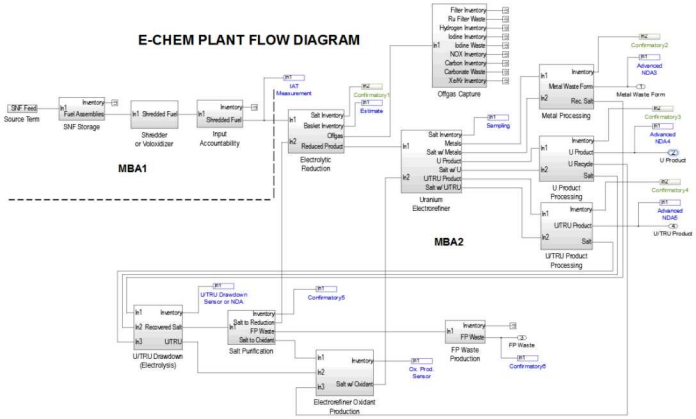
SAND2019-4376PE

Milestone 2020 (Echem) Safeguards Modeling



PRESENTED BY

Ben Cipiti & Nathan Shoman

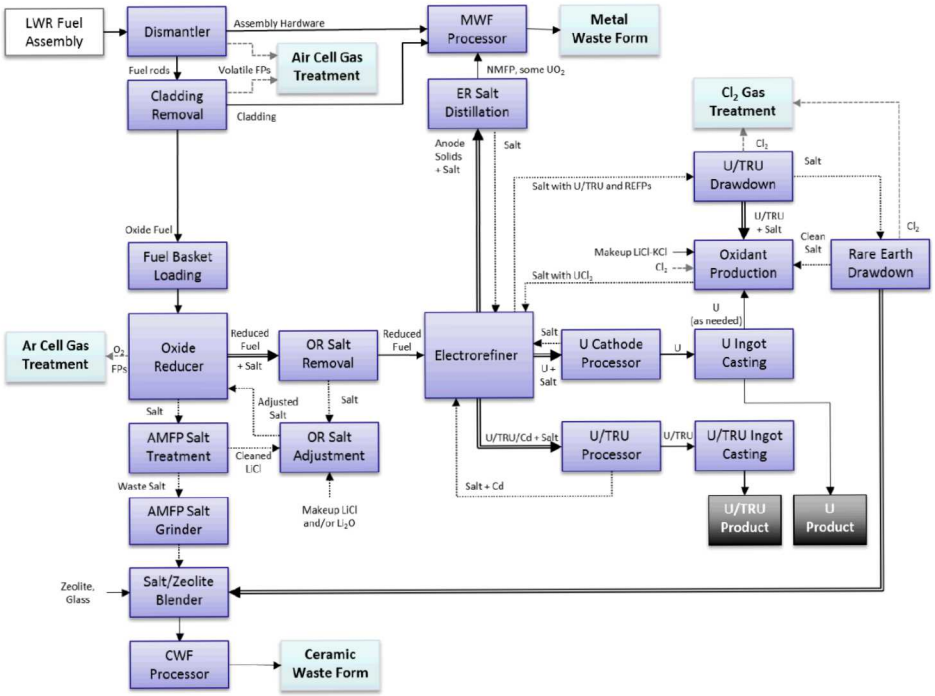
SAND2018-xxxPE

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

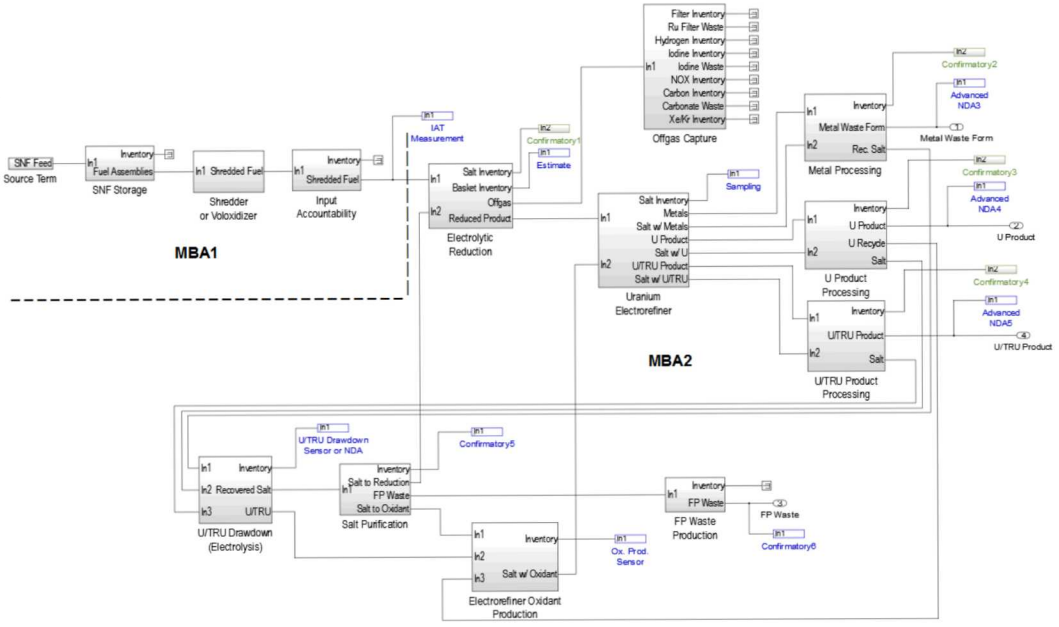
Safeguards Modeling for the 2020 Milestone

- **The safeguards model has two main tasks toward meeting the Echem 2020 milestone:**
  - Develop an overall safeguards approach for electrochemical facilities.
  - Determine the safeguards performance metrics through diversion scenario analysis.
- **Last year, the SSPM was updated for better data outputs, and the diversion scenario analysis was updated:**
  - Improvement to the GUI, standardization of output data, addition of full isotopic tracking, integration with GADRAS, expansion of statistical tests, evaluation of machine learning algorithms.
- **This year, we are focusing more on integration with the rest of the campaign and evaluating baseline and alternative safeguards approaches.**
  - The flowsheet is being modified based on the ANL M2 from last year.

Baseline Flowsheet



- **The following changes will be made to the SSPM:**
  - Decladding at the front end
  - Addition of OR salt removal (separate OR and ER salts)
  - Addition of AMFP salt treatment

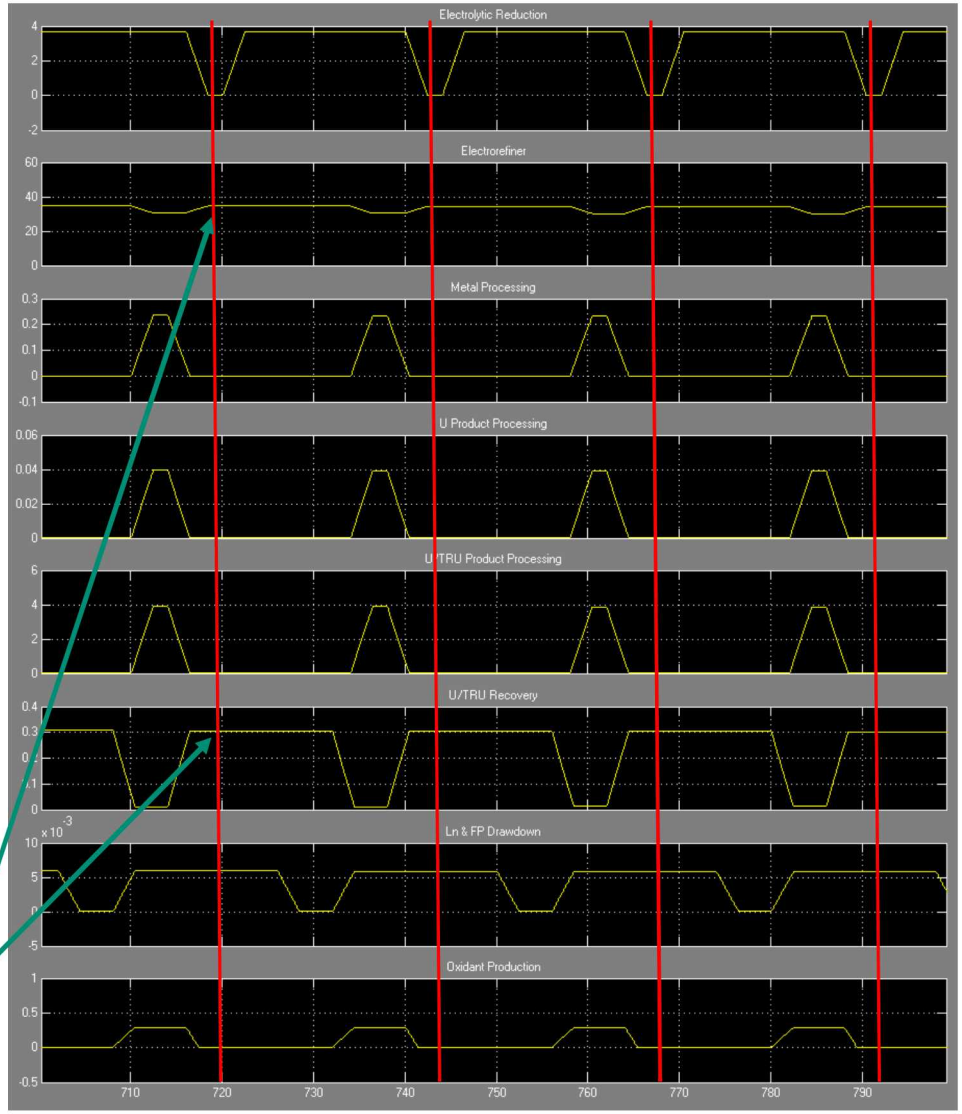


Safeguards Challenges/Opportunities

- **Plant Flushouts** – Some plant designs are not suited to a yearly plant flushout, so will require reliance on inventory measurements.
- **Input Accountability** – Key challenge since fuel is not dissolved before processing.
- **Obtaining Representative Salt Samples** – Salts can have inhomogeneities.
- **Accountability of U and U/TRU products** – Metallic products present different measurement forms.
- **Confirmatory Measurements in the Hot Cell** – Challenges with the high dose environment.
- **Process Monitoring Information** – Echem has unique additional information that can be part of the safeguards approach.

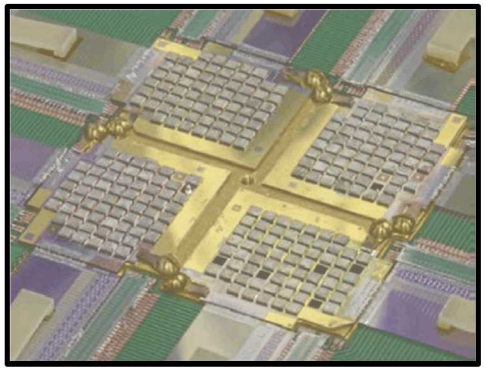
Baseline Safeguards Approach

- **The baseline approach assumes a periodic material balance period with no yearly plant flushout.**
  - Period is likely to be every 1-3 months.
  - The reduced number of processing units makes this more feasible for echem (as compared to aqueous).
- **Inputs and Outputs are always measured.**
- **Plant inventory is measured every 1-3 months.**
  - We have spent time evaluating the timing sequence in order to minimize the number of vessels that need to be measured with precision.
  - At the time of the material balance, actinides are present in only the electrorefiner and drawdown vessels



Input Accountability

- **The baseline approach is some type of homogenization or representative sampling of the shredded fuel, followed by DA.**
  - How well this will perform is still unknown (perhaps 2-3%)?
- **NDA approaches are also being considered, including microcalorimetry.**

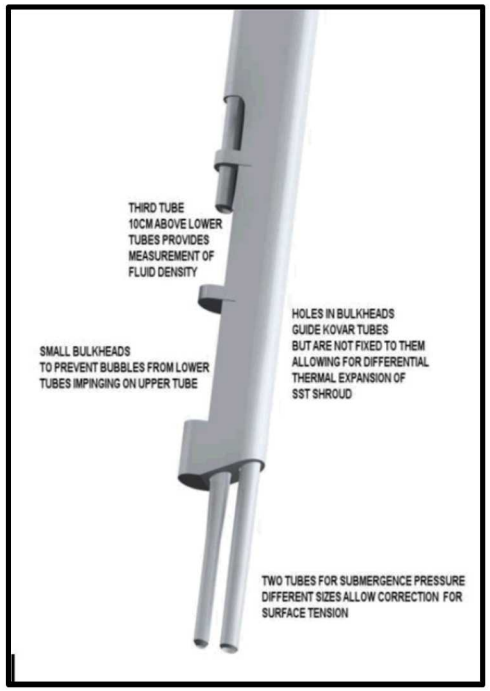


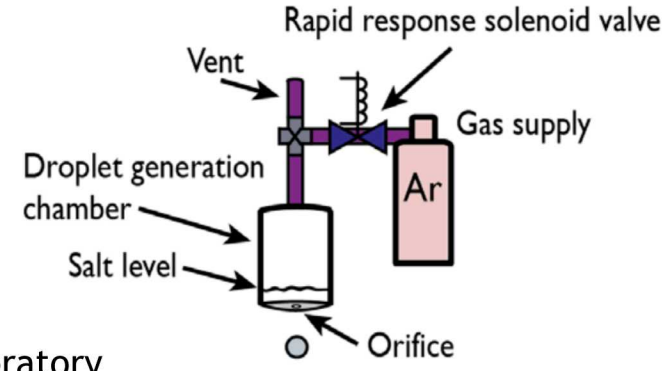
- **An alternative approach can use the ER vessel to establish input accountability, but requires a particular plant design. If U extraction only occurs while spent fuel is in the basket, a measure of the increase of Pu in the salt can be used to establish the input. Then if the U/TRU extraction occurs with only DU in the basket, the Pu in the U/TRU product should balance with the change in the salt.**

Microcal: Croce et al., Los Alamos National Laboratory

Salt Sampling

- **Since the ER salt contains high quantities of actinides, precision measurements are required.**
- **The triple bubbler and micro-droplet generator are two technologies that are being developed.**
- **The ER vessel can have debris on the bottom, fines in the salt (likely U), and dross on the top.**
  - These are likely engineering issues that can be resolved through operations.

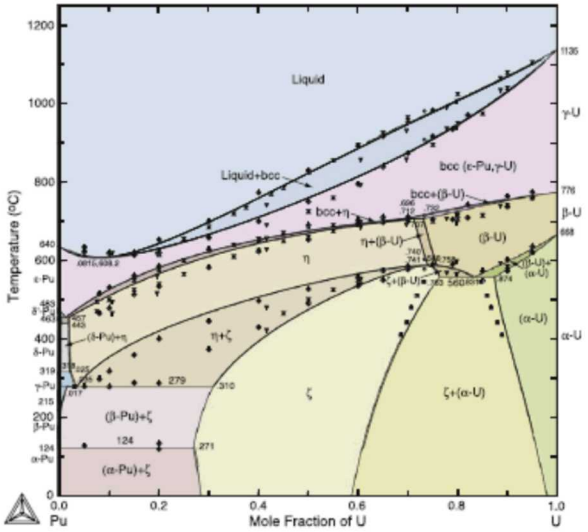




Bubbler: Williams et al., Idaho National Laboratory
Micro-Analytical Sampling: Launiere et al., Argonne National Laboratory

Measurements of U and U/TRU Products

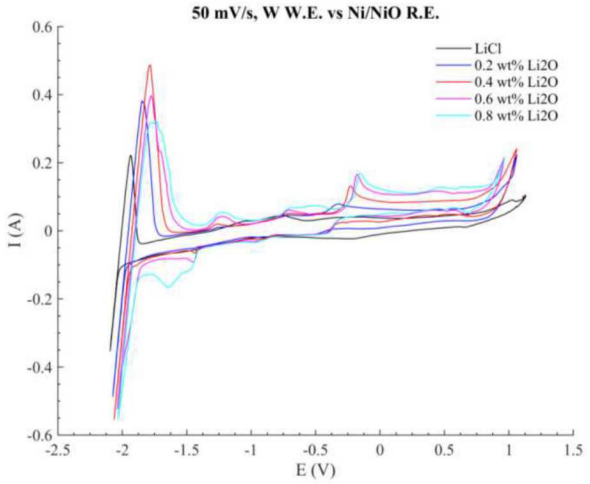
- **The baseline approach is to sample the products during melting followed by DA, but this may be burdensome for routine measurements.**
- **NDA measurements would be preferable, and the High Dose Neutron Detector and In Situ Actinide Monitor are two technologies which may be applicable.**
- **Waste forms also could be measured with neutron or gamma measurements.**



HDND: Henzlova et al., Los Alamos National Laboratory
In Site Actinide Monitor: Westphal et al., Idaho National Laboratory

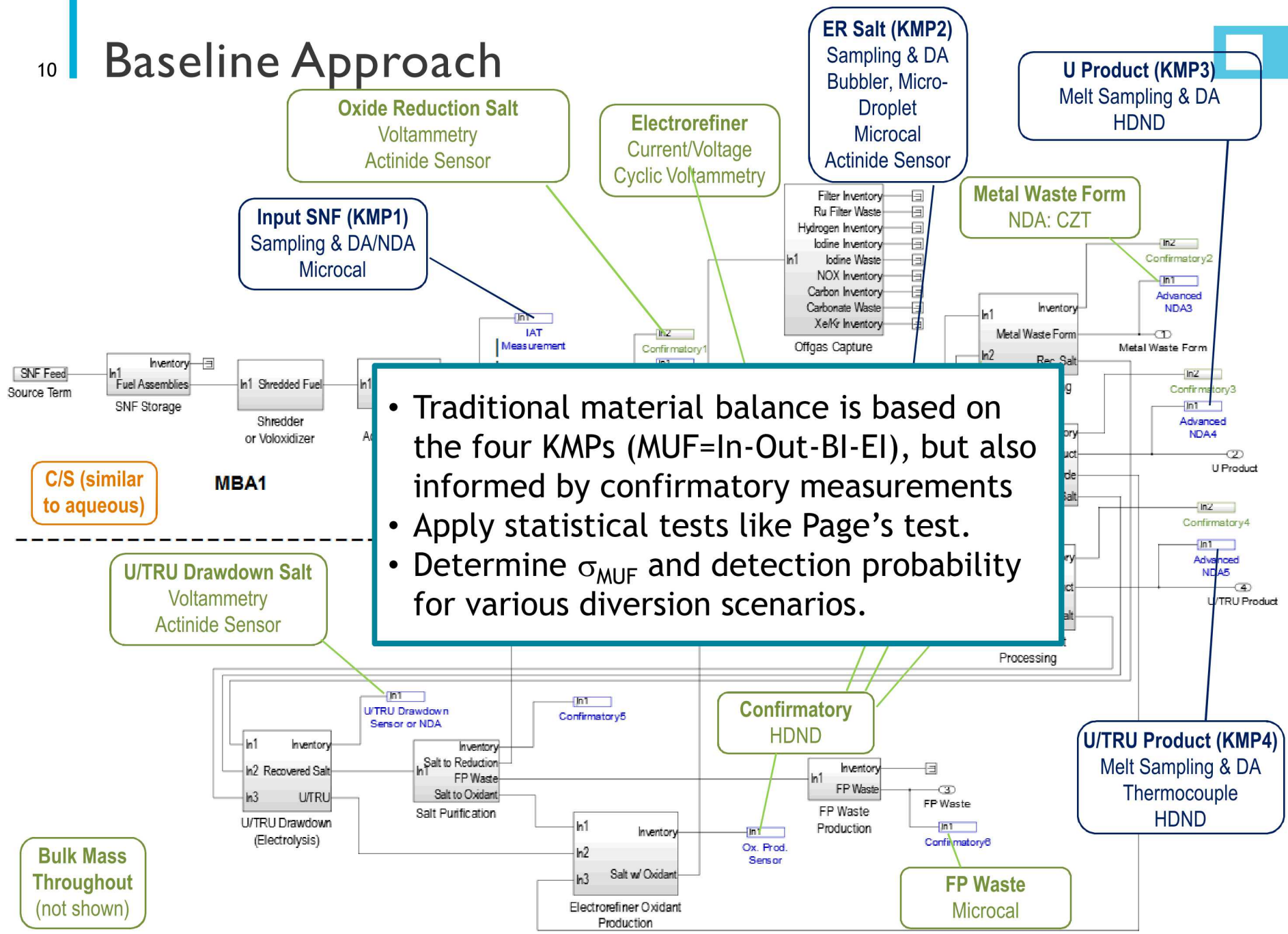
Confirmatory Measurements in the Hot Cell

- **A number of unit operations will contain no or only trace actinides during the inventory balance, but confirmatory measurements are required.**
- **The High Dose Neutron Detector is also being examined for this role, as well as voltammetry for salts that should have only low quantities of actinides.**



HDND: Henzlova et al., Los Alamos National Laboratory
Voltammetry: Williams et al., Idaho National Laboratory
Williamson & Willit, Argonne National Laboratory

Baseline Approach

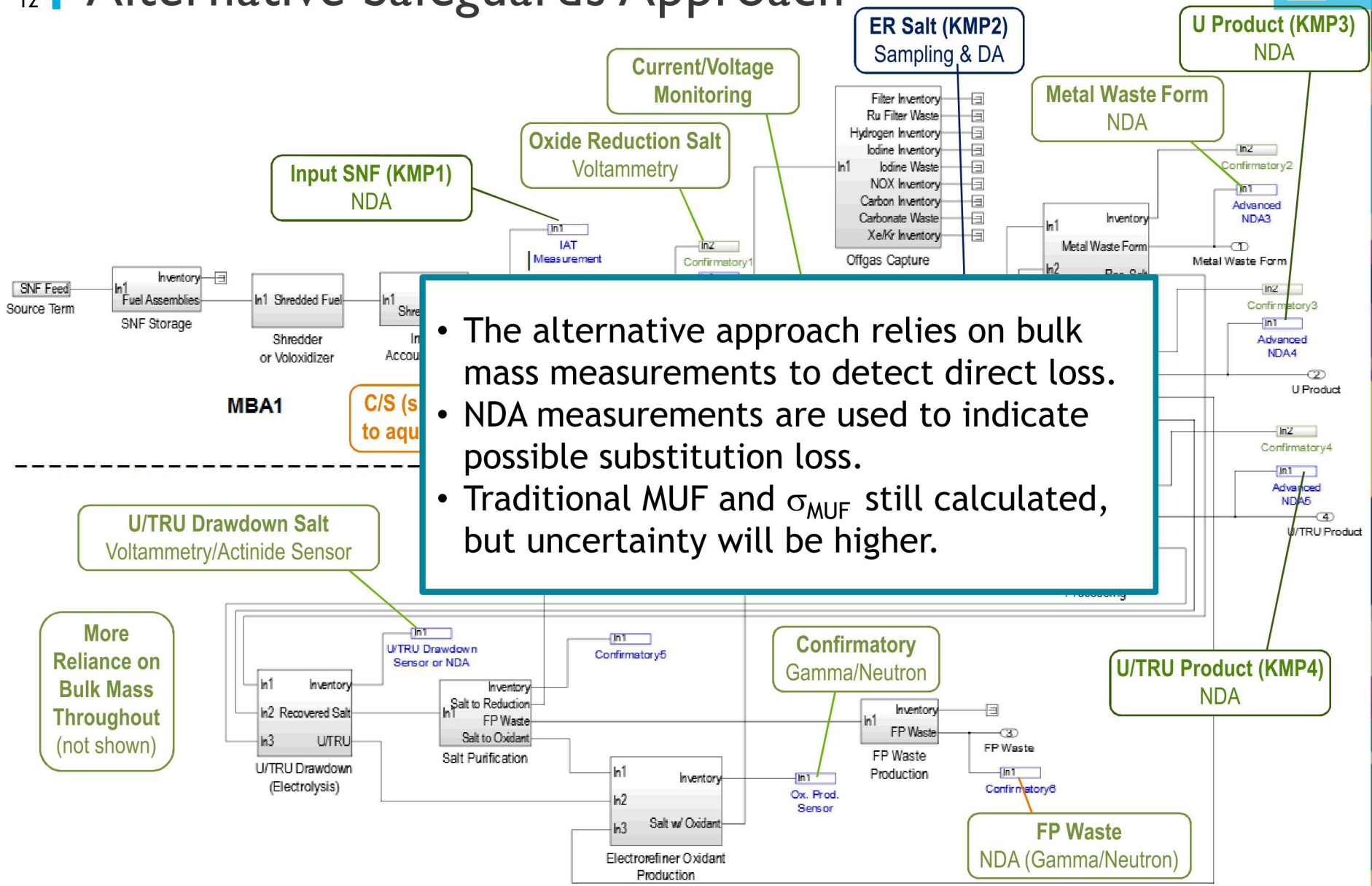


- Traditional material balance is based on the four KMPs (MUF=In-Out-BI-EI), but also informed by confirmatory measurements
- Apply statistical tests like Page's test.
- Determine σ_{MUF} and detection probability for various diversion scenarios.

Diversion Scenario Analysis Results

- **The overall materials accountancy approach was robust to detecting diversions from different locations.**
- **Key take-away is that for a 100 MT/yr facility, in order to meet IAEA regulations (95% probability of detection of 8 kg of Pu within one month) the measurement uncertainties needed to be:**
  - 3% for input and output measurements
  - 1% for the ER salt measurement
- **Addition Points:**
  - One month balance period was assumed.
  - Only abrupt loss (diversion within one month) could meet the requirement.
  - Smaller facility sizes will relax the uncertainty requirement.

Alternative Safeguards Approach

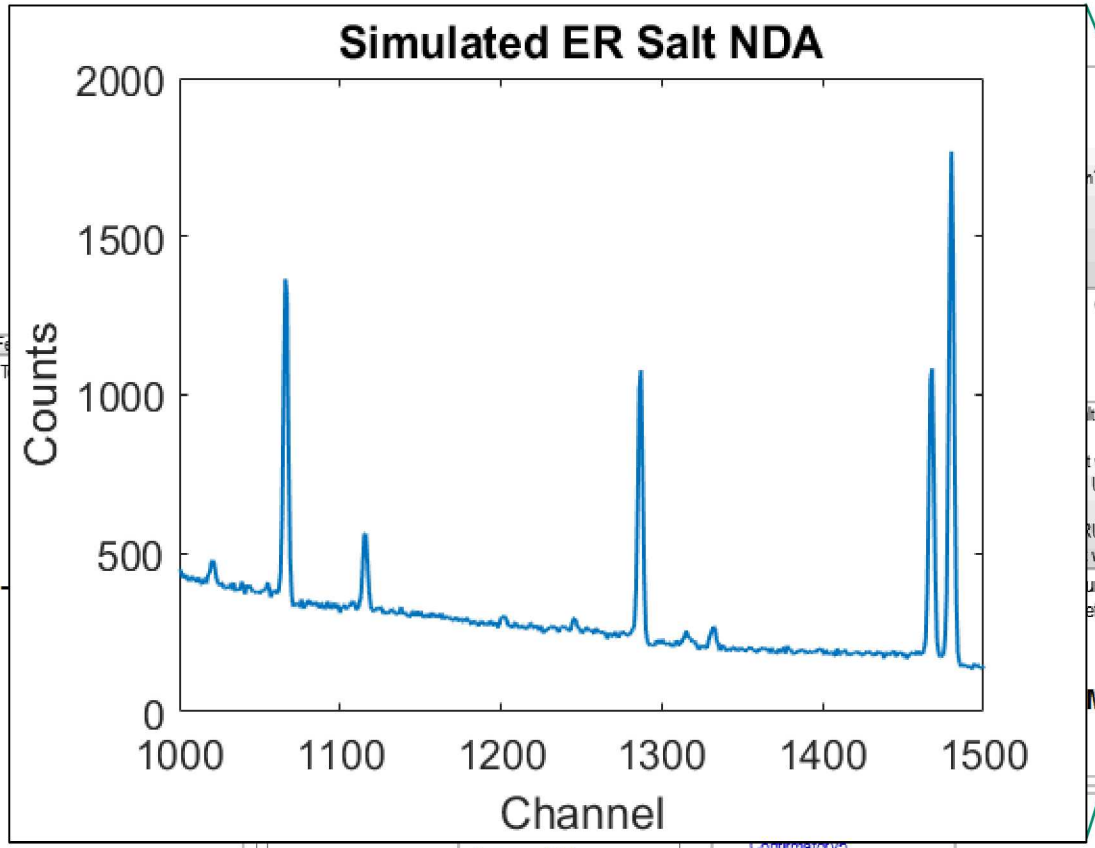


- The alternative approach relies on bulk mass measurements to detect direct loss.
- NDA measurements are used to indicate possible substitution loss.
- Traditional MUF and σ_{MUF} still calculated, but uncertainty will be higher.

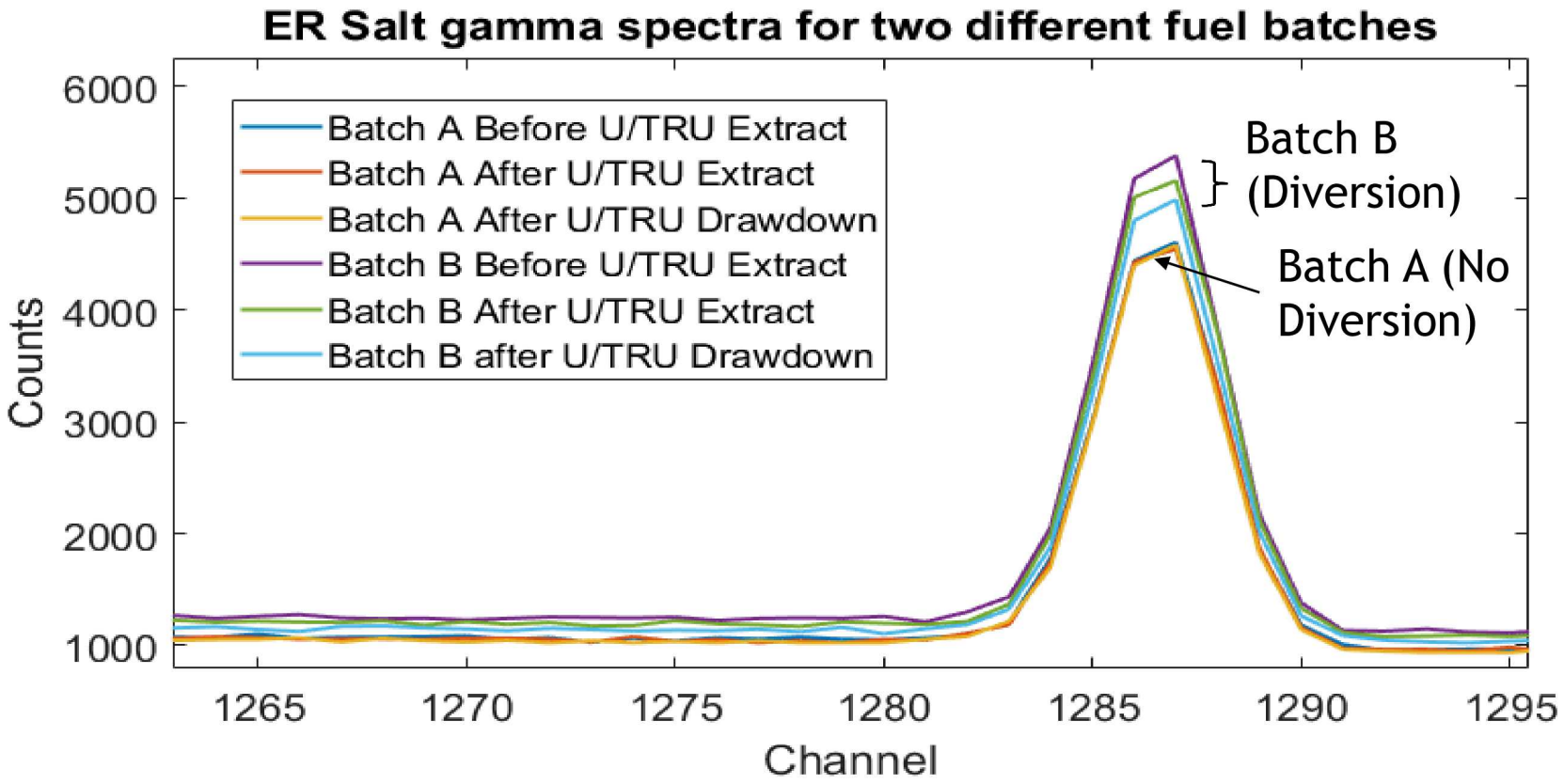
Machine Learning

- **The complication is that neutron and gamma emissions vary depending on fuel characteristics (IE, BU, CT), and reprocessing plants will process a mixture of SNF.**
  - Simply detecting a gross change in neutron emission or gamma peaks will not by itself indicate a substitution loss.
  - The gross change must be correlated with other areas of the plant. For example, a drop-off in the neutron emission rate from a U/TRU product without a drop-off in neutron emission from the ER salt might indicate a problem.
- **Machine Learning techniques are being examined to automate detection for such a system.**
  - A One-Class Support Vector Machine (OCSVM) as well as a Long-Short Term Memory (LSTM) neural network are being examined—these would only be trained using normal data. (It will be very difficult to generate abnormal training data in an actual facility.)

Coupling with GADRAS



Example Substitution Diversion Results



- The SSPM tracks full elemental and isotopic compositions—coupling with GADRAS allows us to simulate gamma spectra for a sample from a particular location.
- This plot shows the effect of diversion on a particular peak.

Echem Safeguards Modeling Next Steps

- **In the process of making minor modifications to the SSPM to be consistent with the ANL baseline flowsheet.**
- **Provide updated data to others in the campaign as needed.**
- **Continue to work with LANL to incorporate calculated measurements uncertainties from the various measurement technologies**
- **For the 2020 Milestone:**
  - Show the baseline and alternative safeguards approaches for the baseline flowsheet.
  - Expand the diversion scenario analysis and provide results.
  - Incorporate other experimental or modeling results from other labs and universities as available.