Analysis of Salt Management Effects on the Molten Salt Research Reactor's Operational Characteristics

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Background

- Molten Salt Reactor Experiment (MSRE) demonstrated a sampler-enricher system
  - Also demonstrated the ability to add poison
- Xe^{135} & Sm^{149} tracked due to relatively large thermal microscopic absorption cross section compared to U^{235}

Isotope	σ_a [b]
U^{235}	5.1E2
Xe^{135}	2.6E6
Sm^{149}	4.2E4

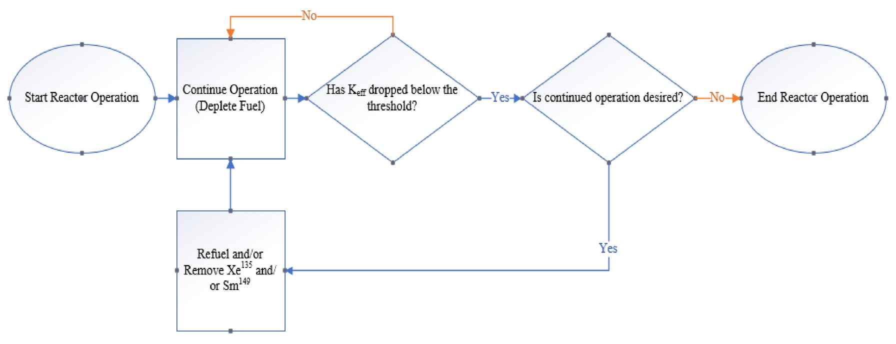
- Example concentration equations:
  - $\frac{dN_{Xe}}{dt} = \gamma_{Xe}\Sigma_f\phi + \lambda_I N_I - \lambda_{Xe}N_{Xe} - \sigma_a^{Xe}N_{Xe}\phi\ - removal\ rate + reinsertion\ rate$
  - $\frac{dN_{Sm}}{dt} = \lambda_{Pm}N_{Pm} - \sigma_a^{Sm}N_{Sm}\phi\ - removal\ rate + reinsertion\ rate$

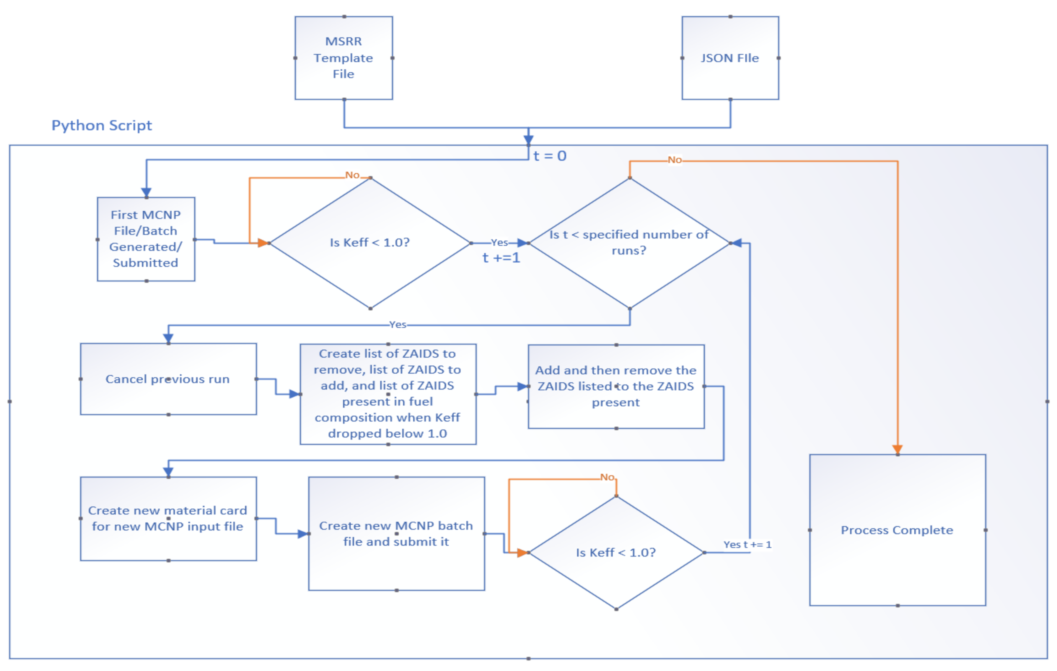
Overview

- Online fuel manipulation of the MSRR was evaluated
- Evaluated the impact on:
  - K_{eff} (related to operational lifetime)
  - Mean generation time
  - Effective delayed neutron fraction
- 3 Main Cases:
  - Adding UF_4
  - Removing Xe^{135} & Sm^{149}
  - Adding UF_4 and removing Xe^{135} & Sm^{149}

Logic

- Modeled reactor operation cycle





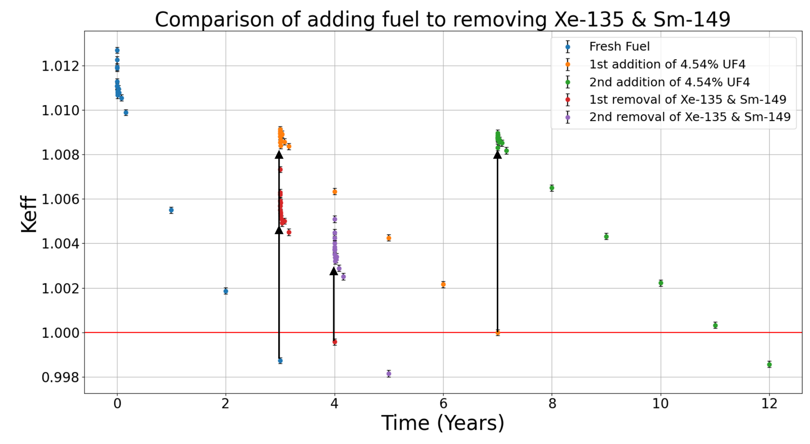
step	duration (days)	time (days)	power (MW)	keff
0	0.000E+00	0.000E+00	1.000E+00	1.01270
1	2.500E-01	2.500E-01	1.000E+00	1.01226
2	2.500E-01	5.000E-01	1.000E+00	1.01194
3	2.500E-01	7.500E-01	1.000E+00	1.01189
4	2.500E-01	1.000E+00	1.000E+00	1.01128
5	5.000E-01	1.500E+00	1.000E+00	1.01109
6	5.000E-01	2.000E+00	1.000E+00	1.01107
7	5.000E-01	2.500E+00	1.000E+00	1.01110
8	5.000E-01	3.000E+00	1.000E+00	1.01080
9	1.000E+00	4.000E+00	1.000E+00	1.01068
10	1.000E+00	5.000E+00	1.000E+00	1.01088
11	5.000E+00	1.000E+01	1.000E+00	1.01096
12	5.000E+00	1.500E+01	1.000E+00	1.01079
13	1.500E+01	3.000E+01	1.000E+00	1.01056
14	3.000E+01	6.000E+01	1.000E+00	1.00990
15	3.050E+02	3.650E+02	1.000E+00	1.00550
16	3.650E+02	7.300E+02	1.000E+00	1.00187
17	3.650E+02	1.095E+03	1.000E+00	0.99873

actinide inventory for material 1 at end of step 17, time 1.095E+03 (days), power 1.000E+00 (MW)

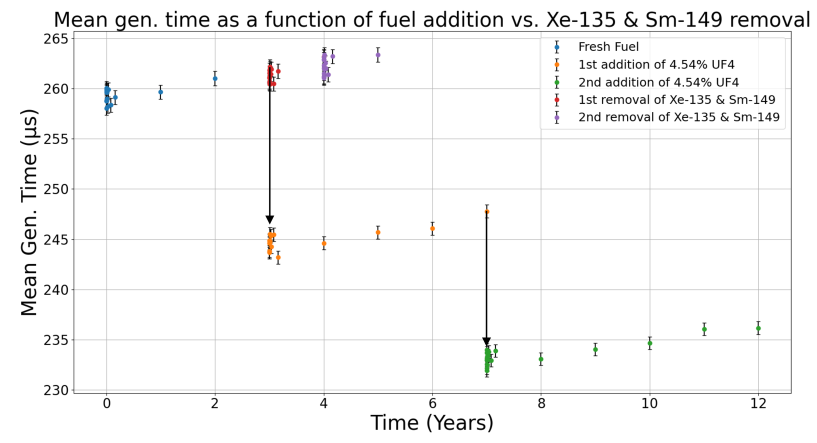
- MCNP was chosen to model the depletion of the fuel
  - Produced the Keff, mean generation time, and effective delayed neutron fraction for each depletion step
  - Fission product tier 2 was selected due to computational time
  - Due to the isotope generator algorithm, each subsequent sequential run required increased time
- Input Parameters:
  - Number of runs
  - Incremental depletion timesteps (days), power fraction for each timestep, operating power (MW), material to be depleted, depletion options such as fission product tier list, material volume, isotopes to be omitted
  - Number of isotopes to remove, the isotope and its corresponding mass to be added or removed between each run
  - The control rod positions (kept constant)

- MCNP was used in conjunction with Python in order to automate the simulation behavior of online refueling and online fission product removal
- First run was fresh fuel to provide a baseline for the operational lifetime
  - Subsequent runs will determine at what frequency and magnitude fuel composition changes should occur
- Lifetime expectations due to fission product removal will be found through the omission of Xe^{135} & Sm^{149}
- Output Parameters:
  - K_{eff}
  - Mean generation time
  - Effective delayed neutron fraction
  - "Lifetime" of the reactor
    - When K_{eff} drops below 1.0, it is determined that timestep is the lifetime of the MSRR

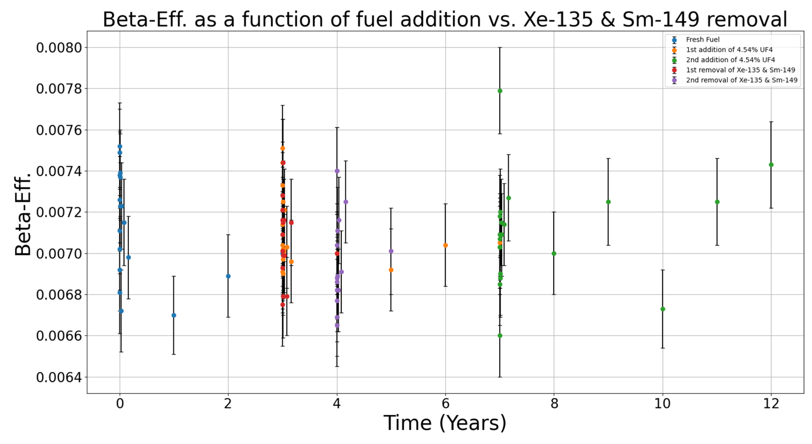
Results



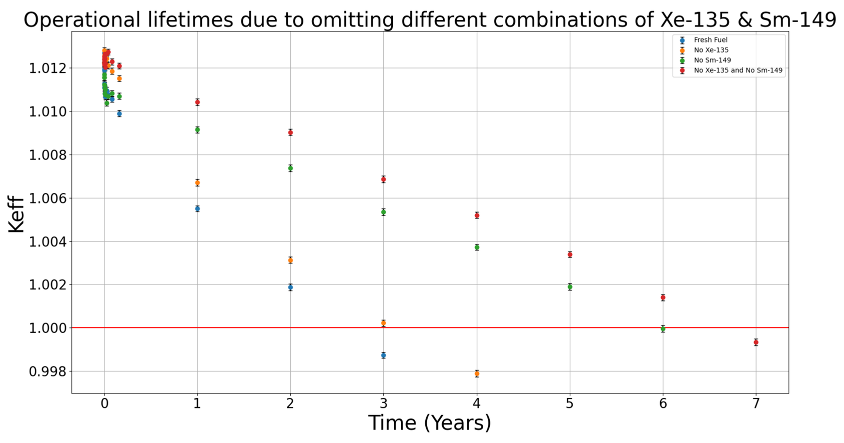
- As can be seen, there was a prompt increase in K_{eff} whenever fuel was added or Xe^{135} & Sm^{149} was removed



- As can be seen, there was a prompt decrease in mean generation time whenever fuel was added, and only a slight, very short-lived effect when Xe^{135} & Sm^{149} was removed



- As can be seen, the delayed neutron fraction has a relatively large uncertainty but tends to remain around approximately 0.007



- Xe^{135} & Sm^{149} omission increased the lifetime by ≈ 170%
- Sm^{149} omission increased the lifetime by ≈ 140%
- Xe^{135} omission increased the lifetime by ≈ 25-30%

Conclusions

- Continuous removal of Xe^{135} and Sm^{149} can extend the lifetime by approximately 170%
- Mean gen. time is sensitive to fuel insertion while influenced to a lesser degree by removal of Xe^{135} & Sm^{149}
- Negligible effects observed on beta-eff.
- If Xe^{135} is the only isotope removed, the effects on all affected parameters are short lived (but noticeable)

Future Work

- Find reliable percentages for solid fission product removal
- Remove fission products on a much shorter time period (Ex. on the timescale of days)
- Run more particles to see if the uncertainty of beta-effective begins to decrease further
- Evaluate the impact of removing the same mass of fuel-salt as the mass of UF_4 being added

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