# Integrating high-resolution gamma-ray spectroscopy into nuclear process monitoring

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**ABSTRACT:**

We will demonstrate that high-resolution γ-ray spectroscopy with emerging microcalorimeter sensors can determine elemental and isotopic fractions with sufficient accuracy to displace much slower mass spectrometry in many safeguards scenarios. Integrating more accurate elemental and isotopic fractions with data on total activity or mass will produce more accurate measurements of elemental and isotopic masses, the fundamental quantities of nuclear materials accounting. We will also use microcalorimeter sensors to improve knowledge of x-ray and γ-ray line energies that are currently a source of systematic error in analyses performed by ubiquitous germanium sensors. These advances will prevent the diversion of nuclear material by enabling nearly real time process monitoring without loss of measurement accuracy.

The size of the material flows at large nuclear facilities poses a significant safeguards challenge. Traditional material inventories are temporally sparse and have 1% uncertainty levels. As a result, they cannot rule out the diversion of enough fissile material for one or several nuclear weapons. Traditional inventories rely heavily on mass spectrometry which requires extensive sample preparation and therefore is slow. Slow techniques are also expensive; the safeguards for one large reprocessing facility currently consume 20% of the IAEA's total safeguards budget [Johnson, 2009]. In contrast, γ-ray spectroscopy requires little to no sample preparation and thus is intrinsically fast and inexpensive. These aspects of γ-ray spectroscopy are well matched to near real time accountancy which is the preferred safeguards approach for more timely and accurate inventories at a large facility. However, germanium γ-ray spectrometers are not capable of determining elemental and isotopic fractions with sufficient accuracy.

Recent investment by DOE NEUP has produced a revolutionary microwave readout technology that provides 500x more measurement bandwidth for arrays of cryogenic microcalorimeters. These unusual γ-ray sensors achieve energy resolution as good as 22 eV FWHM at 97 keV, compared to almost 500 eV for germanium sensors [Bacrania, 2009]. This improved energy resolution can reduce both statistical and systematic errors in elemental and isotopic fractions compared to germanium measurements [Hoover, 2014]. Individual microcalorimeters count slowly, so multi-sensor arrays and array readout technology are required. Previous work on microwave readout has culminated in the construction of a field-leading microcalorimeter γ-ray spectrometer called SLEDGEHAMMER whose count rate is sufficient for practical materials analysis for the first time in the history of microcalorimeter technology.

Here, we will use the SLEDGEHAMMER instrument to measure fuel-cycle relevant materials in measurement campaigns at Los Alamos and Savannah River National Laboratories. For example, we have identified sample points at SRNL's H-Canyon reprocessing facility that provide access to material that is representative of the input, separations, output, and waste stages of any large aqueous reprocessing plant. We will develop techniques to extract elemental and isotopic fractions from microcalorimeter data and compare our results to measurements of the same samples performed with germanium and mass spectrometry. Finally, we will use the unique properties of microcalorimeter data to determine the energies of poorly known spectral features that are currently an important source of systematic error.