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What We Learned By Measuring Billions Of Counts with an Operational 256-Pixel Microcalorimeter Gamma-Ray Spectrometer: Lessons for the Next Wave of X-ray & Gamma-ray Arrays

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Gamma-ray spectroscopy with microcalorimeter spectrometers has transformative potential for nuclear forensics, international safeguards, treaty verification, and improving basic nuclear data. We now have a very large body of real data, literally billions of counts in the spectra, from real gram-quantity special nuclear material of various isotopic and chemical compositions. These data were collected with an operational, 256-pixel microcalorimeter gamma-ray spectrometer with average resolution of ~70 eV at 100 keV (resolving power E/DE~1400). A detailed look at these data is instructive for understanding system performance, thinking deeply about measurement uncertainty for quantitative materials analysis, and extracting lessons for the anticipated wave of kilopixel microcalorimeter X-ray and gamma-ray arrays. For

over three decades, gamma-ray isotopic non-destructive analysis of special nuclear material has operated with an effective ~1% barrier in uncertainty for isotopic ratios or fractions. This barrier forces world nuclear safeguards to rely instead on radiochemical destructive analysis that is more costly, more hazardous, and that has weeks to months of latency. Using a 256-pixel microcalorimeter gamma-ray spectrometer, we have recently demonstrated the first concrete evidence indicating that the 1% barrier can be overcome with potential improvement to ~0.1-0.2%. Ultra high resolution microcalorimeter spectra have an inherent immunity to systematic uncertainties in tabulated peak centers, an immunity that is not shared by conventional semiconductor spectra. However, through a process similar to cross calibration, this immunity is potentially transferable from benchmark microcalorimeter experiments to worldwide use of HPGe sensors. A similar approach is being pursued in X-ray materials analysis, with benchmark measurements of characteristic X-ray peak centers and shapes being measured with improved precision informing independent analyses of different materials with lower resolution sensors (e.g. SDDs). The extent to which this approach will work is under experimental investigation. In the gamma-ray case, benchmark experiments for measuring reformulated basic nuclear data are not feasible with current hardware due to limited speed and efficiency (single runs require ~100 hours). Similarly, current hardware is not suitable for use in operational nuclear facilities due to high complexity and measurement times of 6-24 hours, well out of range of the <1 hour target at reprocessing facilities or of customary IAEA field practice (<20 min). The development of sensor arrays and readout with thousands of pixels will reduce all of these measurement times by more than a factor of twenty. Improvement in readout simplicity and spectrometer ease of use will also be needed.