MPACT
Materials Protection Accounting and Control Technologies

U.S. DEPARTMENT of ENERGY | Office of Nuclear Energy

FY2025 QUARTER 3 NEWSLETTER

Materials Protection Accounting and Control Technologies (MPACT) Quarterly Newsletter

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Program Manager Note

Happy Spring everyone!

Just as everything is starting to bloom here in North America, I am excited by all the U.S. nuclear activities getting underway. U.S. nuclear is on the move! Let me start this quarterly newsletter with some interesting activities I am following.

We have all been watching the advanced reactor development over the past few years. With many promising designs coming into focus, attention is turning to the rest of the fuel cycle to support these designs. Obviously, a critical fuel cycle component is fuel supply. Many of the advanced reactor designs call for slightly higher uranium enrichments (up to 5%) or even higher enrichments called high assay low enriched uranium. These higher enrichments and fuel designs require modified or all new fuel fabrication facilities and infrastructure. MPACT is one of the programs supporting U.S. nuclear energy by developing material control and accounting (MC&A) technologies for these new facilities. From modeling fuel fabrication for domestic safeguards assessments to instructing the next generation of safeguards practitioners and developing real-time holdup measurement tools, MPACT commits to developing tools for the safe and secure future of nuclear energy in the U.S.

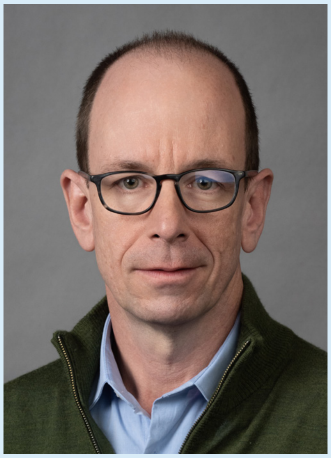
Our sister program, the Advanced Reactor Safeguards and Security program held its spring meeting in April. The program addresses cyber and physical security as well as MC&A needs for advanced reactors. The great work this program is doing highlights the need to ensure that all advanced fuel cycle MC&A needs are addressed. To that end, MPACT kicked off a new activity this year, the Comprehensive Fuel Cycle MC&A Initiative. MPACT traditionally focuses on facility-level MC&A technology development to support the U.S. nuclear fuel cycle. With the advent of the advanced reactors being designed, the U.S. fuel cycle may begin to look significantly different than it does today. New facility types, new material types, the potential for facilities that combine activities of multiple traditional facilities, and the potential for facilities for which there is no Nuclear Regulatory Commission guidance may challenge our traditional views of MC&A systems. The initiative's goal is to identify potential gaps in MC&A technologies and approaches for these new facilities and the spaces between traditional U.S. nuclear fuel cycle facilities. The fiscal year 2025 product of this initiative will be a summary report to guide MPACT technology developments in FY-26 and beyond. We welcome any thoughts you may have to help us with this effort!

Finally, we are preparing for our own annual meeting on June 24-26, the week after the American Nuclear Society annual meeting. Our meeting offers MPACT researchers a chance to present their work to colleagues and engage in technical discussions related to domestic safeguards. While our annual meeting is not open to the public, we are considering an open Q&A session about our program and how to get involved. Please watch our website for updates.

Thanks for reading our quarterly newsletter!

Tansel Selekler

MPACT FEDERAL PROGRAM MANAGER



Principal Investigator Profile: *Daniel Becker, Ph.D.*

Daniel Becker is a research associate at the University of Colorado and a member of the National Institute of Standards and Technology's Quantum Sensors Division (QSD). He has worked in the fields of low temperature sensors, electronics and cryogenic systems since 2006. He leads the QSD's efforts to develop and deploy gamma-ray spectrometers using cryogenic microcalorimeters. In close collaboration with Los Alamos National Laboratory, his team has deployed spectrometers to four Department of Energy labs for use in nuclear accounting and safeguards applications. The team also deployed gamma-ray spectrometers to two international beamline facilities and flew the first microcalorimeter gamma-ray detectors in a scientific balloon mission. Becker has a strong interest in creating automated data analysis pipelines and in modeling microcalorimeter detectors. He was a member of the QSD team that developed the microwave SQUID multiplexer, a new microwave-frequency multiplexed readout system for low-temperature detectors. As a graduate student working in the QSD, he built a video-rate passive imaging system operating at 350 gigahertz using cryogenic detectors, and he designed microwave components for cryogenic detectors that have been deployed in multiple cosmic microwave background observatories. Prior to his scientific career, Becker worked for 12 years as a computer programmer and consultant.

Principal Investigator Profile: *Devin Rappleye, Ph.D.*

Devin Rappleye is the director of the Pyrochemical Research and Operations (PyRO) lab at Brigham Young University (BYU), where he leverages his 14-plus years of experience in pyrochemical research and operations to mentor and develop students. His work focuses on advancing electrochemical techniques and sensors for molten salts, improving and innovating pyrochemical processes, and developing hydrodynamic electrodes for molten salts.

Before joining BYU, Rappleye worked at Lawrence Livermore National Laboratory for four years, where he conducted and developed pyrochemical operations. His doctoral and postdoctoral research centered on developing electroanalytical techniques and analysis for complex molten salt mixtures containing multiple analytes.

Rappleye's education includes a Ph.D. in metallurgical engineering from the University of Utah (2016), a master's degree in nuclear engineering from North Carolina State University (2013), and a bachelor's degree in chemical engineering from BYU (2010). His research interests encompass electrochemical processing, electroanalytical techniques and the purification of rare earths.

In addition to his research, Rappleye is the editor of Reviews, Analyses, and Instructional Studies in Electrochemistry, an open-access journal aimed at bridging the gap between broad textbooks and advanced scientific studies in electrochemistry. He is dedicated to mentoring the next generation of electrochemists and electrochemical engineers through rigorous and accessible research publications.

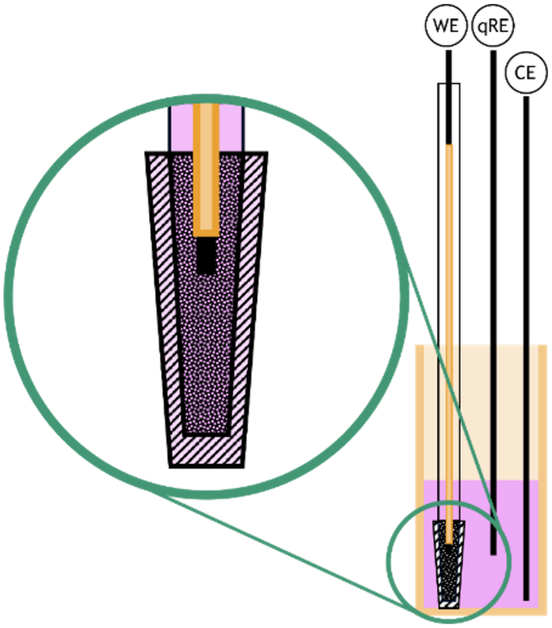
Under Rappleye's leadership, the PyRO lab at BYU has a dual aim: advancing research in pyrochemical processes and electrochemistry while fostering the development of individuals within the lab. This environment encourages both scientific innovation and personal growth, ensuring that team members are equipped for future challenges in their careers.

Outside of his professional interests, Rappleye enjoys reading good books, writing poetry and exploring the outdoors through hiking, skiing and rafting with friends and family.

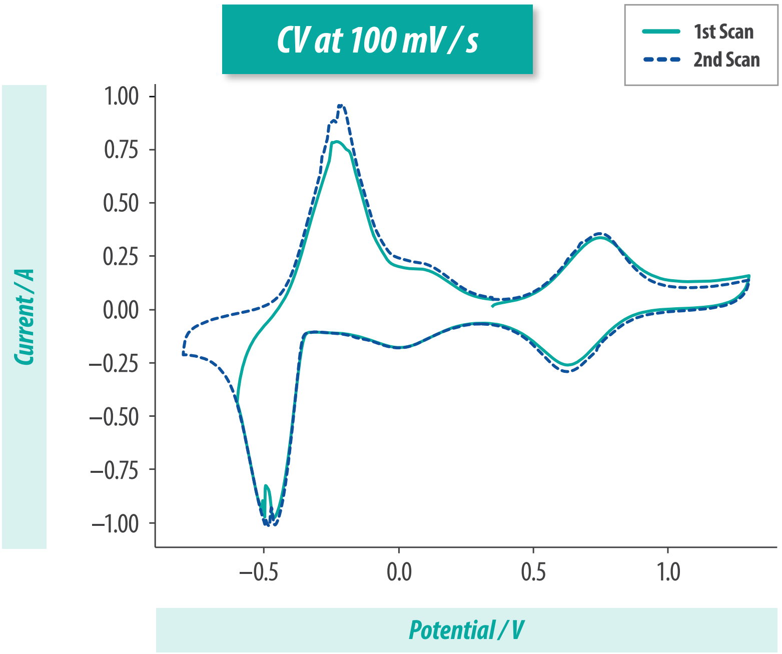
MPACT Technical Update Highlight – *TLES*

Several material control and accounting (MC&A) applications are intrinsically linked with molten salt electrolytes (e.g., molten salt reactors, electro refiners). Spectroscopy and electrochemistry are often cited as the go-to strategies for real-time analyses associated with MC&A, but electroanalytical methods are less established when the analyte is concentrated because of complicated mass transfer mechanisms. Brigham Young University and Argonne National Laboratory are teaming up to develop thin-layer electrochemical sensors (TLES) that greatly simplify the mass transfer of analytes to the electrode and, therefore, the analysis of electrochemical data.

Brigham Young University is preparing a couple TLES designed to operate in molten chloride salts, optimizing apparatuses in uranium bearing molten chloride salts. This summer, the university team will bring its TLES to Argonne National Laboratory for tests in a plutonium bearing molten chloride salt. The current iteration of the TLES uses a packed bed of graphite powder (74-104 µm) as the electrode. The extremely small spaces between the graphite particles ensure that the mass transfer for the solution between the graphite particles can be neglected. With no mass transfer, Faraday's law and simple thermodynamics and kinetics are primarily required to model the system.



*The image above contains a diagram of the electrochemical cell **(right)**, picture of the bottom of a TLES after an experiment in UCl_3-LiCl-KCl **(upper left)** and powdered graphite after the sieving process (top right), and cyclic voltammogram data demonstrating the bell-shaped curves returning to baseline current that is typical for electrochemical reactions with no mass transfer **(bottom left)**.*



Cyclic voltammogram (CV) data demonstrating the bell-shaped curves returning to baseline current that is typical for electrochemical reactions with no mass transfer.

MPACT Technical Update Highlight – *Nuclear Material Accountancy of TRISO-Fueled Pellets*

This project aims to develop and evaluate nondestructive assay techniques for TRISO-fueled pebbles to support nuclear material accountancy across the pebble bed reactor fuel cycle. We're focused on enabling rapid, reliable measurements of in-reactor burnup and actinide content at discharge — with particular attention to measurement uncertainty and throughput constraints. These capabilities are essential for safeguards and fuel management in high-throughput systems where individual pebbles contain gram-scale quantities of nuclear material.

Our approach combines detailed simulations with experimental gamma-ray spectroscopy using both high purity Germanium (HPGe) and microcalorimeter detectors. We believe that HPGe and microcalorimeters are complementary, with the superior resolution of microcalorimeters below 250 keV providing improved peak separation and background rejection in complex spectra. By modeling and validating measurements on irradiated TRISO compacts at ORNL, we aim to define optimal detector configurations, assess achievable performance metrics, and identify key requirements for future nondestructive assay sensor technologies.

A key outcome of HPGe and microcalorimeter measurements of irradiated AGR2 and AGR5/6/7 compacts was demonstrating that microcalorimeter systems can quantitatively resolve the X-ray peaks of uranium and plutonium in irradiated fuel spectra. In these items, the lines originate mostly from self-fluorescence of uranium and plutonium atoms, making them promising signatures for passive, nondestructive determination of plutonium/uranium ratios [1]. Of particular interest are the closely spaced U Kα_1 (98.4 kiloelectron volt) and Pu Kα_2 (99.5 kiloelectron volt) lines, where the similarity in detection efficiency simplifies interpretation.

On the modeling side, we have SCALE/ORIGEN models of the irradiated compacts that we measured, as well as irradiated pebbles, which provide us with the radionuclide content of the items post-irradiation. We have also completed Monte Carlo models of both compacts and pebbles, including beta-decay and bremsstrahlung effects, and are nearly complete with models of detectors. We can combine all three types of models to produce simulated spectra for any of the modeled items at any cooling time. Figure 1 shows a comparison of the measured and simulated spectra in the U Kα_1 and Pu Kα_2 X-ray region. We are using these models to identify additional potential burnup signatures and to quantify achievable measurement uncertainties.

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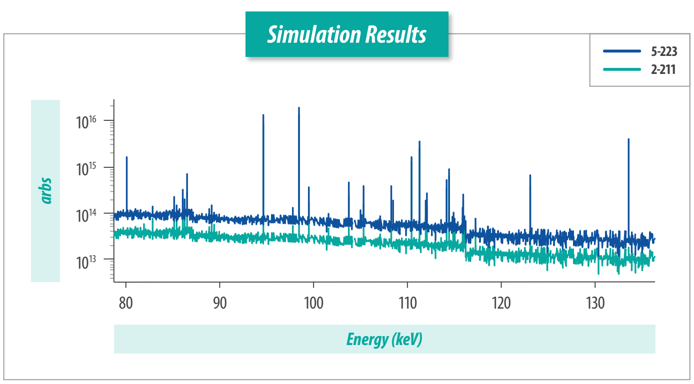

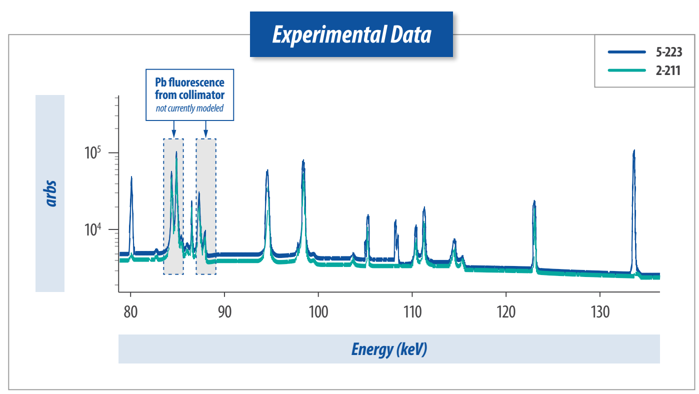

A comparison of microcalorimeter spectra for the 5-223 (blue) and 2-211 (teal) compact, both experimentally collected (right plot) and simulated (left plot). The simulated spectra show the same peaks as the experimental data, with the exception of Pb fluorescence from the collimator, which was not included in this simulation. The two most prominent differences between 5-223 and 2-211 are the presence of strong 133.5 keV and 80.1 keV Ce144 peaks in the 5-223 compact that are not present in the 2-211 compact.

[1] A. S. Hoover et al. Measurement of Plutonium in Spent Nuclear Fuel by Self-Induced X-Ray Fluorescence. Tech. rep. LA-UR-09-03481. LANL, July 2009. url: https://www.osti.gov/biblio/989786.

The MPACT newsletter is prepared by INL in coordination with all MPACT labs.

Idaho National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, Argonne National Laboratory, Oak Ridge National Laboratory, Brookhaven National Laboratory, Los Alamos National Laboratory.