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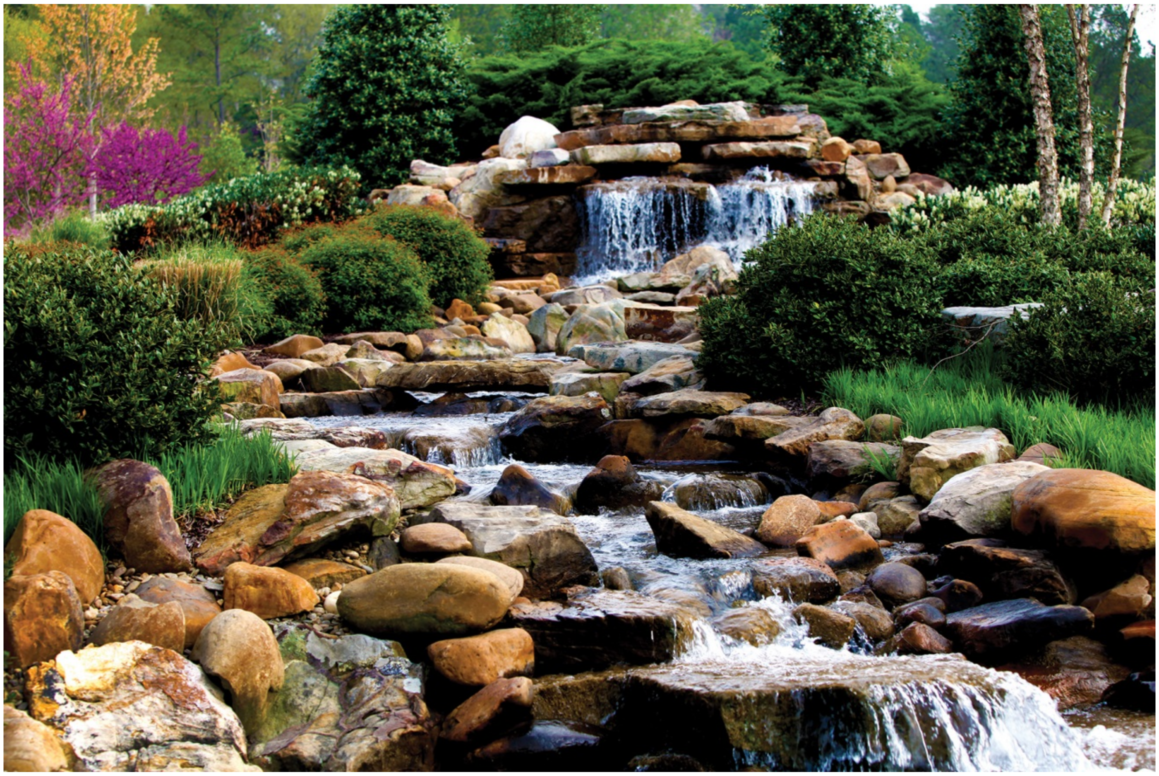
Support for Advanced Fuel Fabrication MC&A Approaches



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September 2025

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Oak Ridge National Laboratory

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Nuclear Nonproliferation Division

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CONTENTS

ABBREVIATIONS

FUDD	fuel debundling detector
HLW	high-level radioactive waste
MC&A	material control and accounting
MPACT	Material Protection, Accounting, and Control Technologies
NMAC	nuclear material accounting and control
NRC	US Nuclear Regulatory Commission

ABSTRACT

This report summarizes the key activities of the Material Protection, Accounting, and Control Technologies (MPACT) program's safeguards training work package for FY25. The work focused on two main areas: domestic safeguards training and the development of new technologies for nuclear material accounting and control (NMAC). A key development during this FY was the delivery of NMAC statistics for US Nuclear Regulatory Commission requirements refresher course. The course objective was to assist industry in meeting the MC&A program requirements for fuel cycle facilities; this training focused on front-end bulk fuel cycle processes. At the same time, a report was prepared on the research output of an effort that focused on the benefits of commercial fuel debundling for NMAC and waste management. The MPACT team evaluated various technologies and proposed a fuel debundling detector that integrates gamma spectroscopy and neutron detection as the most practical solution. The scope of activities under this work package for FY26 focuses on developing a fundamental nuclear material control plan, also known as MC&A plan, for tristructural isotropic (TRISO) fuel fabrication facilities. This plan will address the various NMAC requirements for facilities that handle Category II.

This report, produced for the Materials Protection, Accounting, and Control Technologies (MPACT) program under the US Department of Energy (DOE), Office of Nuclear Energy, Nuclear Fuel Cycle and Supply Chain.

1. SUMMARY OF FY25 ACTIVITIES

The purpose of this report is to describe the efforts of the Material Protection, Accounting, and Control Technologies (MPACT) program's work package supporting domestic safeguards training and workforce development in learning NMAC techniques and new NMAC technologies. It describes FY25 engagements and opportunities and plans for further industry engagement in the coming year.

In FY25, the activities comprising this work package centered on safeguards guidance for practitioners. Tom Pham, with expertise and knowledge acquired over a 30 year career in the private sector and at the US Nuclear Regulatory Commission (NRC), supported the activities by developing and implementing training that fills the gaps between what is currently available and what is needed in the near- to medium-term.

1.1 DOMESTIC SAFEGUARDS COURSES TAILORED TO US SAFEGUARDS NEEDS

This section covers the task related to domestic safeguards courses tailored to US safeguards needs. After offering a full statistics course in 2024, MPACT offered a material control and accounting (MC&A) statistics for NRC requirements refresher course over 2 half-day sessions on August 19 and 21, 2025.

Course objectives included exploring online engagement opportunities and upcoming webinars. The course focused on front-end bulk fuel cycle processes and aimed to meet MC&A program requirements for fuel cycle facilities. Training modules covered a statistics and regulations refresher, inventory difference and uncertainty budgets for a model fuel fabrication facility, types of errors and biases in statistics, measurement controls, inventory exercises, control charts and statistical tests, and an overview of a uranium enrichment reference facility based on the MPACT MC&A guidance for enrichment plants, and deep dive topics.

1.2 COMMERCIAL FUEL DEBUNDLING FACILITY IN THE US

The project also supported the commercial fuel debundling facility in the US. The concept of fuel debundling involves removing all nonfuel parts of a fuel assembly before beginning the recycling process. The concept was introduced to reduce the volume and cost of disposing of high-level radioactive waste (HLW) during recycling in the US. However, NMAC programs could also benefit from fuel debundling because it decreases the amount of self-shielding material in individual fuel rods compared to a complete fuel assembly.

An evaluation of the spent nuclear fuel recycling process by the Office of Materials and Chemical Technologies (NE-43) within the US Department of Energy's Office of Nuclear Energy led to a recommendation to remove all nonfuel, stainless steel components from the waste stream to reduce disposal costs. In the chop-and-leach process, fuel assemblies are chopped up and subjected to leaching, which causes all parts to be classified as HLW. Separating the stainless steel structural components from a fuel assembly allows these parts to be disposed of as low-level radioactive waste instead of HLW. Estimates forecast that reducing the volume of HLW produced during recycling will save millions of dollars in repository costs.

The MPACT organization is evaluating how measuring separated rods compares to measuring bulk assemblies for NMAC. Fuel debundling offers several benefits for NMAC programs, including cost savings on waste disposal. One benefit is that a full fuel assembly has significant self-shielding because of multiple rows of UO_2-filled rods, which reduce the gamma and neutron energy that reaches the exterior of the bundle. Another advantage is a reduction in gamma dose rates and heat by up to 200 times, which lowers detector exposure. Last, the smaller mass of a fuel rod enables more precise measurements of heavy metal input than can be achieved with an entire fuel assembly. Initially, the applicable regulations established by the NRC were reviewed to find a feasible way forward. Also, throughput parameters were set before all potential options for performing NMAC for a single fuel rod were explored. In the end, a few technologies were proposed as practical solutions for satisfying NMAC requirements.

The proposed fuel debundling detector (FUDD) will integrate gamma spectroscopy and neutron detection techniques to estimate Pu mass in a fuel rod for NMAC at an independent fuel debundling facility in the US. The gamma ray system can be used to determine pin burnup using isotopic ratios and the neutron coincidence rate. The doubles rate can be combined with burnup data to estimate Pu mass. Currently, the team believes that either a thermal or fast neutron counting system could provide adequate count rates, although each type of system has limitations that may affect the choice of technology. A comprehensive uncertainty analysis will be needed to ensure that uncertainties from both gamma ray and neutron assay systems are properly propagated into the measured Pu mass. For gamma ray burnup determinations, uncertainties in net peak areas and calibration parameters must be included in the burnup calculations. For the neutron system, the uncertainties in the doubles rate and burnup calculation will both affect the overall uncertainty in the Pu mass.

Fuel debundling could be combined with the recycling of used nuclear fuel to lower the costs of HLW disposal and improve measurements for NMAC. Considering current NRC regulations and guidance, the team's recommendation is to establish an independent fuel debundling facility. This setup would allow fuel debundling to occur in a facility that needs only a material possession license, thus avoiding the need to meet NMAC standards for a Category I or II facility. However, obtaining Pu mass measurements for better dissolver input accounting may be helpful.

Many technologies and methodologies were evaluated for performing NMAC in an independent fuel debundling facility in the US. However, most would not meet throughput demands or achieve measurement uncertainties suitable for input accountancy in a recycling facility. The exceptions were passive gamma ray spectroscopy and neutron coincidence counting, which proved capable of meeting throughput demands and potentially providing mass values for input accountancy. The proposed FUDD design will incorporate both methods to estimate Pu mass for NMAC and input accountancy. A comprehensive uncertainty analysis will be carried out to determine which assumptions can be made to meet input accountancy goals before finalizing the FUDD design and beginning experimental activities.

The final debundling report was submitted for review at Los Alamos National Laboratory and is completed for this FY, ending September 2025.