

Machine-Learning Assisted Plutonium Quantification Using High-Purity Germanium Gamma Detectors

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Accurate quantification of plutonium concentration is essential to nuclear safeguards, materials accountability, and environmental stewardship and is governed by federal regulations and institutional directives requiring defensible analytical methods. Current analytical methods for quantifying plutonium require a combination of isotopic determination using High-Purity Germanium (HPGe) gamma spectroscopy coupled with an additional method to determine sample activity. Complementary approaches such as calorimetry and neutron counting are effective but time consuming and logistically intensive within the operating bounds of the facility. We propose a rapid, single-measurement method that integrates HPGe spectroscopy in a fixed, well-characterized geometry coupled with machine learning based regression to provide absolute quantification in a quick and singular measurement.

A major factor that contributes to the analytical uncertainty and computational load is Compton continuum, the removal of which requires either simple linear removal or higher-order approaches such as Whitaker filtering. These approaches introduce additional uncertainty and processing overhead. By establishing a geometry that allows the sample to be considered a point source, the effects of Compton background should be minimized, simplifying these corrections and improving peak isolation.

The use of fixed geometry also enables the development of robust calibration curves based on known, non-interfering gamma lines with well-characterized emission probabilities. Limiting the machine-learning input space to explicitly defined peak features improves stability and preserves physical interpretability of the model. Because the method operates on selectively specified peaks, it can be extended to additional isotopes without modification to the measurement configuration, allowing for greater flexibility.

This framework is intended to reduce assay time and operational burden while maintaining analytical rigor for plutonium quantification, within the established safety systems and envelope of the facility.