Comparison Between Continuous and Batchwise Online Reprocessing in Serpent2

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Introduction

Molten Salt Reactor Online Reprocessing

- Depletion of a reactor provides useful data on safety parameter and fuel cycle evolution
- Depletion of Molten Salt Reactors requires accounting for reprocessing
- Batchwise modeling of Molten Salt Reactors is common [3, 2]
- Continuous modeling offers unique advantages over batchwise modeling

Comparison of Methods

- An identical toy model is implemented for both methods
- Continuous model uses varying number of steps
- Multiple approaches are implemented for the continuous model

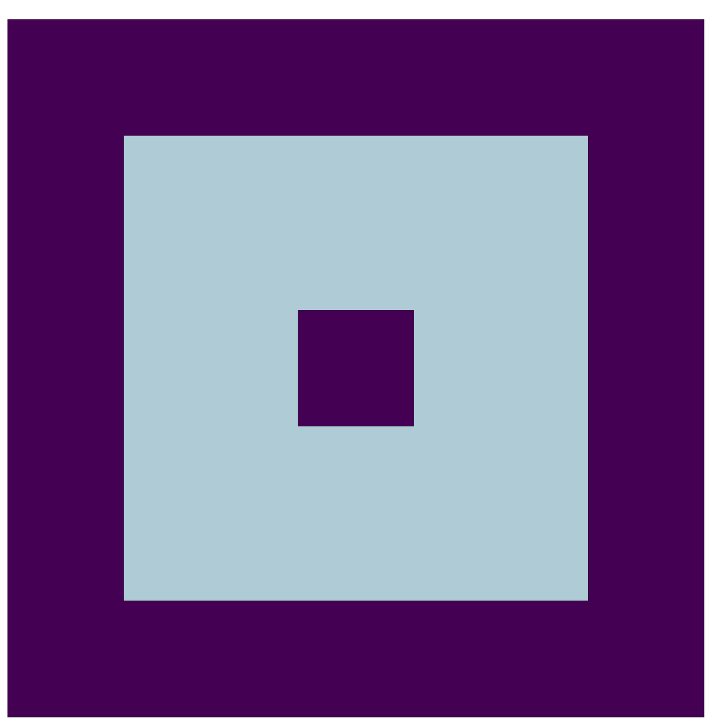

Figure 1: Geometry of toy model used in serpent2 for continuous and batchwise reprocessing models. Composed of a cube of fuel salti (cyan) with a graphite log in the center and a graphite shell (purple).

Table 1: Approach Acronyms and Descriptions

Approach	Description
SP pre	SaltProc steady batch pre-depletion
SP post	SaltProc steady batch post-depletion
CR	Cycle Rate continuous approach
SPCR	SaltProc Cycle Rate continuous approach
CTD	Cycle Time Decay continuous approach
CTRL	Control method (no reprocessing feeds or removal)

Objectives

- Capture the precise differences in continuous and batchwise models
- Determine effective depletion step sizes for continuous reprocessing
- Investigate validity of using average feed rates during depletion

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Reprocessing Models

Batchwise Reprocessing

- Iteratively perform depletion with external adjustments
- ***Steady Batch*** uses small removals each depletion step.

$$X = \frac{1}{T_{cyc}} \tag{1}$$

- T_{cyc} is the cycle time
- X is the fractional removal rate

- ***Bulk Batch*** uses full removal after a set number of depletion steps.
- SaltProc is used to run batchwise reprocessing for Serpent2
- The current version of SaltProc uses the Steady Batch method

Table 2: Batchwise Reprocessing Methods

Approach	Cycle Time	X [s^{-1}]	Step Removal
Bulk Batch [3d]	20 s	-	1
Bulk Batch [3d]	30 d	-	0*
Steady Batch [3d]	20 s	3.86E-6	1
Steady Batch [3d]	3 d	3.86E-6	1
Steady Batch [3d]	30 d	3.86E-7	0.1

* Bulk removal occurs after 30 days, so the step fractional removal becomes 1 at 30 day step.

Continuous Reprocessing

- Adds "decay-like" term to Bateman equation, less iterative [1]

$$\frac{dN_j}{dt}_{base} = \sum_{i \neq j} \left[\left(\gamma_{i \to j} \sigma_{f,i} \Phi + \lambda_{i \to j} + \sigma_{i \to j} \Phi \right) N_i \right] - \left(\lambda_j + \sigma_j \Phi \right) N_j \tag{2}$$

$$\frac{dN_j}{dt}_{net} = \frac{dN_j}{dt}_{base} - \lambda_{r,j} N_j + \sum_{mat} \lambda_{r,i \to j} N_i \tag{3}$$

The symbols given in the equations are defined as follows:

- N_j is the atomic density of isotope j.
- $\gamma_{i \to j}$ is the fractional fission product yield of j in the fission of isotope i.
- $\sigma_{f,i}$ is the microscopic fission cross section of isotope i.
- Φ is the spectrum-averaged scalar flux in the fuel region.
- $\lambda_{i \to j}$ is the decay constant of decay $i \to j$.
- $\sigma_{i \to j}$ is the microscopic transmution cross section of reaction $i \to j$.
- N_i is the atomic density of isotope i.
- λ_j is the decay constant of isotope j.
- $\lambda_{r,j}$ is the reprocessing constant for removal of isotope j.
- σ_j is the microscopic total transmutation cross section of isotope j.
- $\lambda_{r,i \to j}$ is the reprocessing constant for feed of material $i \to j$.

- ***Cycle Time Decay*** (CTD) model treats reprocessing as decay

$$\tau_{1/2} = \frac{1}{2} T_{cyc} \tag{4}$$

$$\lambda_r = \frac{ln(2)}{\tau_{1/2}} \tag{5}$$

- ***Cycle Rate*** (CR) treats as linear fractional removal, same as Steady Batch

$$\lambda_r = ln\left(\frac{1}{1 - X}\right) \tag{6}$$

- ***SaltProc Cycle Rate*** (SPCR) mimics batchwise reprocessing with continuous model

Table 3: Continuous Reprocessing Methods

Approach	Cycle Time	$\tau_{1/2}$	X [s^{-1}]	λ_r [s^{-1}]
Cycle Time Decay	20 s	10 s	6.70E-2	6.93E-2
Cycle Time Decay	3 d	1.5 d	5.35E-6	5.35E-6
Cycle Rate	20 s	-	0.05	5.13E-2
Cycle Rate	3 d	-	3.86E-6	3.86E-6
SaltProc Cycle Rate	20 s	-	3.86E-6	3.86E-6
SaltProc Cycle Rate	3 d	-	3.86E-6	3.86E-6
SaltProc Cycle Rate	30 d	-	3.86E-7	3.86E-7

Results

Multiple Steps

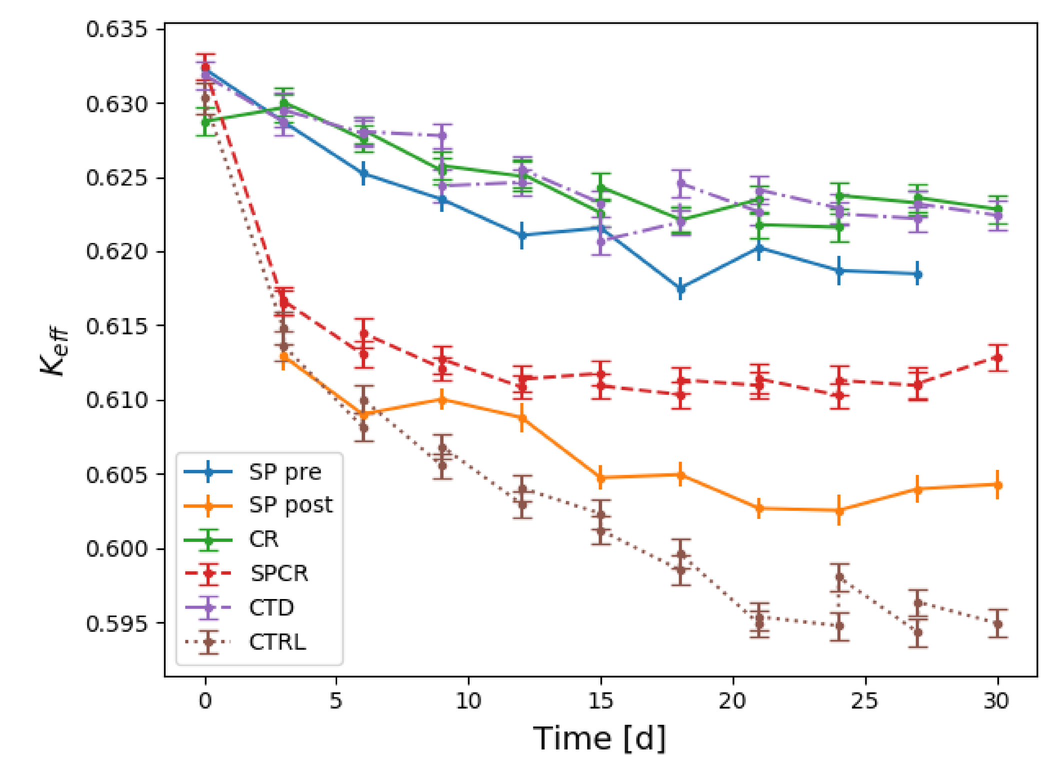

Figure 2: Continuous and batch models k_{eff} over time when using the matching depletion steps and feed rates.

Single Step

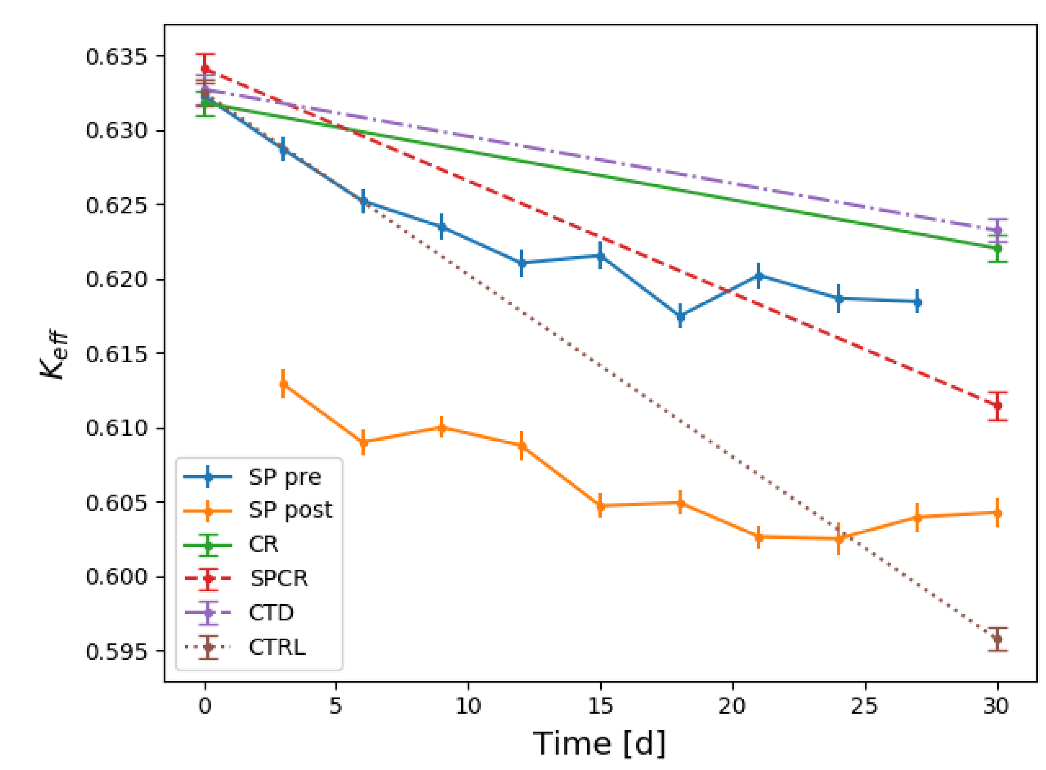

Figure 3: Continuous and batch models k_{eff} over time when continuous uses a single step and average feed rates.

Overall Results

Table 4: k_{eff} at 30 Days for 3 and 30 Day Steps

Approach	3d Step k_{eff}	30d Step k_{eff}	Diff [pcm]
CR	0.622815	0.622043	77
SPCR	0.612871	0.611481	140
CTD	0.62241	0.623246	84
CTRL	0.594924	0.595784	86

Key Takeaways

- Continuous with same depletion steps results in higher k_{eff}
- Step size order of magnitude increase and average feed rate usage resulted in 100 pcm difference in final k_{eff}
- Step size increase reduces computational cost by a factor of 10
- Average feed rate use eliminates double running, making depletion twice as efficient

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