Oak Ridge National Laboratory

04, 2026, Albuquerque, New Mexico

Material Control and Accounting for molten salt fuel synthesis

Oak Ridge National Laboratory

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U.S. DEPARTMENT of ENERGY

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Outline

- Materials Protection Accounting and Control Technologies (MPACT) Program
- Molten Salt Reactor Fuel Characteristics
- Applicability of Regulatory Frameworks to Front-End Activities for Molten Salt Reactors
- MSR fuel cycle and MC&A challenges
- Fuel Salt Synthesis and MC&A considerations
- ORNL Uranium Science Technology Center (USTC)
- Exploring capabilities to model a fuel salt synthesis facility in The Material Inventory Nuclear Tracking Simulator (MINTs)

MPACT Program

MPACT

Materials Protection Accounting and Control Technologies

MPACT program supports the U.S. advanced fuel cycles technology developers to effectively and economically address nuclear materials control and accounting (MC&A) requirements.

What we do:

- Develop technologies to assist nuclear fuel cycle developers meet U.S. MC&A regulatory requirements. Our technologies include fundamental detection systems (e.g. neutron, gamma, and calorimetric) as well as advanced modeling tools, and process monitoring technologies (e.g. molten salt sensors) to responsibly account for special nuclear material in U.S. fuel cycle facilities.

How we apply our work:

- We work closely with U.S. industry, universities, and the DOE complex to apply our technologies and resolve MC&A challenges.

Benefit to the U.S.:

- Our work facilitates implementation of advanced U.S. nuclear energy and supports sustained operations of the current U.S. reactor fleet and associated fuel cycle by reducing the burden on developers/operators in meeting U.S. MC&A requirements. Supports EOs 14299 and 14302.

Short-Term Objectives:

- Develop immediate safeguards solutions for current nuclear fuel cycle MC&A needs.
- Support the development of safeguards practitioners to staff MC&A positions at new U.S. advanced nuclear fuel cycle facilities.
- Work with U.S. nuclear industry to rapidly and responsibly develop U.S. nuclear energy solutions.

Medium-Term Objectives:

- Develop safeguards solutions for anticipated fuel cycle MC&A needs.
- Support the development of a sustainable domestic safeguards practitioner pipeline.

Long-Term Objectives:

- Develop cradle-to-grave and real (or near-real) time domestic safeguards technologies to strengthen U.S. nuclear fuel cycle security.

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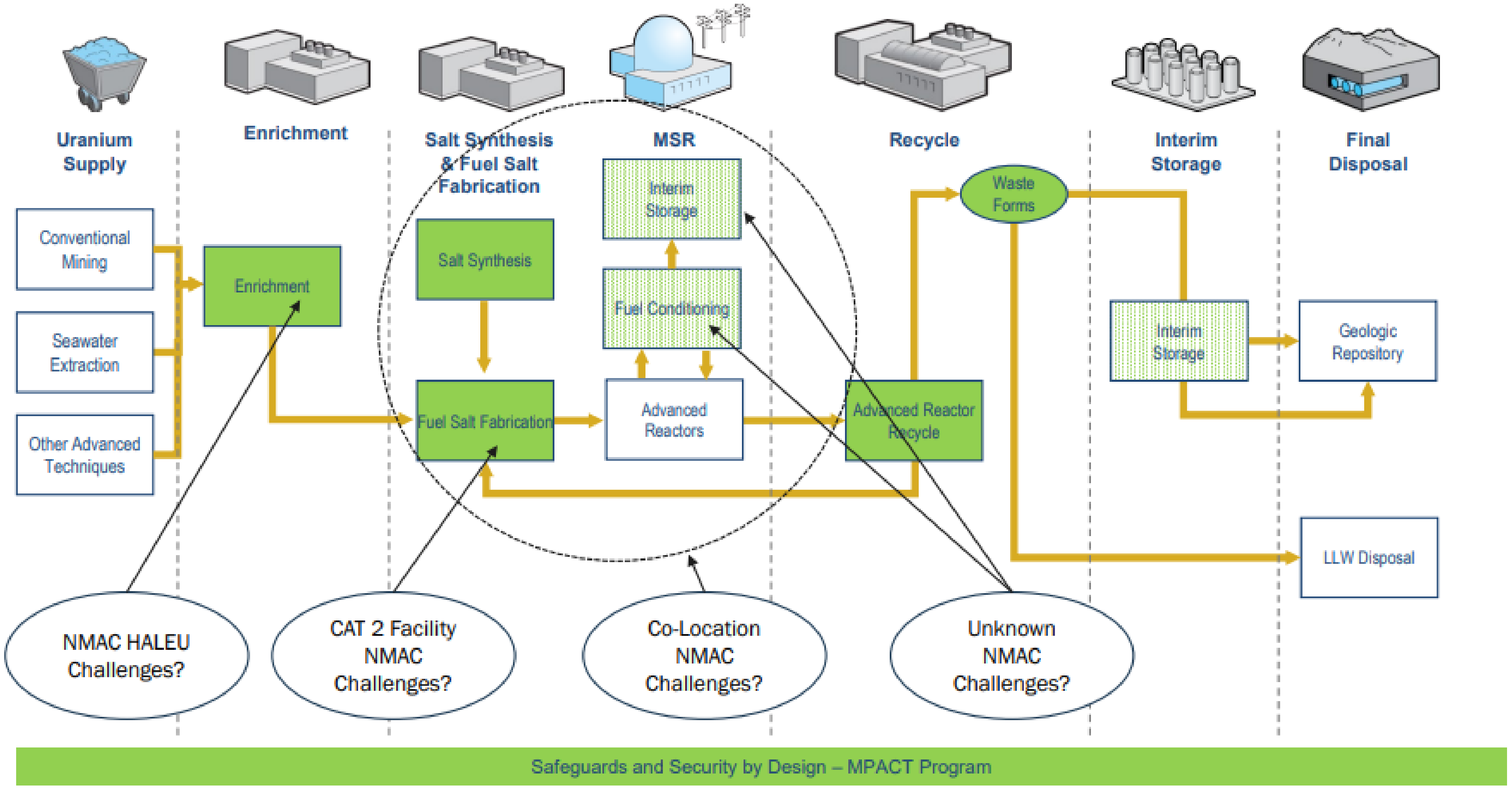
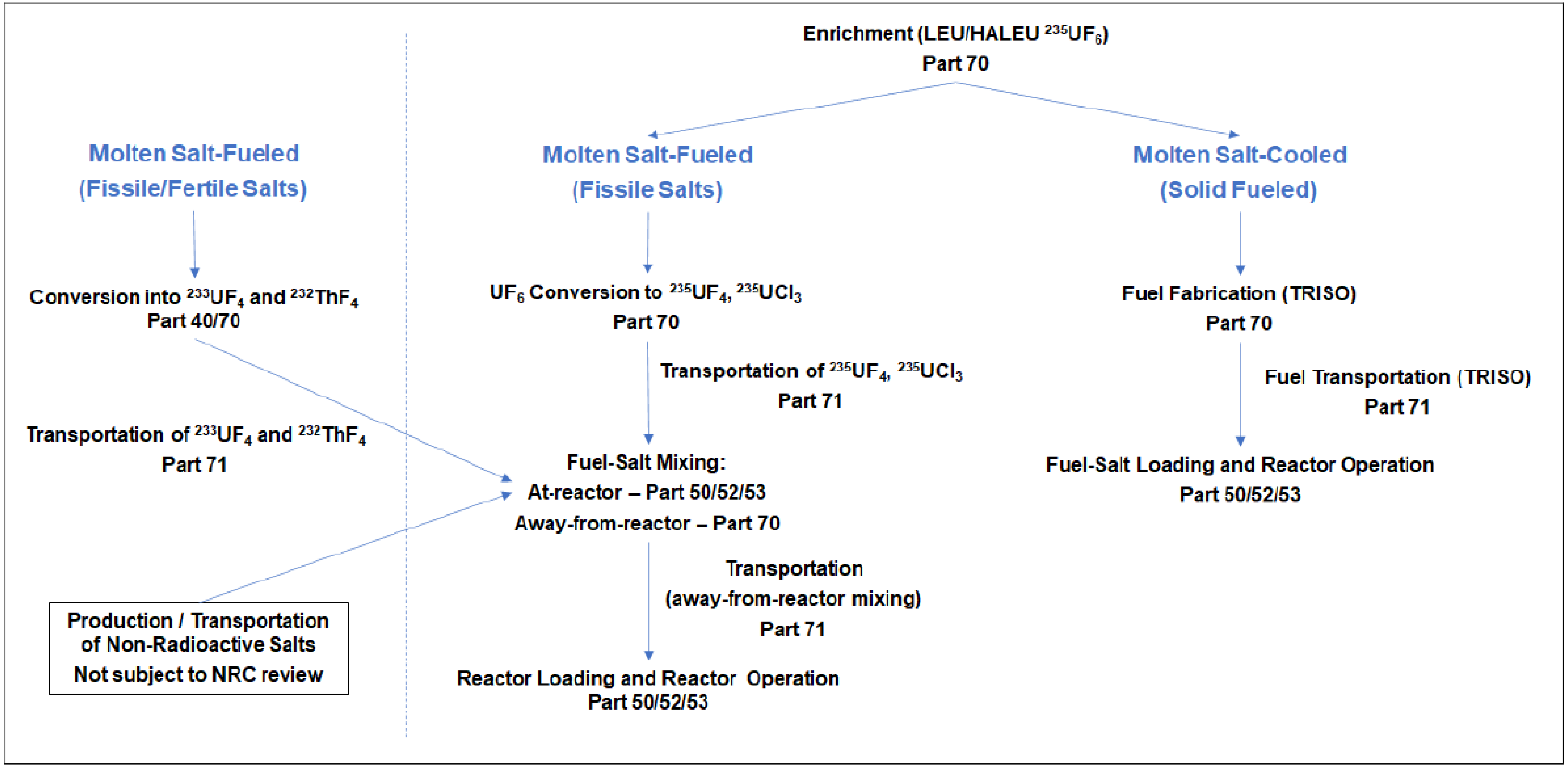
MPACT Program

One Possible U.S. Advanced Reactor Fuel Cycle



Applicability of Regulatory Frameworks to Front-End Activities for Molten Salt Reactors



Source: US NRC, Preliminary Assessment of Considerations for the Front-End Activities for Molten Salt Reactors, TLR-RES/DE/REB-2022-04 , 2022

MSR fuel cycle and MC&A challenges

Stage	Challenge
Enrichment	There are no standardized containers available for transporting uranium with higher enrichment levels (product in the UF6 form) that are economical and able to support the anticipated deployment of several advanced reactors.
Deconversion	The deconversion facilities may include additional processes to convert UO2 (from UF6) to either uranium fluoride or chloride powder form. These processes raise material accounting challenges because there is lack of commercial scale experience, and moreover, there could be SNM holdup in process equipment. There are no standardized containers for storage and transportation of enriched uranium fluoride or chloride powder.
Fuel Salt Synthesis	Fuel salt synthesis occurs in loose, bulk form with distinct chemical and physical processes compared to preparing fuel pellets and discrete fuel assemblies that can be easily tracked and accounted. Another uncertainty exists regarding whether the fuel salt will be synthesized (mixing of fissile material in a suitable form with carrier salt) on the same site as the reactor, or a distant separate site.
Reactor	Material accounting of SNM at MSR will be a challenge because of the use of loose, bulk form fuel salt instead of discrete fuel assemblies. Additionally, fuel salt containing SNM undergoes transmutation and depletion (i.e., their inventories change rapidly), and benchmarked neutronics and fuel burnup codes are not available to estimate the SNM inventory. **Mention this is other sponsor (ARSS)**
Processing / Recycling	Raises significant MC&A questions because limited experience is available to inform this work.
Storage	Standard container designs should be developed for each novel fuel form, including fuel salt, while accounting for criticality and material accounting.
Licensing	Co-siting a nuclear reactor and a fuel salt synthesis facility may introduce added complexity in licensing.

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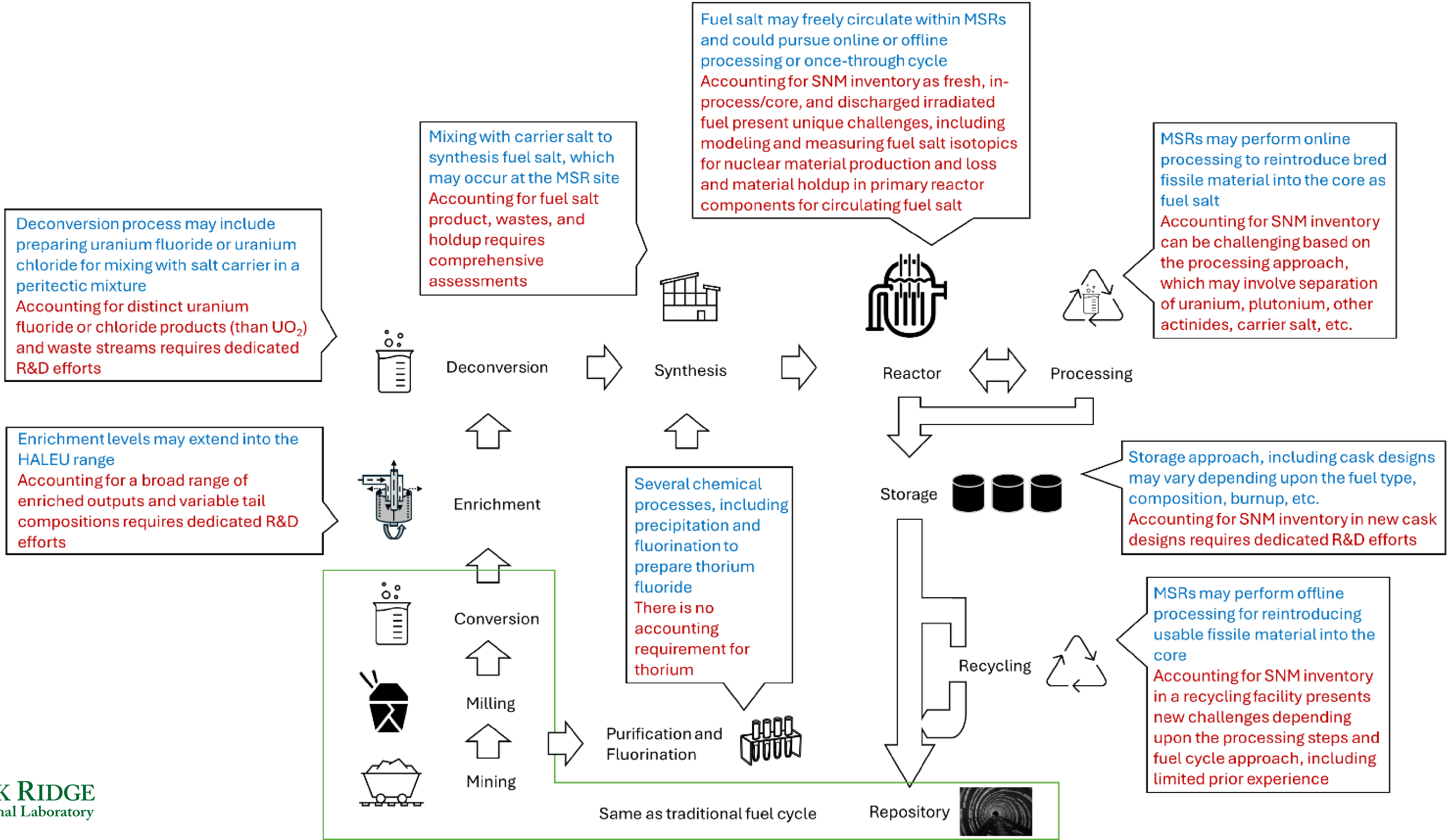
MSR fuel cycle and MC&A challenges



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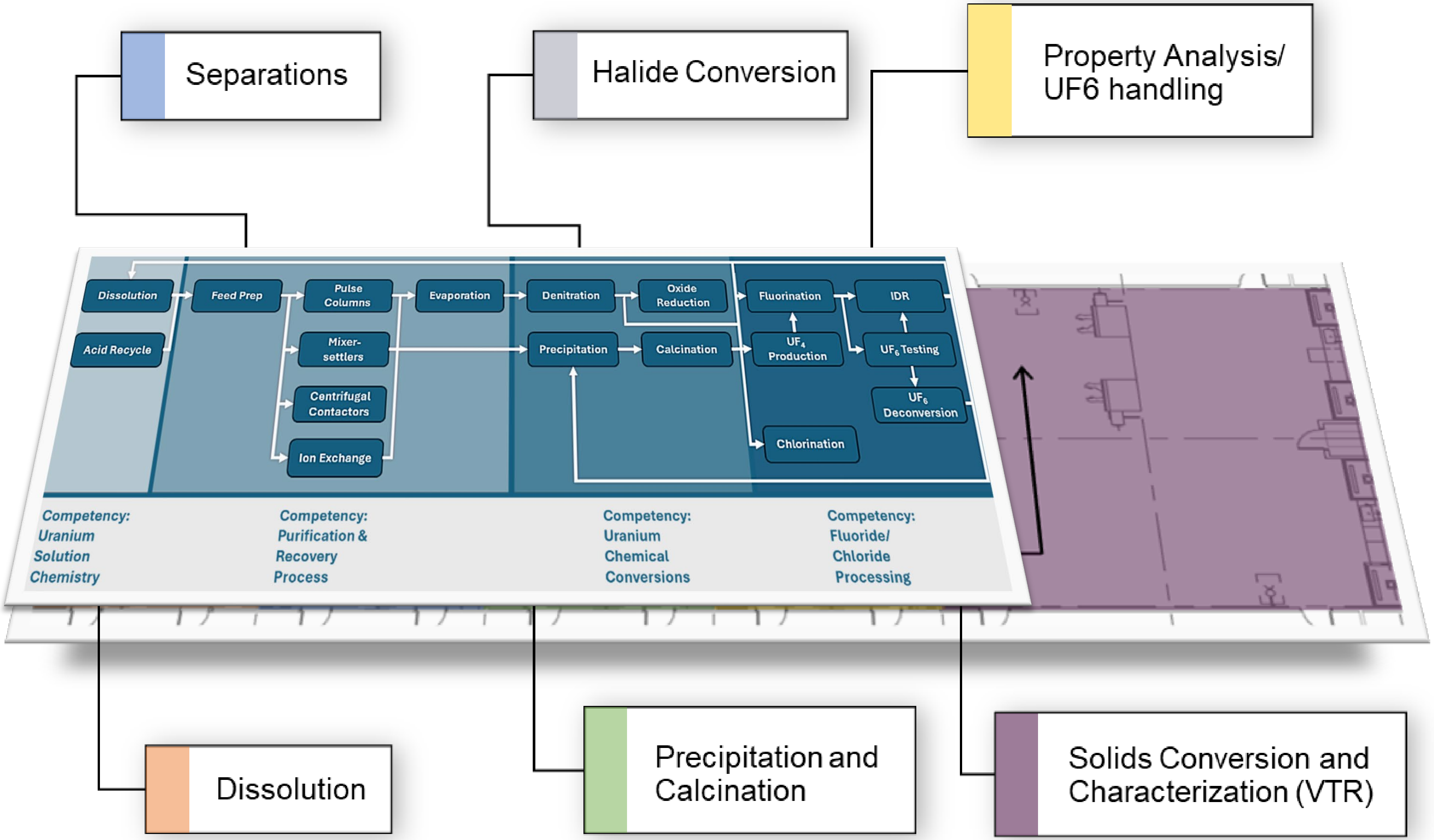
Fuel Salt Synthesis and MC&A considerations

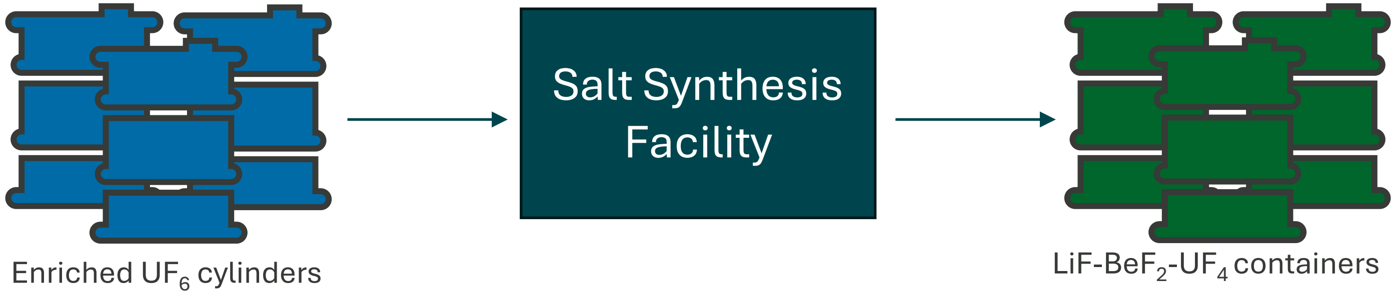
Characteristics / Considerations of fuel salt synthesis relevant for MC&A	Challenge
Bulk liquid with dissolved SNM	• Fuel cannot be counted since there are no fuel assemblies such as an LWR. MC&A for fuel salt synthesis will rely on bulk material accountancy. • This requires developing new measurements, sampling, and modeling.
Fuel salt composition evolves (addition and depletion)	• Continuous tracking of isotopic composition and the amount of SNM. • Requires near real time accountancy and developing an MC&A program that combines process monitoring with periodic inventory.
Fuel salt is assumed to be homogeneous	• Sampling may not be representative. • This introduces measurement uncertainty in inventory estimates.
Fuel salt synthesis can involve processes with restrictive access such as high temperature and corrosive salt environment	• Indirect measurements due to inaccessible environment. • modeling of processes and uncertainties to account for MUF.
Transportation of the carrier salt with SNM	• Carrier salt inclusion and potential criticality issues

Process Area	Methods
Solution Chemistry	Large Scale Dissolver Benchtop Scale Dissolver
Separations Science & Technology	Mixer-Settlers Pulsed Columns Centrifugal Contactors Ion Exchange Columns
Oxide Conversion Systems	Precipitation Calcination Thermal Denitration Oxide Reduction Integrated Dry Route
UF_4 Conversion & Deconversion Systems	Aqueous Hydrofluorination Ionic Liquid Carbon Tetrachloride
UF_6 Conversion & Handling Systems	Fluorination Fluid Bed Flame Tower UF_6 Handling Loop
Final Forms Science & Technology	Metallothermic Reduction Product Handling Glove Boxes

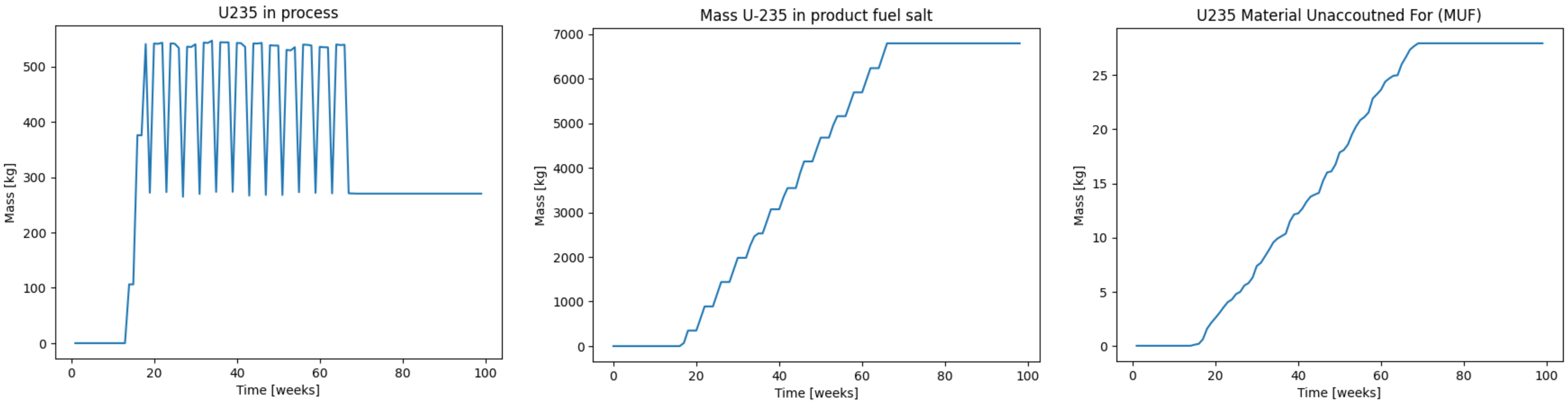
ORNL Uranium Science Technology Center - Laboratory Layout



Exploring capabilities to model a fuel salt synthesis facility in MINTs



Nominal process being modeled takes in enriched UF_6 from an enrichment facility as the input and produces fueled FLiBe (LiF-BeF_2-UF_4) as the output.



Nominal values for U-235 currently in process steps (left), in the product fuel salt (center) and material unaccounted for (right). Figures were produced using exploratory values to verify model behavior and do not reflect expected values for a salt synthesis process.

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