# A large-scale demonstration of TES microcalorimeters: The SLEDGEHAMMER gamma-ray spectrometer

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Microcalorimeters based on transition-edge sensors (TESs) have been successfully deployed in numerous spectroscopic instruments that operate over a large range of incident photon energies. TES microcalorimeter arrays combine unmatched energy resolution with broadband spectral coverage and high quantum efficiency. An important application requiring these characteristics is non-destructive isotopic analysis with gamma-ray spectroscopy of the complex mixtures of actinide isotopes found in the nuclear fuel cycle. The precision of existing gamma spectroscopy methods is insufficient to safeguard large facilities. Higher-precision methods are slow, labor-intensive, and destructive to the sample. Steady progress has been made over the last 10 years developing TES microcalorimeter instruments with this capability, leading to the development of arrays demonstrating significantly better energy resolution than state-of-the-art High-Purity Germanium (HPGe) detectors. Previous gamma-ray measurements with TES arrays have demonstrated lower uncertainty than HPGe and shown the potential to reduce reliance on destructive analysis. However, TES arrays with much higher count rate capability are needed to (1) match the measurement speed of HPGe, and (2) assess and minimize the systematic errors in deduced material composition.

To achieve these count rates, over the past few years our group has developed a new readout technology: the microwave superconducting quantum interference device (SQUID) multiplexer. Using microwave based readout increases the available readout bandwidth from a few MHz to several GHz, allowing many more devices to be read out as well as supporting readout of much faster individual devices.

The microwave SQUID multiplexer has now matured to the point where it has been deployed with the SLEDGEHAMMER gamma-ray spectrometer. This pathfinder instrument currently consists of 256 TES microcalorimeters read out using the microwave SQUID multiplexer, and will be increased to 512 TES microcalorimeters later in the program. This instrument has already been taken to Los Alamos National Laboratory and used to measure the isotopic content of a wide variety of samples relevant to actinide accounting during the nuclear fuel cycle, including plutonium isotopic standards and a sample containing fission products taken from spent reactor fuel. We describe the development of the instrument, present spectra of measured samples, and discuss prospects for further improvements in system performance. We also describe planned applications of the microwave SQUID multiplexer to spectrometers operating at other energy ranges, where both the total bandwidth and per-detector bandwidth are crucial for successful deployment of instruments.

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