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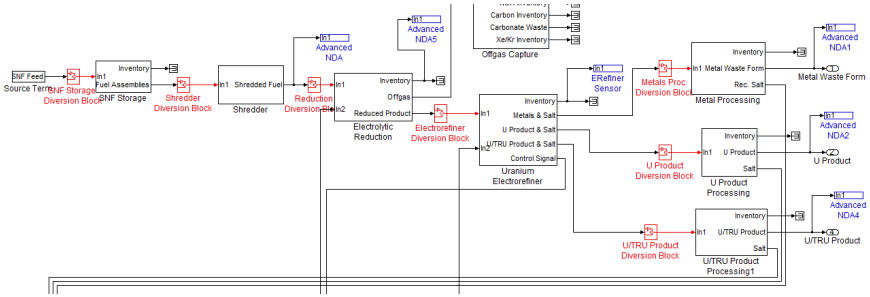

Process Monitoring Considerations for Reprocessing

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Overview

- Process Monitoring (PM) has been examined as a way to provide additional safeguards data or reduce the burden of traditional safeguards measurements.
- Lessons learned from past work on the integration of PM in aqueous plants will be discussed.
- A preliminary analysis of potential PM use in electrochemical plants will be presented.

What is Process Monitoring?

- **"Process Monitoring is a methodology to ensure that special nuclear material is in its authorized location and when effectively implemented, it is a useful tool to detect anomalous process conditions and indicate losses of special nuclear material well before the scheduled physical inventory."**

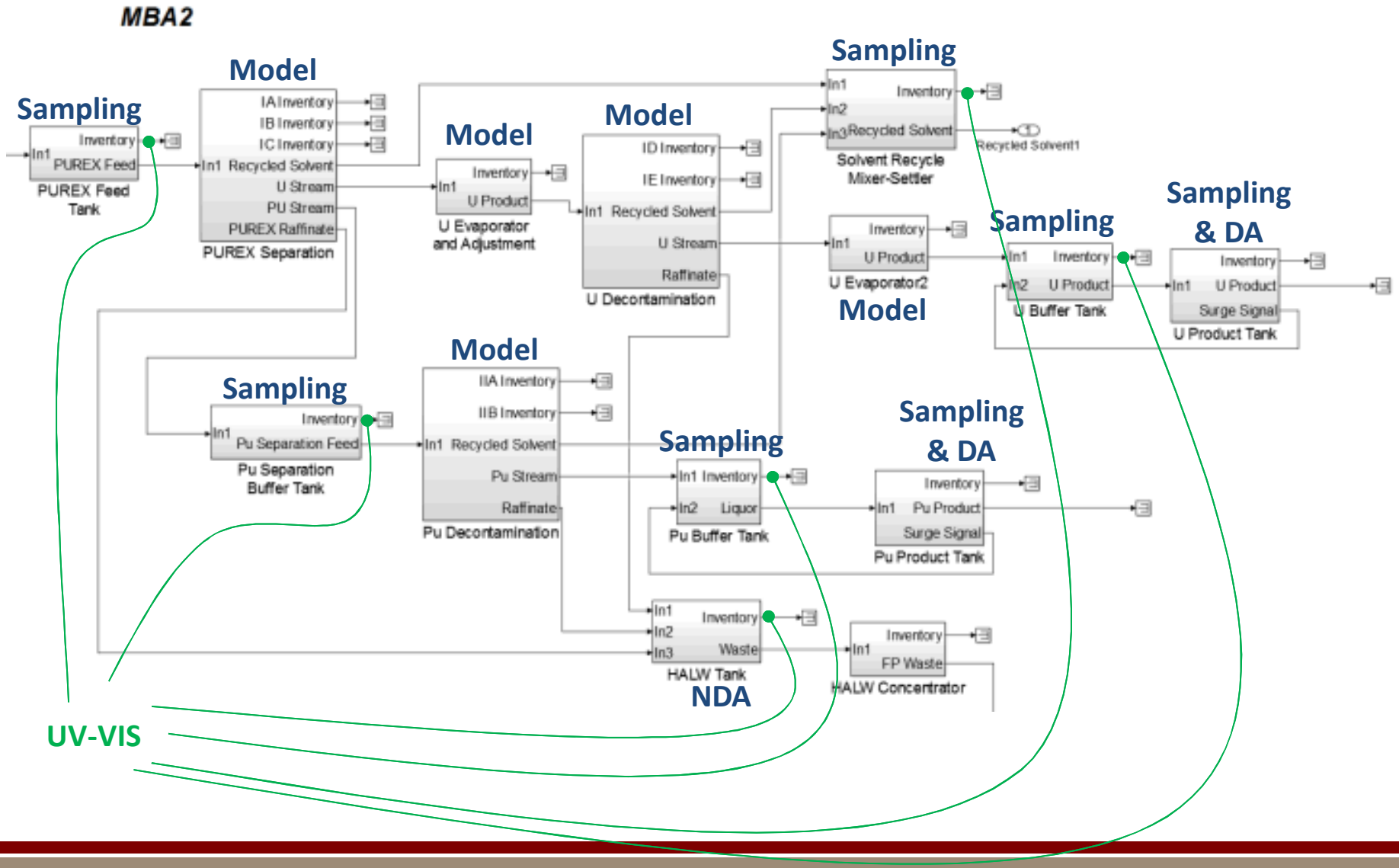
  - U.S. DOE Standard, DOE-STD-1194-2011 Change 3, "Nuclear Materials Control and Accountability," paragraph 6.2.4.5 (2013).

- **Includes bulk measurements:**
  - Load cell, electronic balance, electromanometer, triple bubbler, flowmeter, temperature, current, voltage, power, capacitance, heating/cooling required, pH monitors
- **Or on-line process measurements:**
  - Off-gas monitor, voltammetry, UV-Vis-NIR spectroscopy, gross gamma or neutron measurement, MIP monitor.

Aqueous Plants

- Sampling and precision level measurements provide low measurement uncertainties for solutions in aqueous plants, but sampling is burdensome and requires time (days) to provide results.
- PM would be most useful as a way to improve timeliness while optimizing costs of safeguards.
- Recent work has examined use of in-line spectroscopies to reduce sampling for interim material balances.
  - Measurement uncertainties could potentially be similar to HKED, but data is provided almost continuously.
  - More frequent material balances (daily) have been considered.

Example Approach for MBA2



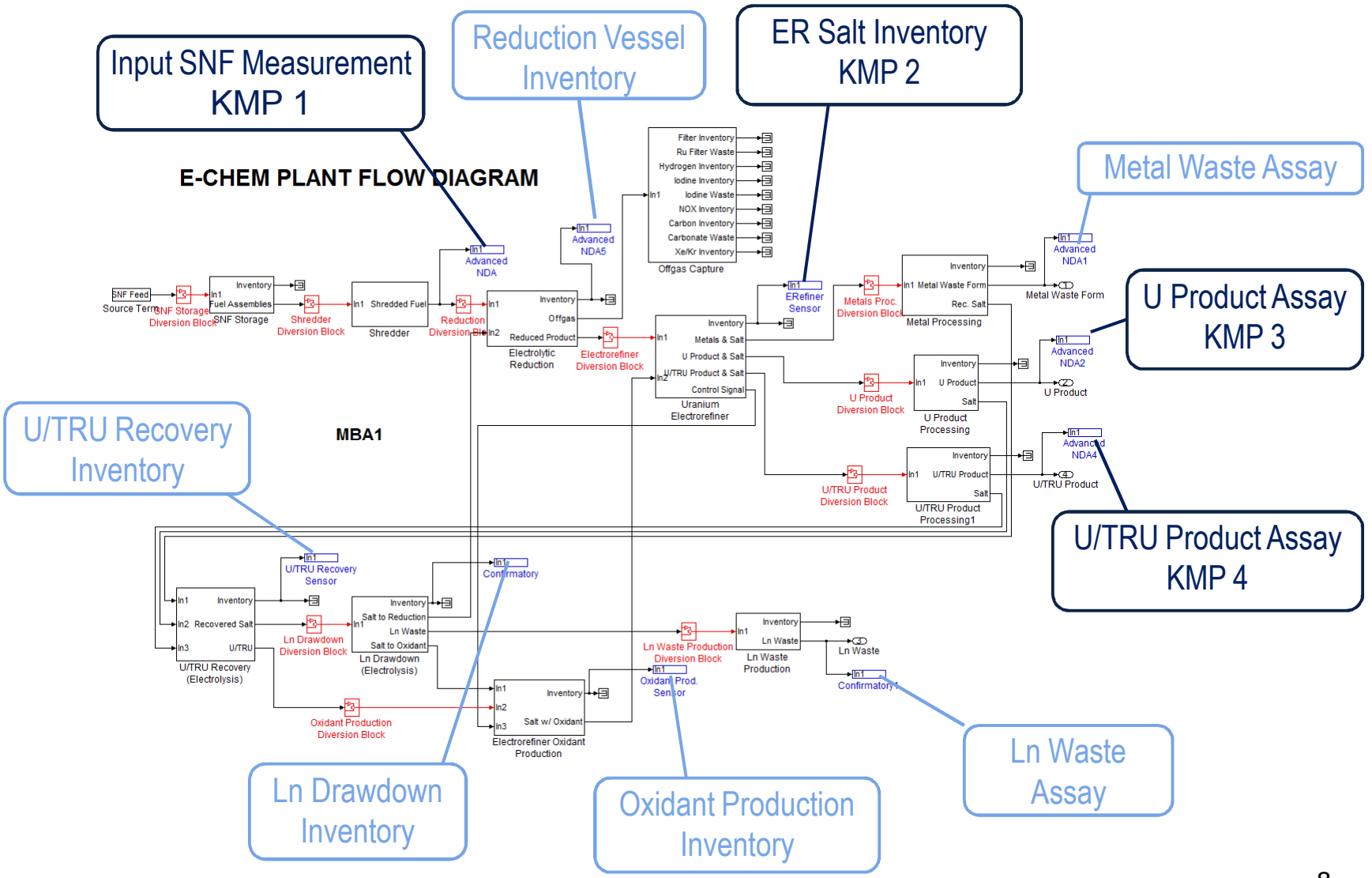
Aqueous PM Considerations

- In-line spectroscopy will work better if applied directly to vessels (or recirculation lines on vessels)—this makes retrofitting difficult, but could be useful for new builds.
- More frequent balances will increase false alarm rates, so statistical tests need to be made less sensitive to compensate.
- For areas processing solids (front end and back end), gamma or neutron spectroscopies could be used instead. However, improving timeliness or measurement uncertainty may not be practical.
  - Improvements to the front end will not be useful unless a better spent fuel measurement exists.
  - New approaches for powder processing areas (which drives the overall MUF of the plant) do not appear to be available.

Electrochemical Plants

- Electrochemical processing is significantly different from aqueous and so requires different technologies and approaches for safeguards.
- The materials are in molten salt and metallic forms and require high temperature operation.
- Safeguards Challenges:
  - Input and output accountability is difficult
  - No plant flushouts
- PM is being examined as a potential way to solve the challenges and fill in the gaps in safeguards.

Accountancy Structure



PM Analysis: Oxide Reduction

- In normal operation, shredded oxide fuel is contained in baskets and lowered into a molten salt. Electrolysis is used to convert oxides to metals, and oxygen is released in the process. Actinides stay in the basket, but some fission products will go into the salt (active metals and some lanthanides).
- **Safeguards Goal:** ensure that actinides are not in the salt and ensure that shredded fuel has not been removed.
- **PM Options:**
  - As opposed to salt sampling and DA or NDA, voltammetry could be considered to identify if actinides are present or if agents have been added to extract actinides into the salt.
  - Bulk mass balances can be considered, but a load cell on the reduction vessel may not be feasible. The mass of baskets before and after along with an off-gas monitor could provide enough information for a mass balance (but will have a slight positive difference due to the fission products that go into the salt).

PM Analysis: Electrorefiner

- In normal operation, a specified voltage applied across the cathode and fuel baskets will extract U onto the cathode. A separate cathode is operated at higher voltage to extract a U/TRU product. Noble metals remain in the basket.
- **Safeguards Goal:** Account for U/TRU content in the salt, ensure that actinides go where intended.
- **Key Measurement Point:** Due to the high TRU content in the salt, salt sampling will be needed to get a precision inventory measurement.
- **PM Options:**
  - A Triple Bubbler has been developed at INL to determine total volume/mass. An in-situ measurement like the potentiometric sensor or voltammetry could be considered as well, but note that the uncertainty goals will probably be low here (<0.5%).
  - Current and voltage monitoring can help ensure that full extractions occur (no material left in baskets) and that actinides go to the correct cathode.
  - Bulk mass balances probably not feasible since it would be difficult to install a load cell on the electrorefiner.
  - A hot cell off-gas monitor will likely be needed for monitoring anyway, but it can also be used to ensure that hidden extractions are not occurring.

PM Analysis: Metal Waste, U Product, and U/TRU Product Processing

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- For all three products coming from the ER, residual salt is distilled off, and remaining metals will be melted down to form a metal waste form, U product ingot, and U/TRU product ingot.
- **Safeguards Goal:** Confirm low levels of actinides in the metal waste, account for actinide content in the U and U/TRU product, and ensure salt is recycled.
- **Key Measurement Points:** Because these are all outputs, NDA will probably be required for the metal waste, and sampling may be considered for U and U/TRU product during melting. For the U product, it may be difficult to keep up with daily batches, so NDA is also being evaluated.
- **PM Options:**
  - Bulk mass balances can be considered to ensure all salt is recycled and to determine total mass of the products.
  - Note that current and voltage monitoring at the ER helps to ensure that actinides do not stay in the basket and that U and TRU go where intended.

PM Analysis: Actinide Drawdown

- The distilled salt from the product processing steps is recovered for U/TRU drawdown.
- **Safeguards Goal:** Account for actinides in the salt.
- **PM Options:**
  - Accountancy will be required on the salt, but the actinide content is much lower than in the electrorefiner, so higher uncertainty measurements are okay. Can consider potentiometric sensor, voltammetry, or UV-Vis-NIR spectroscopy.
  - Bulk measurements can also be considered for total mass.

PM Analysis: Fission Product Drawdown

- One or two additional process steps will be required periodically to remove fission products from the salt. (Or salt could be removed periodically, depending on the design.)
- **Safeguards Goal:** Confirm no or trace actinide content in the salt and waste form.
- **PM Options:**
  - NDA measurements will probably be required for the waste form, but voltammetry or other in-situ measurements could be considered to confirm no or trace actinide content.
  - Bulk measurements can also be considered.

Electrochemical PM Considerations

- The important non-sampling PM measurements will be:
  - Triple Bubbler for the ER salt
  - Voltammetry or in-situ measurements for OR and possibly drawdown steps
  - Current and Voltage monitoring in the ER
  - Mass measurements of the product processing steps.
- ER models are being developed, and PM data could potentially be used to predict inventories. However, models have higher uncertainty and require extensive research for validation. For international safeguards, the monitoring of several PM measurements could add more burden than sampling and DA.