Enabling techniques within OpenMC for dynamic models of molten salt reactors

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Table of Contents

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Table of Contents

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Introduction

- $100 MW_{th}$ thorium MSR thermal breeder
- 40ft container sized reactor, mass manufactured on an assembly line
- Active development of MSR critical components

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Introduction

- ^{7}LiF-ThF_4-PuF_3 starting fuel salt / ^{7}LiF-ThF_4 blanket salt / unpressurized heavy water moderated
- Burn-then-breed (Th-U fuel cycle)
- no control rods (reactivity control via controlling water lever) / no online refueling for the life of the reactor.
- autonomous operation / all control is done in software with consumer grade electronics inside the container using consensus steering software.
- pumping through dump tanks / all salt and moderator drains passively to respective dump tanks when pumps are shut off.
- walk-away and prime-minister safe / dump tank have constant parasitic heat loss to allow for decay heat removal when the salts are drained / all off-gases are contained within the radiation shielding and all potential water boil off is condensed and contained within the radiation shielding /only water coolant, nitrate coolant salt, power, and data uplink penetrates the container.

Table of Contents

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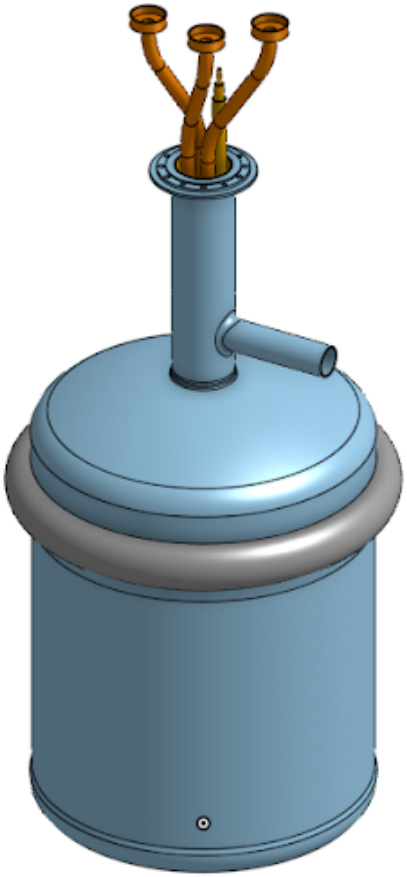
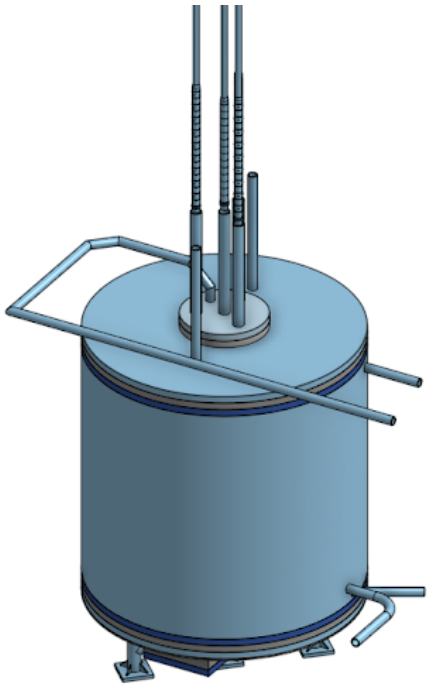
OpenMC tool chain from CAD to depletion simulation

- Open source MC neutron and photon transport
- Kernel in C++ / Python API
- Install scripts made available on Github for main Linux distro (`https://github.com/openmsr`)
- CAD meshing relies on DAGMC (similar to MCNP, Geant4, Fluka, etc.)
- Workflow available to go from CAD to OpenMC through Gmsh (entirely open source) or Cubit (`https://github.com/openmsr/step_to_h5m`)

OpenMC tool chain from CAD to depletion simulation





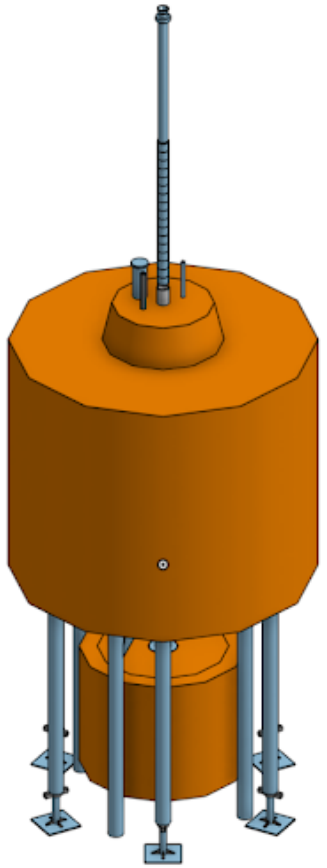


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Table of Contents

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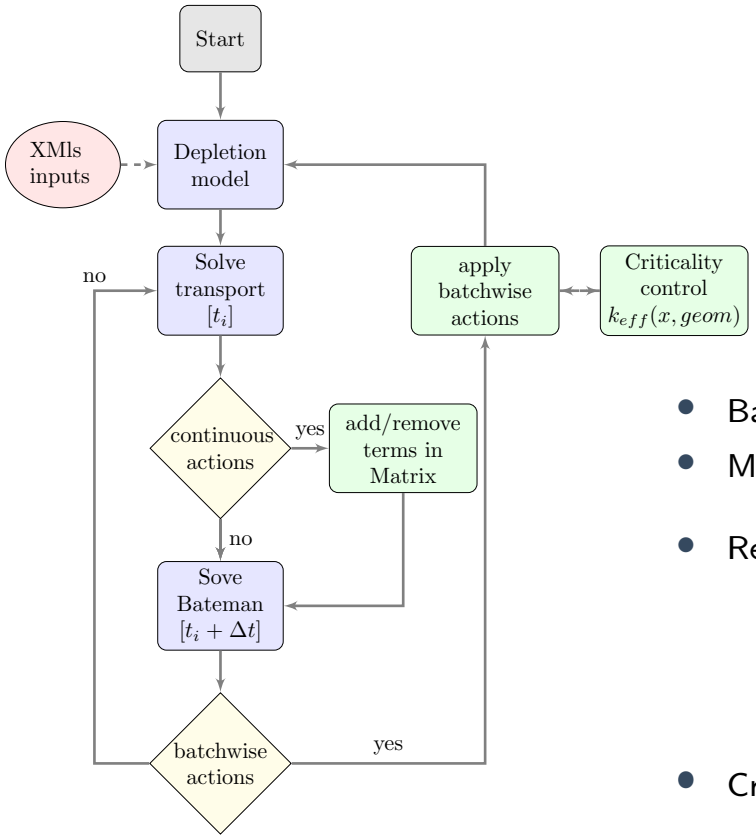
Reprocessing scheme in depletion analysis



- Coupling between transport and depletion

$$\frac{dn_i(t)}{dt} = \sum_j \gamma_{j\to i} n_j \left(\overline{\sigma_j \phi} + \lambda_{j\to i}\right) - n_i \left(\overline{\sigma_i \phi} + \lambda_{i\to j}\right)$$

$$\frac{d\mathbf{n}}{dt} = \mathbf{A}\mathbf{n}$$

$$\mathbf{n}_{t+\Delta t} = e^{\mathbf{A}\Delta t}\mathbf{n}_t$$

- Bateman matrix exponential: 48th order IPF CRAM
- Main assumptions not valid for liquid fueled reactors
- Reprocessing actions:
  - Continuous
  - Batch
- Criticality control parametrization:
  - Geometry
  - Material composition

Inspiration: *EQL0D fuel cycle procedure and its application to the transition to equilibrium of selected molten salt reactor designs. Hombourger, Krepel, Pautz.*

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Table of Contents

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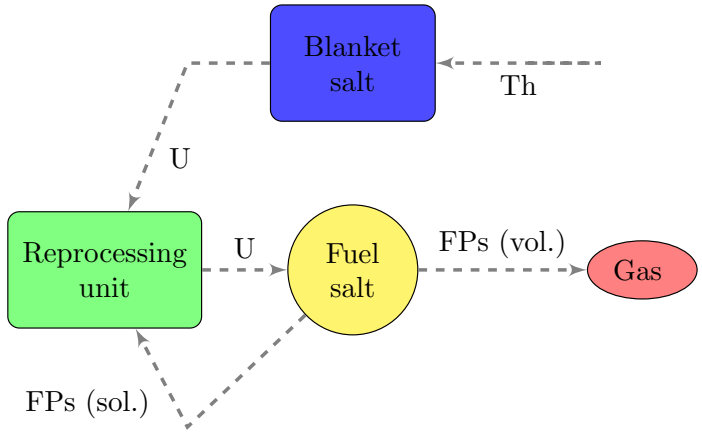
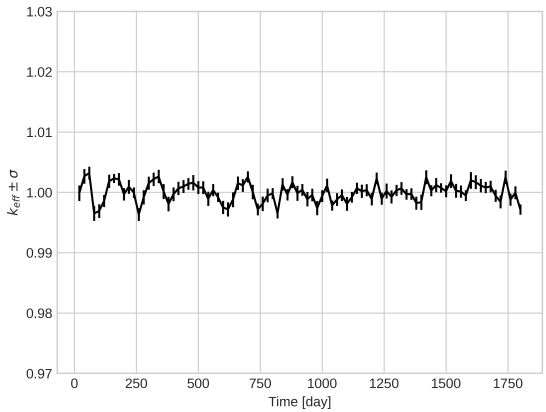
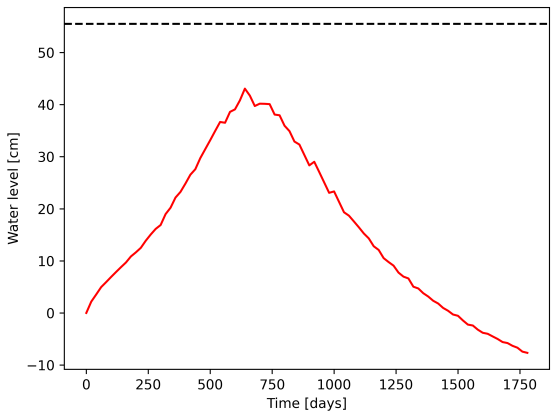
Test case

- U separation from blanket and transfer to fuel
- FPs online removal:
  1. volatile (He bubbling / spraying)
  2. metallic state (plating out)
  3. oxide precipitates (fluorination)
  4. lanthanadies (distillation)
- water level variation to compensate for burnup







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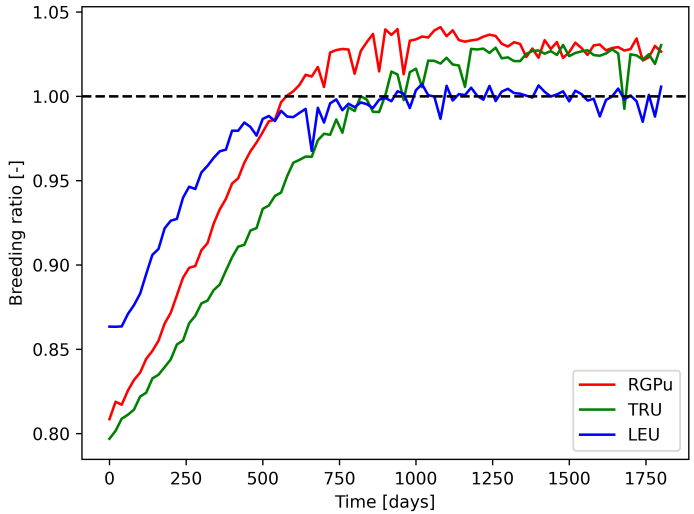
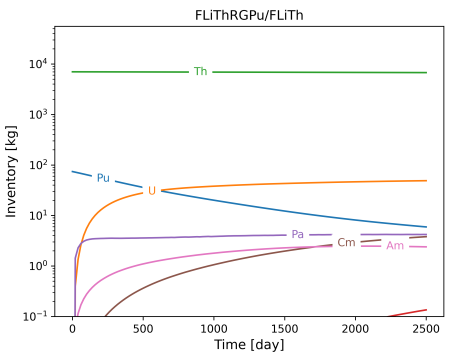
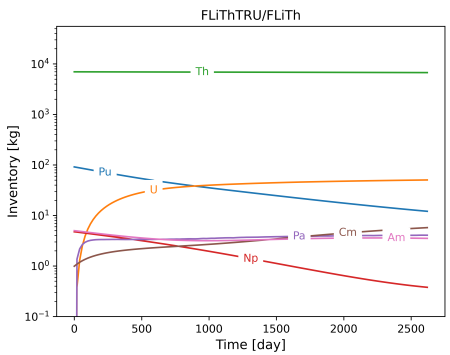
Results

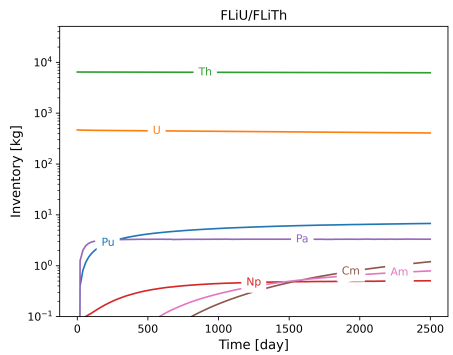
Assuming:

- $100 MW_{th}$
- $\sim$ 400L LiF-ThF_4- $(RGPu/TRU)F_3$ or LiF-$(LEU)F_4$ fuel salt
- $\sim$ 3000L LiF-ThF_4 blanket salt
- $\sim$ 3000L D20
- highly depleted lithium 4-5N
- c/c composite core
- online removal of fission products transfer of uranium from blanket salt to fuel salt.









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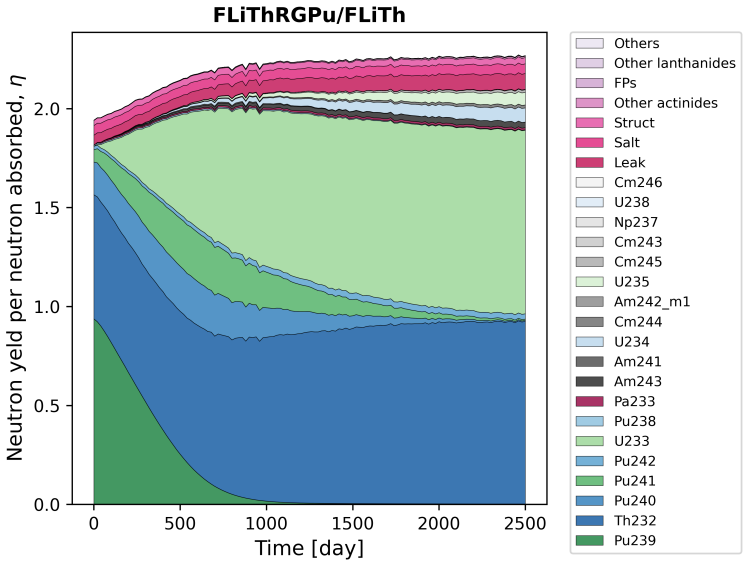
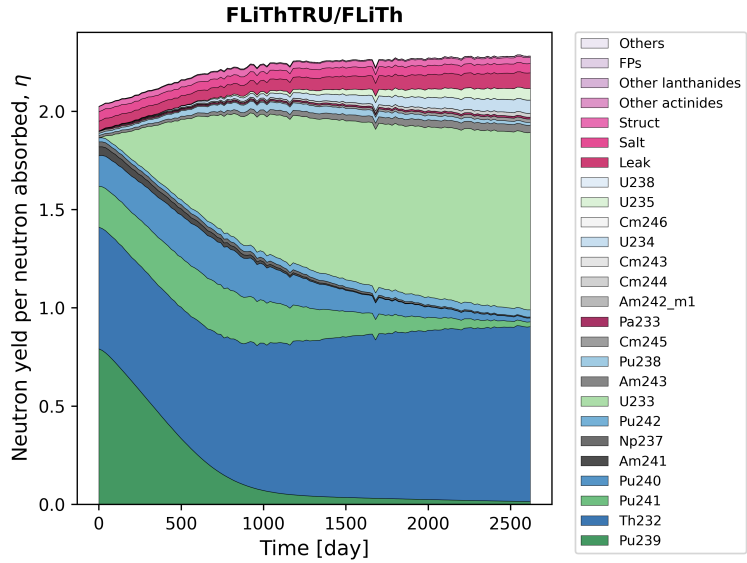
Results





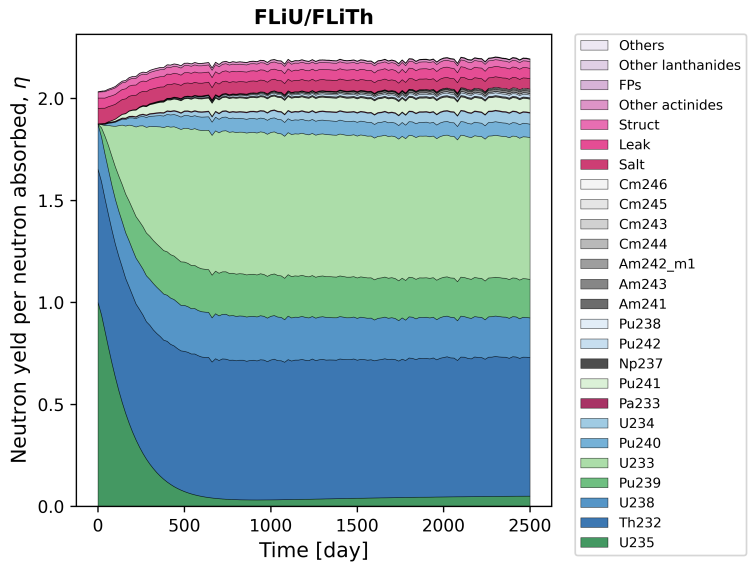


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Table of Contents

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Conclusions

- An entire open source toolchain to simulate detailed CAD geometries is available on github (`https://github.com/openmsr/step_to_h5m`)
- OpenMC has proven to be a flexible tool to allow preliminary reprocessing operations implementation during depletion analyses, as intended for MSRs. (`https://github.com/openmsr/openmc/tree/ca-deplete-batchwise`)
- The CA thermal breeder reactor has proven to become feasible, under various assumptions.

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