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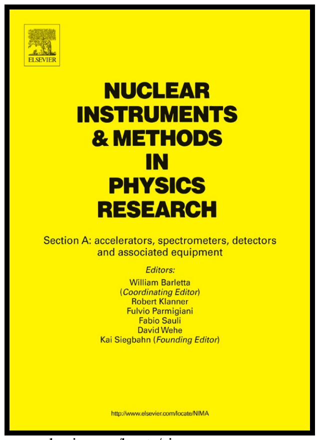

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SENSITIVITY ANALYSIS OF HIGH RESOLUTION GAMMA-RAY DETECTION FOR SAFEGUARDS MONITORING AT NATURAL URANIUM CONVERSION FACILITIES☆

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Abstract

Under the policies proposed by recent International Atomic Energy Agency (IAEA) circulars and policy papers, implementation of safeguards exists when any purified aqueous uranium solution or uranium oxides suitable for isotopic enrichment or fuel fabrication exists. Under IAEA Policy Paper 18, the starting point for nuclear material under safeguards was reinterpreted, suggesting that purified uranium compounds should be subject to safeguards procedures no later than the first point in the conversion process. In response to this technical need, a combination of simulation models and experimental measurements were employed in previous work to develop and validate gamma-ray nondestructive assay monitoring systems in a natural uranium conversion plant (NUCP). In particular, uranyl nitrate ($UO_2(NO_3)_2$) solution exiting solvent extraction was identified as a key measurement point (KMP). Passive nondestructive assay techniques using high resolution gamma-ray spectroscopy were evaluated to determine their viability as a technical means for drawing safeguards conclusions at NUCPs, and if the IAEA detection requirements of 1 significant quantity (SQ) can be met in a timely manner. Building upon the aforementioned previous validation work on detector sensitivity to varying concentrations of uranyl nitrate via a series of dilution measurements, this work investigates detector response parameter sensitivities to gamma-ray signatures of uranyl nitrate. The full energy peak efficiency of a detection system is dependent upon the sample, geometry, absorption, and intrinsic efficiency parameters. Perturbation of these parameters translates into corresponding variations of the 185.7 keV peak area of the ^{235}U in uranyl nitrate. Such perturbations in the assayed signature impact the quality or versatility of the safeguards conclusions drawn. Given the potentially high throughput of uranyl nitrate in NUCPs, the ability to assay 1 SQ of material requires uncertainty << 1%. Accounting for material self-shielding properties, pipe thickness, and source-detector orientation is instrumental in determining the robustness of gamma-ray detection in the process monitoring of uranyl nitrate in NUCPs. Monte Carlo models and ray-tracing models were employed to determine the sensitivity of the detected 185.7 keV photon to self-shielding properties, pipe thickness, and source-detector geometry. Considering the implementation of the detection of 1 SQ, diversion of 1 SQ becomes essentially undetectable given the systematic uncertainty, in addition to considerations such as propagating uncertainties due to pipe offset/position, as well as minor variations in pipe thickness. Consequently, pipe thickness was the most sensitive variable in affecting full energy efficiency of the 185.7 keV signature peak with up to 8% variation in efficiency for ±0.5 mm changes in Schedule 40 304L stainless steel piping. Furthermore, computation of the attenuation correction factor of the uranyl nitrate solution [CF(AT) (i.e. ε_{sample})] using Parker's method using with the approximation for the geometrical factor $\kappa \approx \pi/4$ was validated through experimental, Monte Carlo and ray-tracing calculations for a uranyl nitrate filled transfer pipe segment. Quantifying sensitivity in detector position, as well as voiding effects due to bubbly flow or laminar flow with an air gap in the uranyl nitrate becomes increasingly important as considerations from (static) design-scale measurements translate into (dynamic) field operations tests.

Keywords: natural uranium, international safeguards, conversion, significant quantity, gamma-ray detection, efficiency, self-attenuation, nondestructive assay, ISOCS, validation, Monte Carlo

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