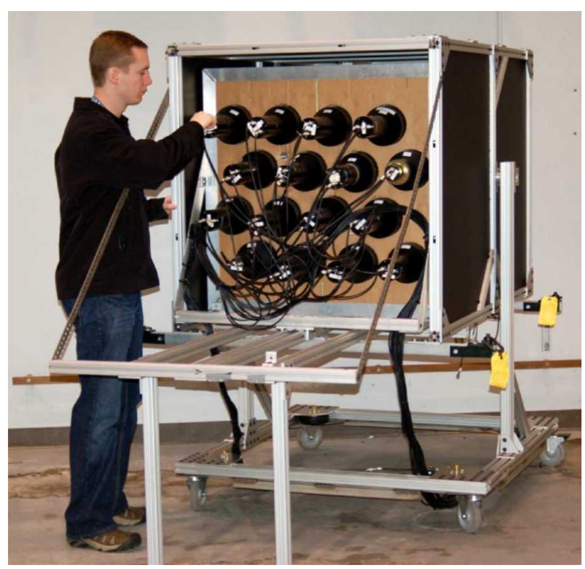

Figure 2. The neutron Scatter Camera deployed for neutron spectrum measurement.

b) Neutron spectrum analysis

Principal Component Analysis (PCA), among other possible techniques, was used to analyze the measured neutron spectra from the combined AmF and Cf-252 sources. The PCA technique is a mathematical technique involving a procedure that transforms a number of correlated variables into uncorrelated variables called principal components (PCs) [3]. The PCA technique has proven to be advantageous in various fields for data characterization, feature analysis, anomaly detection, image classification, gamma-ray spectral analysis, etc. The goal in PCA analysis is: 1) the reduction in the dimensionality of the data set, and 2) identification of underlying meaningful variables or features in the data set. Spectra measured using the combined sources for varying source arrangements were analyzed using the PCA technique for recognition of features that are attributes of the measured neutron spectra. Each measured neutron spectrum, based on the source arrangements used, has features that emulate UF_6 enrichment that can be discriminated using techniques similar to PCA.

c) Neuron source validation

MCNP5 was used to simulate the neutron transport through the combined AmF and Cf-252 source setup enclosed in a steel container. Several source arrangements and configuration involving a series of shielding materials and containers were used to emulate the UF_6 spectra and enable implementation in the NSC measurements. MCNP5 PTRAC card was used to record the energy deposition within the NSC detectors used in the measurement.

RESULTS

Typical neutron pulse height spectrum simulated using the NSC detector is shown in Figure 3. Figure 4 shows plot of PCs using simulated source-detector setup.

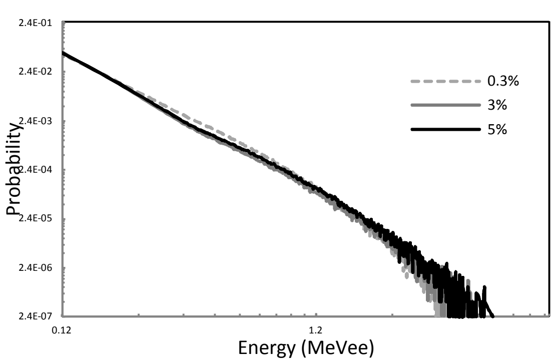

Figure 3. Typical neutron pulse height spectrum (PHS) plotted for source arrangements to emulate 0.3%, 3%, and 5% enriched UF_6.

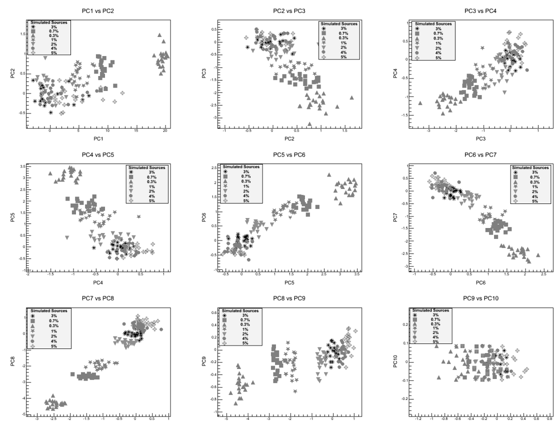

Figure 4. Plot of principal components (PCs) using simulated source-detector setup.

It was observed that discrimination of enrichments is possible by including more PCs in the analysis. Based on the present work it has been proved that neutron spectrometry has the advantage of overcoming problems observed in the current state-of-the-art techniques that include passive and active approaches. Neutron spectroscopy coupled to spectral feature analysis techniques, such as PCA, has proved promising in the verification of declared UF_6 enrichments for safeguards application. Future measurement using Sandia's NSC has been planned at UF_6 enrichment and storage facilities for further validation of neutron spectrometry and analysis technique implemented in the present work.

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