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Statisticial Signal Processing and Artificial Intelligence Applications in the Nondestructive Assay of U/Pu Bearing Materials

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Over the years a number of techniques have been developed to determine the quantity and distribution of radiative isotopes contained in given assay samples through the measurement and analysis of penetrating characteristic radiations. An active technique of particular utility when assaying samples containing very small quantities of fissionable material or when high gamma ray backgrounds are encountered is the delayed neutron nondestructive assay (DN-NDA) technique.[1,2,3,4] Typically, analysis of the delayed neutron signal involves relating the gross delayed neutron count observed following neutron irradiation of an assay sample to total fissionable material present via a linear calibration curve.[1,3,4] In this way, the technique is capable of yielding the mass of a single dominant fissionable isotope or the total fissionable mass contained in a sample. Using this approach the only way to determine the mass of individual fissionable isotopes contained in a sample is to correlate *total* fissionable mass to individual isotopics via calculations or other means, yielding an *indirect* measure of isotopics. However, there is isotope specific information in the temporal delayed neutron signal due to differences in the delayed neutron precursor yields resulting from the fissioning of different isotopes.

We present the results of an analysis to evaluate the feasibility of using Kalman filters[5] and genetic algorithms[6] to determine multiple specific fissionable isotopic masses contained in an assay sample from a cumulative delayed neutron signal measured following neutron irradiation of the sample. Delayed neutron measurement data were generated to simulate the ideal response of the leached fuel clad monitor located at Argonne National Laboratory - West (ANL-W).[7] The simulated measurement data were generated by calculating the cumulative delayed neutron count following the irradiation of a sample containing 5.9 g ^{238}U, 9.8 g ^{235}U, 16.9 g ^{239}Pu, and 3.1 g ^{240}Pu. Data were simulated for ~14 MeV neutron irradiation and irradiation with a moderated neutron beam with average neutron energy of ~200 eV, which yields a larger fissile/fertile fission ratio than the 14 MeV irradiation.

The simulated measurement data, with various levels of random noise superimposed, were analyzed using both the Kalman filter and genetic algorithm, details of which are beyond the scope of this summary. For both the genetic algorithm and Kalman filter, the 14 MeV and 200 eV data were processed simultaneously. The mass of ^{240}Pu is assumed known from coincidence measurements and *a priori* masses were chosen to be 50% in error from correct values. The Kalman filter was executed in successive iterations on the same data set with the *a priori* for a given iteration taken to be the best estimate from the previous iteration with the covariance matrix reset at each iteration to avoid filter saturation. Because of this, uncertainties for the Kalman filter estimates are biased and therefore not reported. To obtain an estimate of the uncertainty of each mass estimate and improve the accuracy of the estimates obtained using the genetic algorithm, batches of genetic algorithms were run for each case. The predicted mass was then taken to be the average of the individual estimates from the 50 batches and the uncertainty calculated as the standard deviation of the population of estimates about the mean. The genetic algorithm represented the masses of each isotope as a string of 11 binary bits on a chromosome.[6] The fitness (accuracy of mass estimate) of each chromosome was evaluated at each generation by comparing the calculated delayed neutron emission (calculated from a model developed using calibration data) resulting from the given mass estimates with the measured delayed neutron signal. The results of the analyses are presented in Table II and show mass estimation accuracies better than 3% for the Kalman filter and better than 6% for the genetic algorithm with 10% Gaussian noise on the simulated measurement data.

Table I: Mass Estimates[a]

Isotope	Kalman Filter Results N(0, 2%) Noise on Measurement	Kalman Filter Results N(0, 10%) Noise on Measurement	Genetic Algorithm Results[b] N(0, 2%) Noise on Measurement	Genetic Algorithm Results[b] N(0, 10%) Noise on Measurement
^{238}U	5.91 (0.2%)	5.97 (1.3%)	5.72±0.37 (-3.1%)	5.73±0.37 (-2.9%)
^{235}U	9.95 (1.5%)	9.68 (-1.2%)	9.98±1.06 (1.8%)	9.41±1.18 (-4.0%)
^{239}Pu	16.69 (-1.3%)	17.32 (2.5%)	16.71±1.77 (-1.1%)	17.84±1.96 (5.6%)
^{240}Pu	3.10 (0.0%)	3.10 (0.0%)	3.10±0.00 (0.0%)	3.10±0.00 (5.6%)

a. Percent deviation from actual in parentheses.
b. 50 batches, 2500 generation; Mutation probability=65%, crossover probability=5%.

The results of the study demonstrate the feasibility of extracting isotope specific information from a cumulative delayed neutron measurement using statistical signal processing and artificial intelligence techniques, thus providing a direct measure of Pu content in an U/Pu bearing sample. Performance of the techniques using actual measurement data will be evaluated in the near future with success most likely depending strongly on the ability to acquire very accurate calibration data.

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