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Nondestructive assay of UF_6 in 30B storage cylinders using the Neutron Scatter Camera

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INTRODUCTION

Measurement of the ^{235}U enrichment and mass in UF_6 storage containers is of great interest in nuclear material nonproliferation. Nondestructive assay (NDA) techniques are commonly used for safeguards inspections to ensure accountancy of declared nuclear materials. In the present study, Principal Component Analysis (PCA) technique is investigated for effective discrimination of UF_6 enrichment in 30B storage cylinders. The PCA technique was implemented using MCNP5 and Geant4 simulated neutron energy spectra for selected ^{235}U enrichments and filling profiles.

Neutron Scatter Camera

The neutron scatter camera (NSC) is a passive standoff fast neutron (1-10MeV) and gamma radiation detector/imager for use in nuclear nonproliferation applications. The NSC is composed of Liquid Scintillator detectors coupled to photomultiplier tubes (PMT)[1].

MCNP5-Geant4 Simulations

Sandia developed NSC was modeled to simulate neutron spectrum from UF_6 in 30B storage cylinder using MCNP5 and Geant4 tools[2][3]. Neutrons from UF_6 cylinder were transported using MCNP5 until incident on NSC (see Figure 2). The incident neutrons were further transported in the NSC using Geant4. MCNP5 transports neutrons through UF_6 faster. Geant4 enables discriminating particles depositing energy within the NSC.

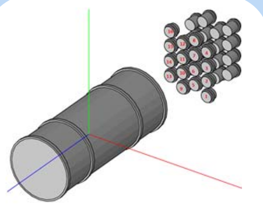

Figure 1. Schematic of simulated 30B cylinder and NSC

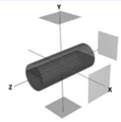

Figure 2. Rectangular surfaces where neutrons are incident on NSC.

Figure 3. Schematic of simulated UF6 filling profiles.

UF_6 enrichments were varied between 0.3 at% to 12 at%. SOURCE 4C[4] was used to determine the isotopic energy distribution . Five different filling profiles, shown in Figure 3, were used based on Berndt et al.[5] description.

Simulated Spectra

Simulated neutron energy spectra from each cell of the NSC were folded with detector response function. Measured light yield and energy resolution were used. Folding the detector response to simulated energy spectra makes discrimination of UF_6 enrichment difficult.

There are subtle differences in the detector response folded spectra that may not be easy to determine using common technique. An appropriate statistical technique that can discriminate such differences will be helpful in the analysis of UF_6 enrichments.

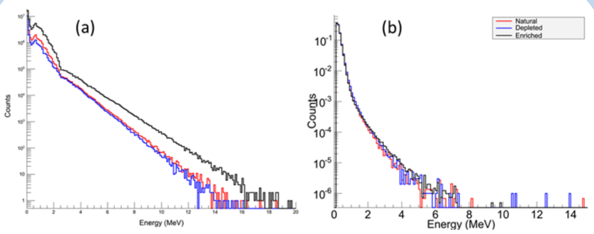

Figure 4. Typical simulated spectra (a) Before folding detector response (b) After folding detector response (Normalized)

Principal Component Analysis (PCA)

PCA is a technique that allow representation of data having many variables with a few set of significant variables. Data dimensionality reduction is key aspect without losing characteristic data features.

PCA will enable characterize or learn the trend for declared ^{235}U enrichment, mass, and filling profile. Diversionary scenario with undeclared ^{235}U enrichment may be detected as an anomaly or outlier using PCA.

Preliminary Result

Each simulated spectrum was divided into nine energy groups. PCA was trained using all simulated spectra. Figure 5 shows the PC plots. Clearly the first Principal components (PC's) is the most significant. The considered enrichments, depleted, natural, and 5 at% are all discriminated using PC1. However training the PCA using the natural spectra results in almost all PCs being significant (See Figure 6). Investigation is being made to determine the appropriate approach for training the PCA in the context of UF_6 NDA.

Metric is being developed using the Mahalanobis distance for quantitative discrimination.

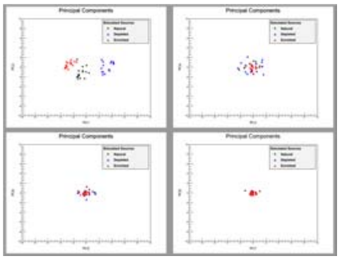

Figure 5. Plot of principal components determined using depleted, natural, and 5 at% enriched UF_6. All spectra from the different enrichments were used to train the PCA.

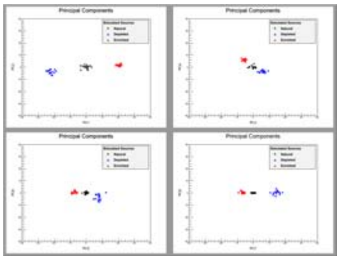

Figure 6. Plot of principal components determined using depleted, natural, and 5 at% enriched UF_6. The natural UF_6 was used to train the PCA.

References

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5. Berndt. R, Franke. E, Mortreau. P, "^{235}U enrichment or UF_6 mass descrimination on UF_6 cylinders with non-destructive analysis methods," *Nucl. Instr. Meth.*, A612, 2010, pp. 309-319.

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