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FUEL FABRICATION MATERIAL CONTROL AND ACCOUNTING MODELING

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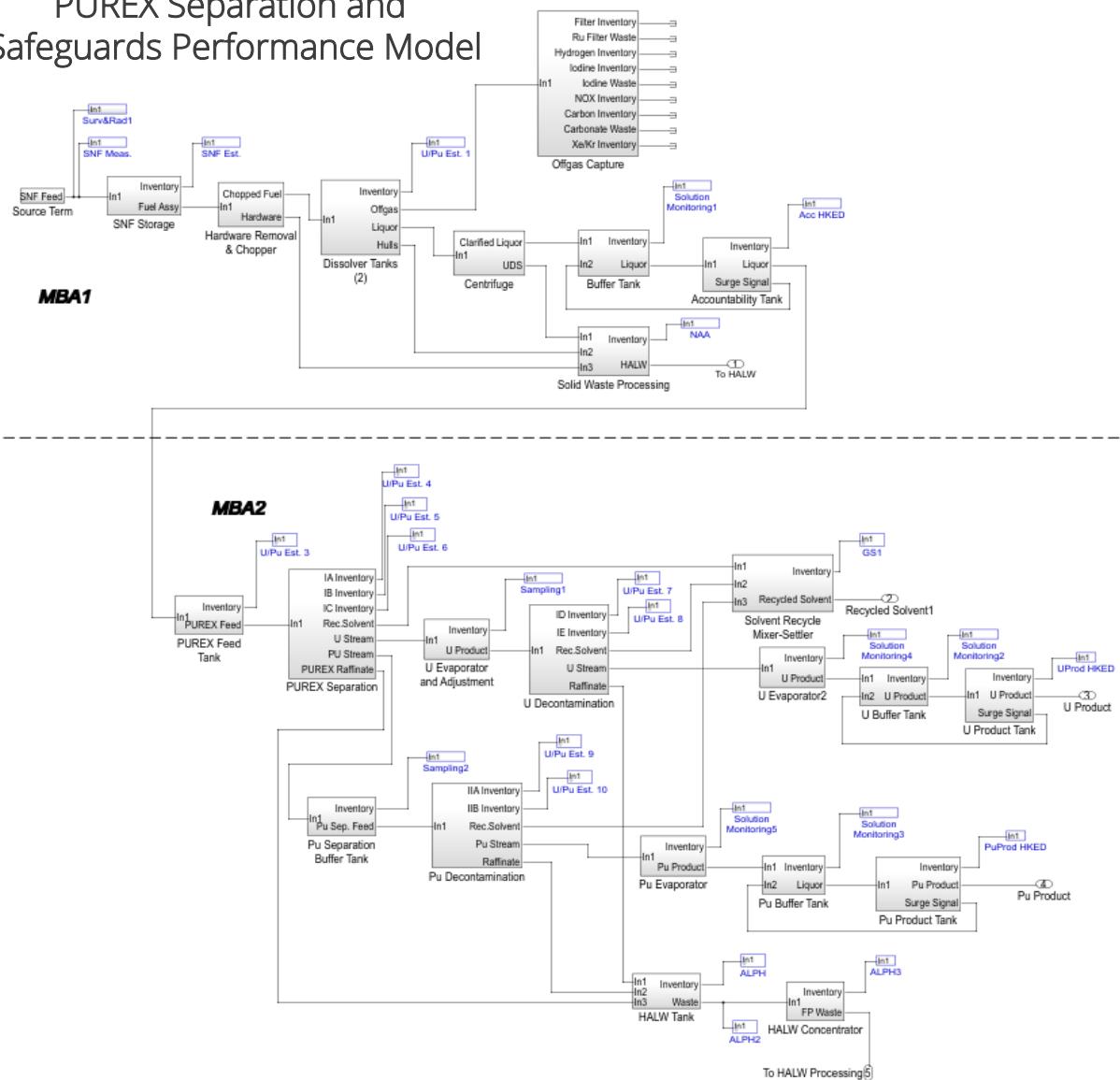
USE OF MOD/SIM TO SUPPORT THE U.S. NUCLEAR INDUSTRY

The Material Protection Accounting and Control Technologies (MPACT) program (within the Office of Nuclear Energy in the U.S. Department of Energy) funds R&D to support domestic safeguards and security of fuel cycle facilities.

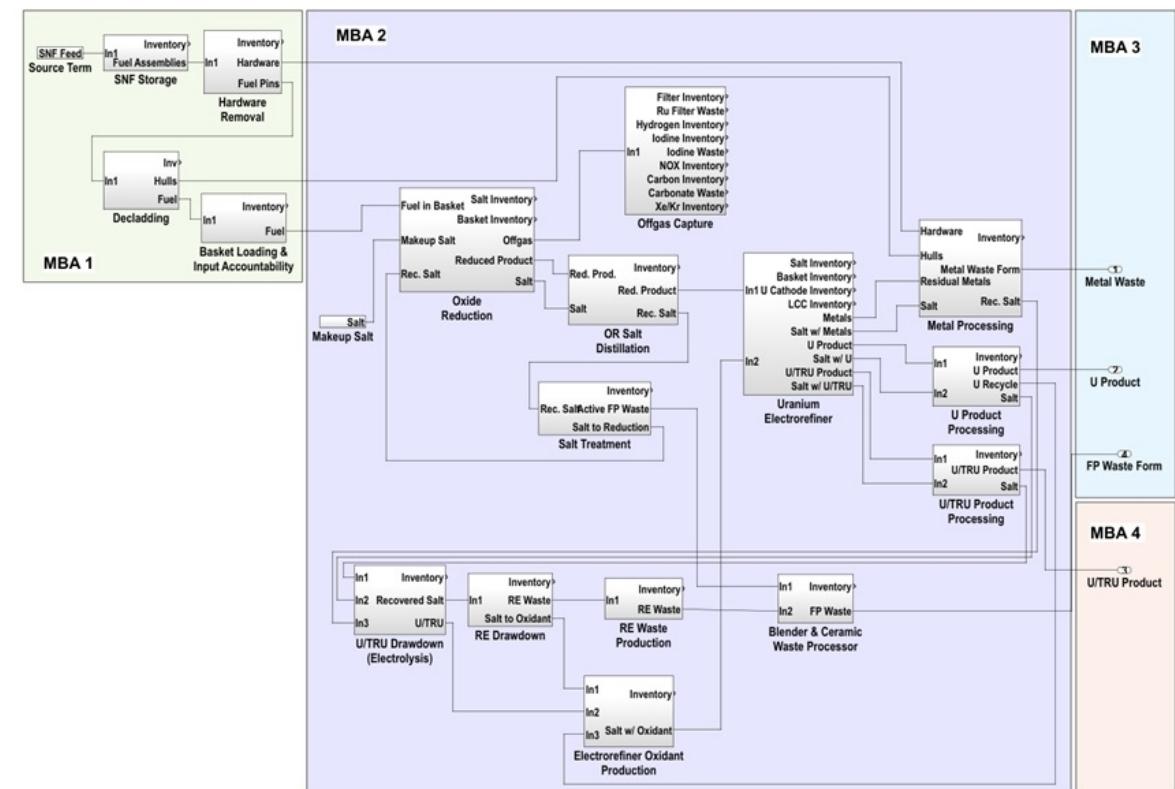
- New fuel fabrication facilities (including standard LWR fuel, fast reactor assemblies, TRISO fuel, and salts) are being designed, and many will need to meet Category II requirements for Material Control and Accounting (MC&A).
- Modeling and simulation is being used to support industry.

SEPARATION AND SAFEGUARDS PERFORMANCE MODEL (SSPM)

PUREX Separation and Safeguards Performance Model



Pyroprocessing Separation and Safeguards Performance Model

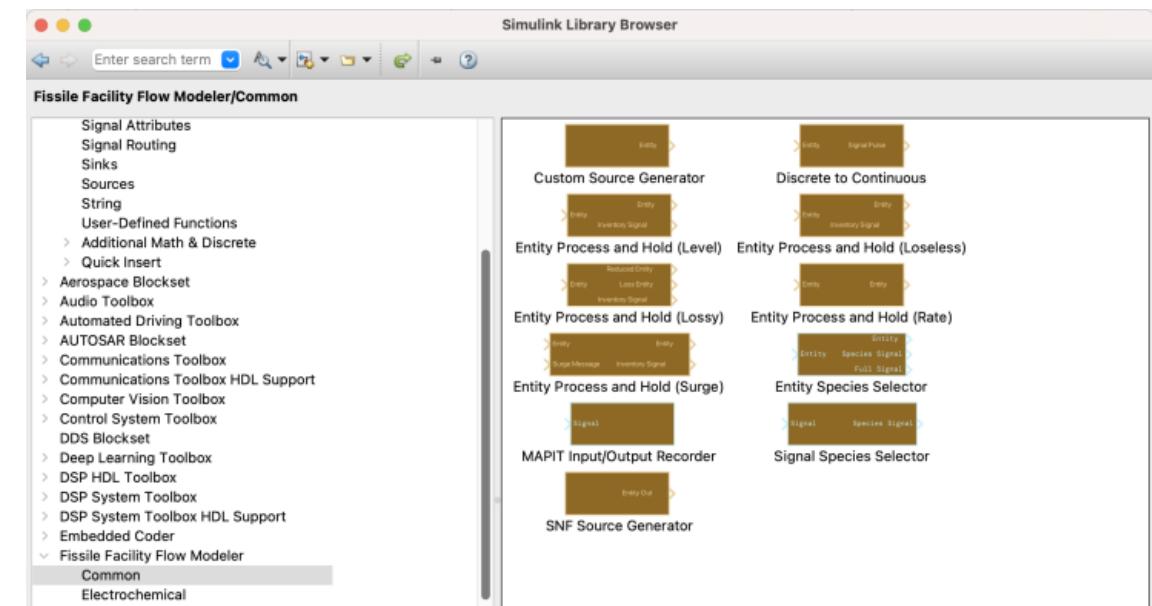


DEVELOPING MORE EFFECTIVE MC&A THROUGH MODEL OPTIMIZATION

- Fissile Facility Flow Modeler (F3M)
- New framework to model bulk nuclear facilities
- Plug and play modules that can be customized and interconnected
- Designed to produce datasets for statistical analyses
- Built in MATLAB SIMULINK
- Leverages lessons learned from 18+ years of development on SSPM

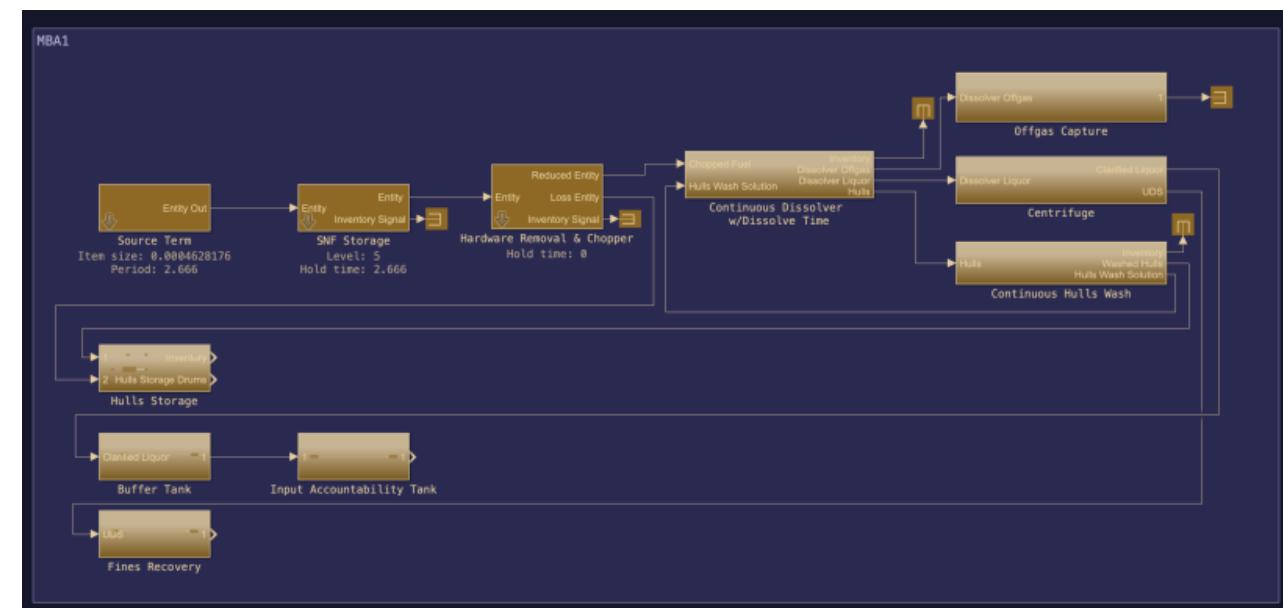


F3M



EXTENDING SSPM TO BUILD A NEW MODEL LIBRARY (SSPM-L)

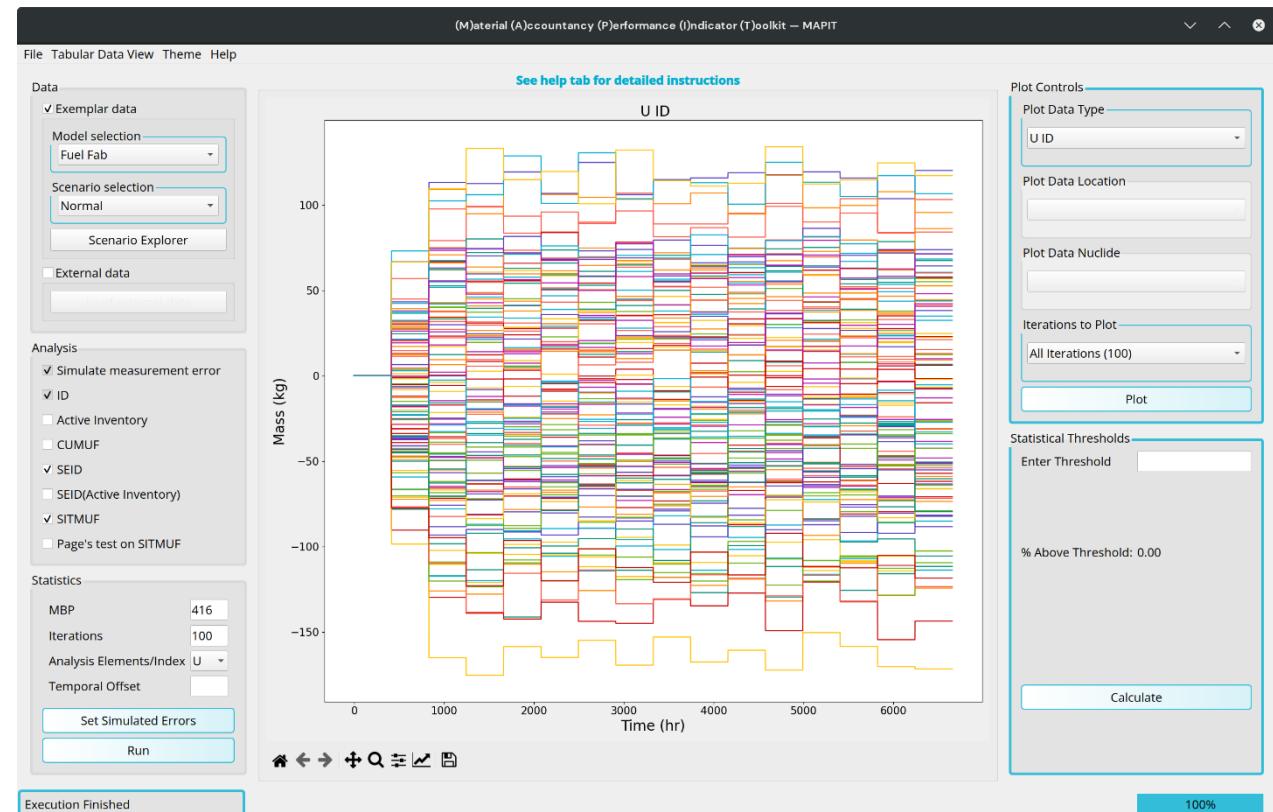
- SSPM is a versatile mod/sim platform that has supported numerous MC&A analyses
- Sharing SSPM directly often requires proper licensing which can become a barrier
- Know-how on model construction can be lost over time
- Current efforts are ongoing to convert fuel cycle facility models to the new format.
- Pursuing a more standardized way to access SSPM model library.



MATERIAL ACCOUNTANCY PERFORMANCE INDICATOR TOOLKIT (MAPIT)

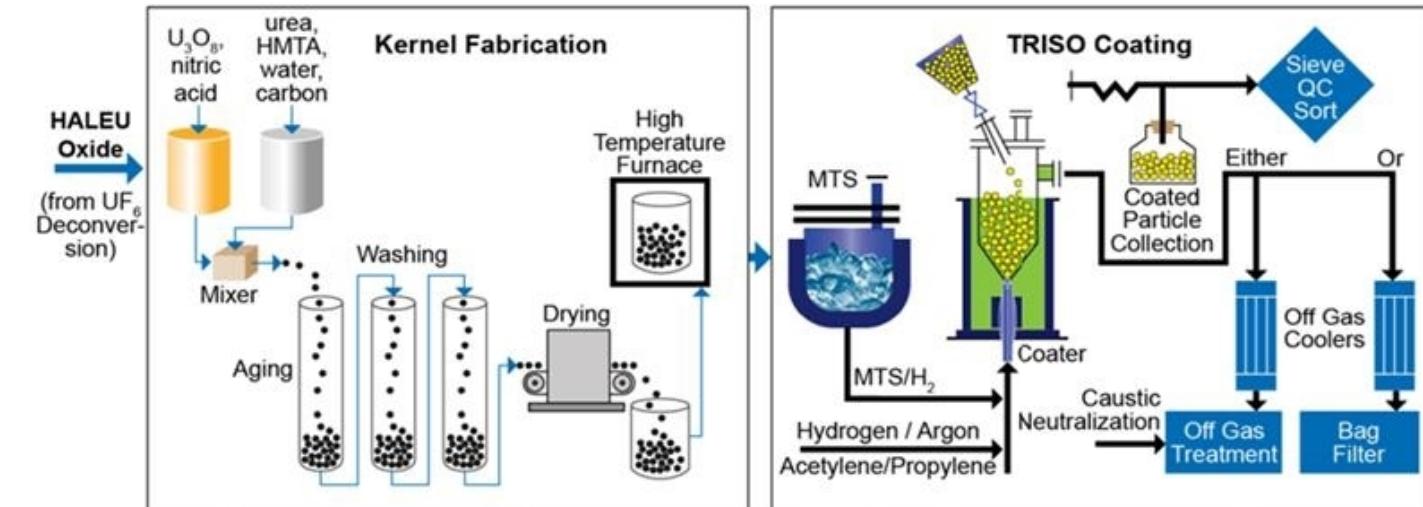
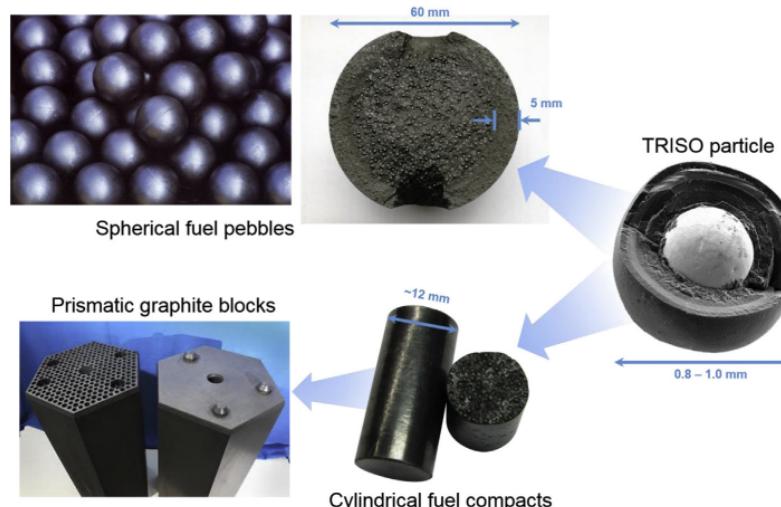
- MAPIT is a toolkit written entirely for MC&A design and statistical analysis of bulk facilities.
- Written entirely in Python
- Utilizes datasets generated by the SSPM-L models.
- Automated error propagation
- Implementation of common statistical tests
 - MUF, σ_{MUF} , SITMUF, Page's trend test, CUMUF
- Intuitive GUI

MAPIT

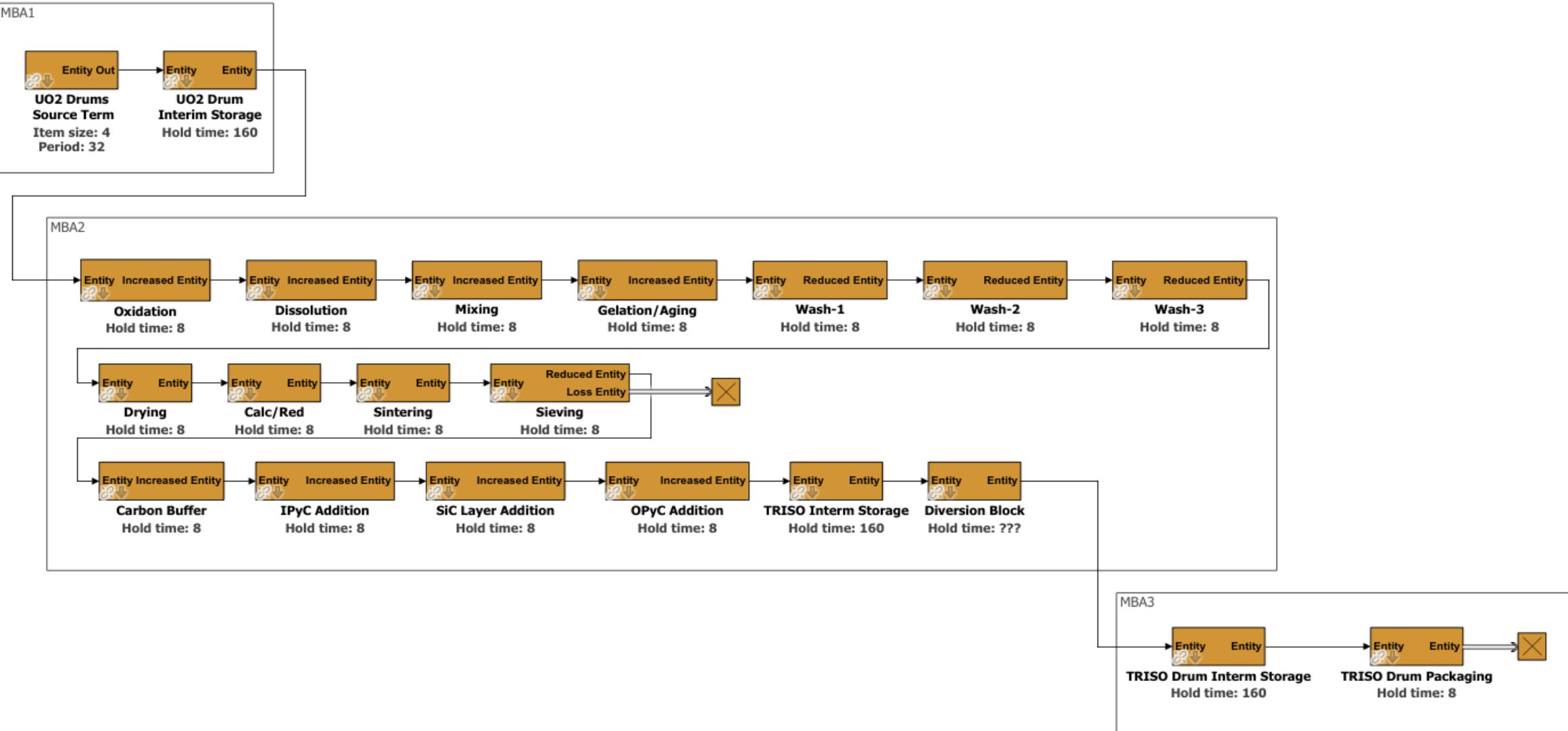


FUEL FABRICATION BACKGROUND

- Currently, multiple vendors are planning on deploying HTGRs as power reactors around the world.
- HTGRs are fueled with TRi-structural ISOtropic particle fuel (TRISO fuel). With the goal to deploy these reactors around the world, fuel fabrication facilities need to be developed to produce fuel.
- These fuel fabrication facilities utilize different processes and materials which will require designing the MC&A system.



TRISO FUEL FABRICATION SAFEGUARDS MODEL BUILT USING F3M

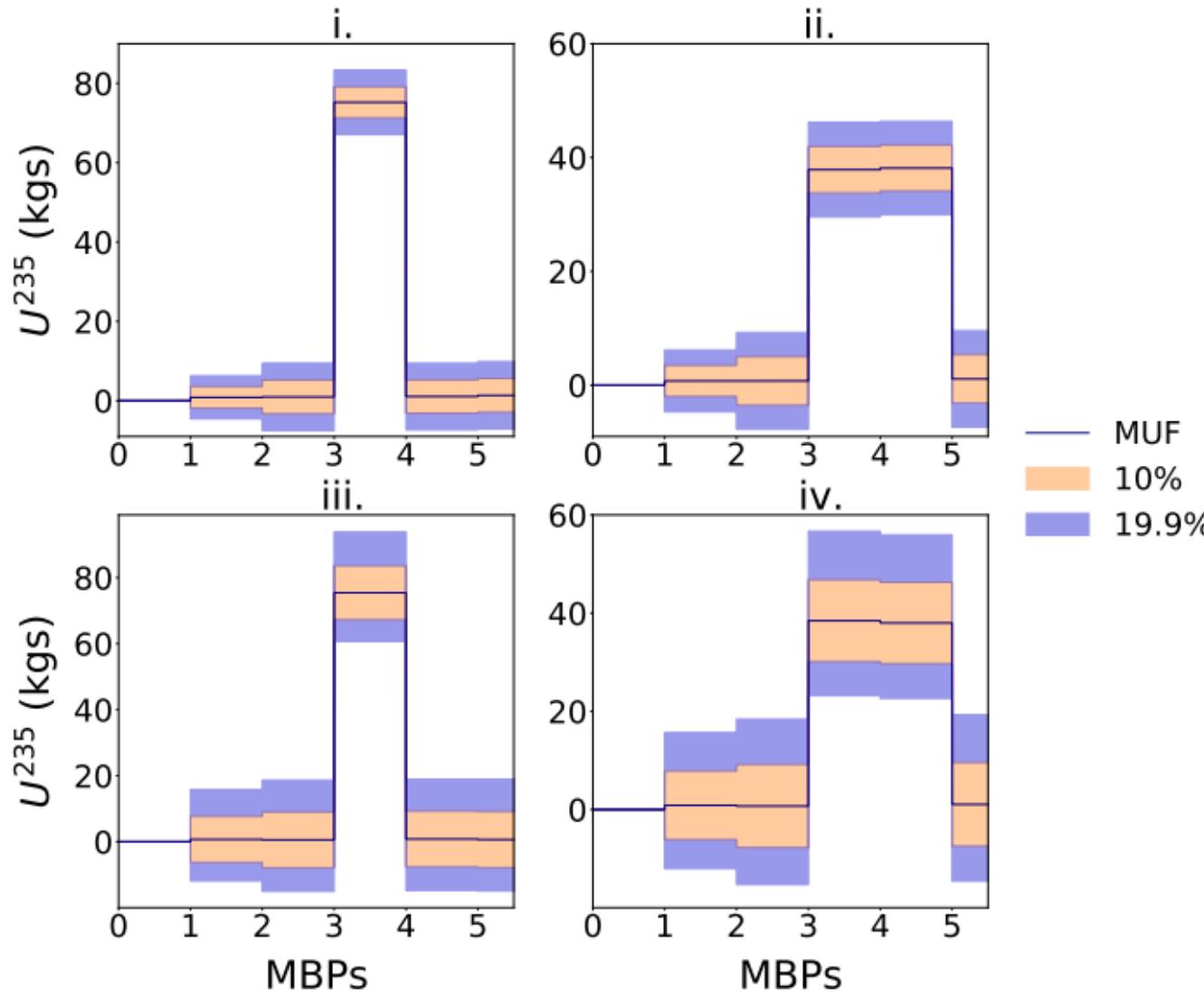


TRISO FUEL FABRICATION MODEL KEY ASSUMPTIONS

- The model is based on a hypothetical facility and a notional throughput of 22 metric tons U is selected for analysis
- Two HALEU enrichments are evaluated: 10% U^{235} and 19.9% U^{235}
- Two MBPs are tested: 2 and 4 months
- Two material loss scenarios are modeled for two different MBPs (abrupt and protracted)
- The quantity of material within the material loss scenarios is 1 significant quantity (SQ) of U^{235} (75 kgs U^{235})

Characteristic	Quantity
Notional Throughput	22 Metric Tons U/year
Starting Fuel Form	Powdered UO_2
End Fuel Form	UCO TRISO Fuel Pebbles
Enrichment _a	10% U^{235}
Enrichment _b	19.9% U^{235}
MBP ₁	1400 hours (2 months)
MBP ₂	2800 hours (4 months)

MATERIAL LOSS SCENARIOS



- The plots on the left show abrupt loss versus protracted loss for different assumptions for measurement uncertainty.
- Plots i) and ii) have a lower measurement uncertainty.
- Plots iii) and iv) have a higher measurement uncertainty.
- The error bars are different for the different assumptions of 10% versus 19.9% enriched fuel.

TRISO FUEL FABRICATION MC&A ANALYSIS

- The results shown at the right show the performance based on the ability to detect material loss (> 95% detection probability is the goal).
- Measurement uncertainty needs to be around 1% or less (random and systematic error) in order to meet the 95% detection probability goal.

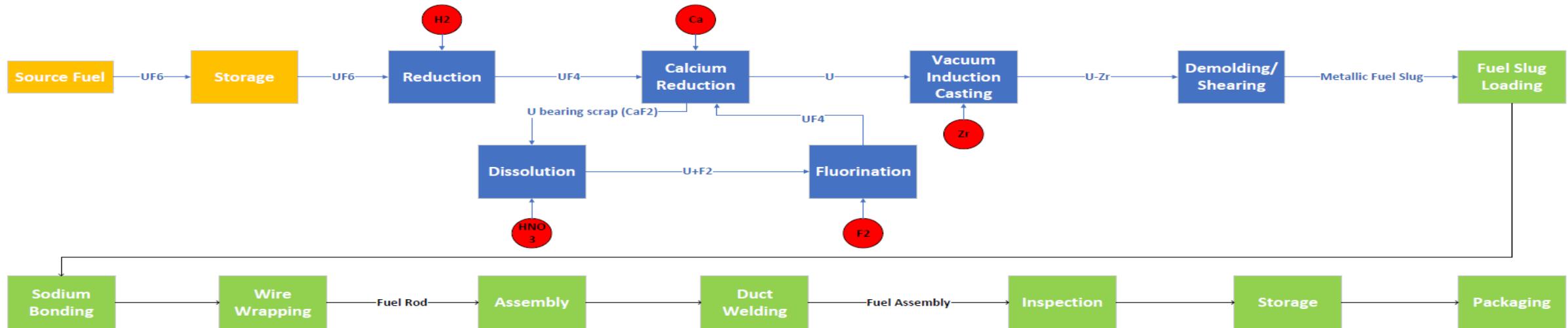
Scenario	Detection Probabilities and SEID as a Function of Measurement Uncertainty (RSD)				
	Enrichment (%U²³⁵)	All 0.5%	All 1%	All 3%	All 5%
Nominal	10%	5%	5%	5%	5%
	19.9%	5%	5%	5%	5%
Abrupt	10%	100%	100%	83.6%	44.8%
	19.9%	100%	98.8%	31.2%	15.5%
Protracted	10%	100%	100%	62%	28.6%
	19.9%	100%	95%	12.4%	6%

METALLIC FUEL FABRICATION

- Fast reactor development programs are also continuing to progress into the deployment phase with a potential ultimate goal of burning up long-lived actinides.
- Metallic fuel fabrication facilities are required to support fast reactors.
- Both domestic MC&A and international safeguards for commercial metal fuel fabrication facilities have not been fully developed.
 - U-based metallic fuels are similar to current LEU fuels but are likely to be at higher enrichments or utilize fissile content (Pu) at 10-19.9%.
 - LEU fuel fabrication facilities could be used as a guide in developing a safeguards approach for metallic fuel fabrication facilities.
 - Computational models simulating fast reactor fuel cycle facilities will aid in the design of MC&A systems.

METALLIC FUEL FABRICATION MODEL

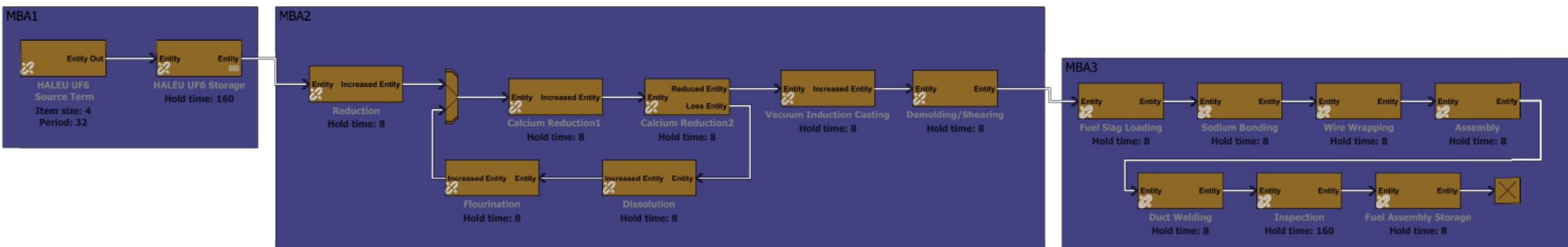
- F3M was utilized to simulate the flow of material through a metallic fuel fabrication facility. SimEvents is utilized to streamline a batch-style approach and allow for multiple different measurement systems to be tested efficiently.
- Assumptions:
 - Metallic fuel fabrication facility utilizes batch style processing
 - UF_6 arrives in gas canisters and leaves in assemblies of U-Zr fuel rods
 - The fresh fuel model follows a series of chemical processes to convert UF_6 to UF_4 into a metallic state to be combined with Zr to then be machined into fuel rods.



METALLIC FUEL FABRICATION MODEL (USING F3M)



- MBA 1 (or Item Control Area)
 - Generates the source fuel and includes storage (item accounting area)
 - User input: size of canister batch, input period, frequency and process times
- MBA 2
 - Chemical reactions to convert UF_6 to U-Zr rods
 - Reduction, Ca Reduction, Fluorination, VIC, Dissolution, Demolding/Shearing
- MBA 3
 - Machining processes to prepare fuel for packing and shipment
 - Only 1 inspection process is included for simplicity
- Random and systematic errors were added to simulated measurements.



CONCLUSION

- The SSPM modeling suite is being designed to allow more open access to tools and facility models:
 - F3M is an open source library of unit operations
 - MAPIT is an open source tool for safeguards analysis
 - SSPM-L will have open source model versions, but may also be used for facility-specific models.
- The safeguards modeling work is being used to help design the MC&A system for future fuel cycle facilities, including both TRISO and metallic fuel fabrication.
- The work on domestic MC&A approaches can help inform international safeguards approaches for these facilities, if needed, in the future.