# Comparison Between Continuous and Batchwise Online Reprocessing in Serpent2

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## Introduction

### Molten Salt Reactor Online Reprocessing

- 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

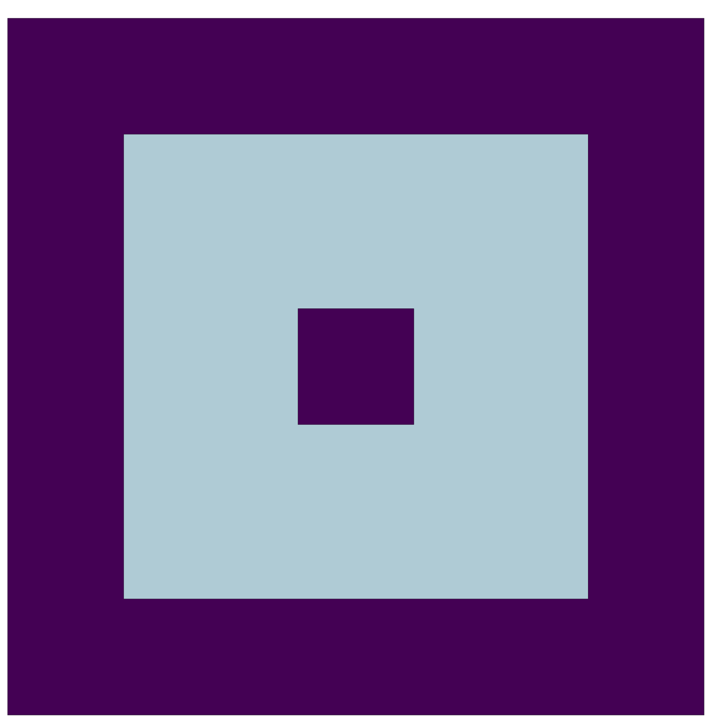

Figure 1: Geometry of toy model used in serpent2 for continuous and batchwise reprocessing models.

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]

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

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

The symbols given in the equations are defined as follows:

- $N_j$ is the atomic density of isotope j.
- $\gamma_{i\rightarrow j}$ 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 $i$.
- $\Phi$ is the spectrum-averaged scalar flux in the fuel region.
- $\lambda_{i\rightarrow j}$ is the decay constant of decay $i \rightarrow j$.
- $\sigma_{i\rightarrow j}$ is the microscopic transmution cross section of reaction $i \rightarrow j$.
- $N_i$ is the atomic density of isotope $i$.
- $\lambda_j$ is the decay constant of isotope $j$.
- $\lambda_{r,j}$ is the reprocessing constant for removal of isotope $j$.
- $\sigma_j$ is the microscopic total transmutation cross section of isotope $j$.
- $\lambda_{r,i\rightarrow j}$ is the reprocessing constant for feed of material $i \rightarrow j$.

- ***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 [$s^{-1}$] | $\lambda_r$ [$s^{-1}$] |
|---|---|---|---|---|
| Cycle Time Decay | 20 s | 10 s | - | 6.93E-2 |
| Cycle Time Decay | 3 d | 1.5 d | - | 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

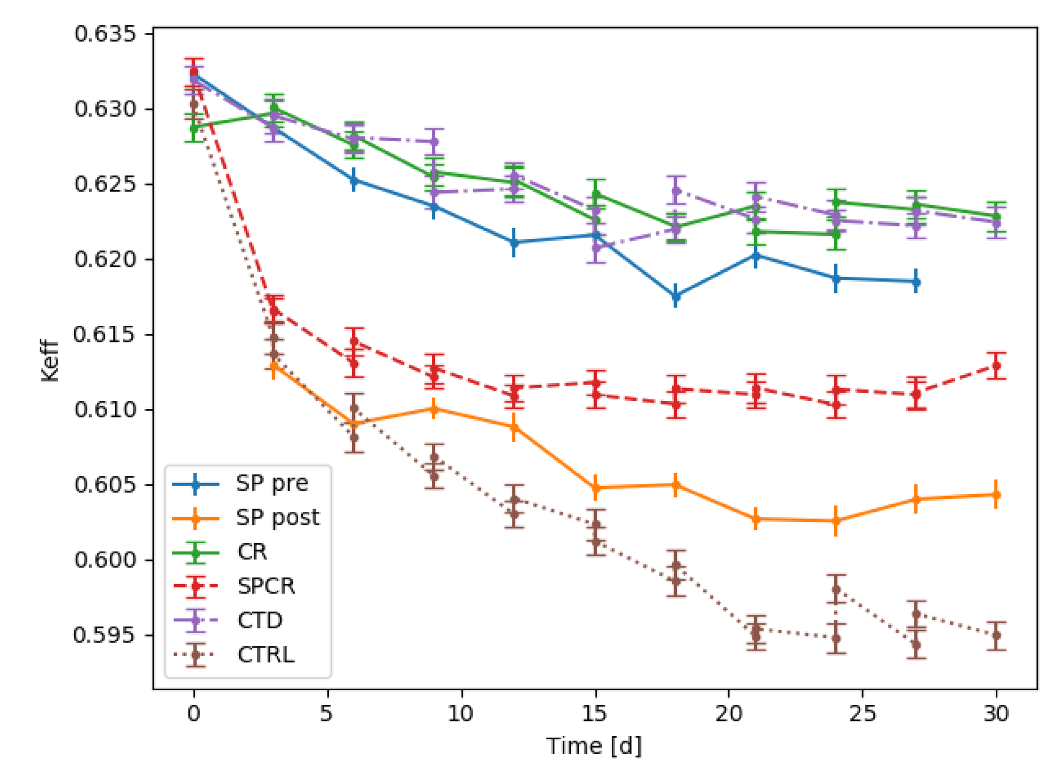


Figure 2: Continuous and batch models $k_{eff}$ over time when using the matching depletion steps and feed rates.

### Single Step

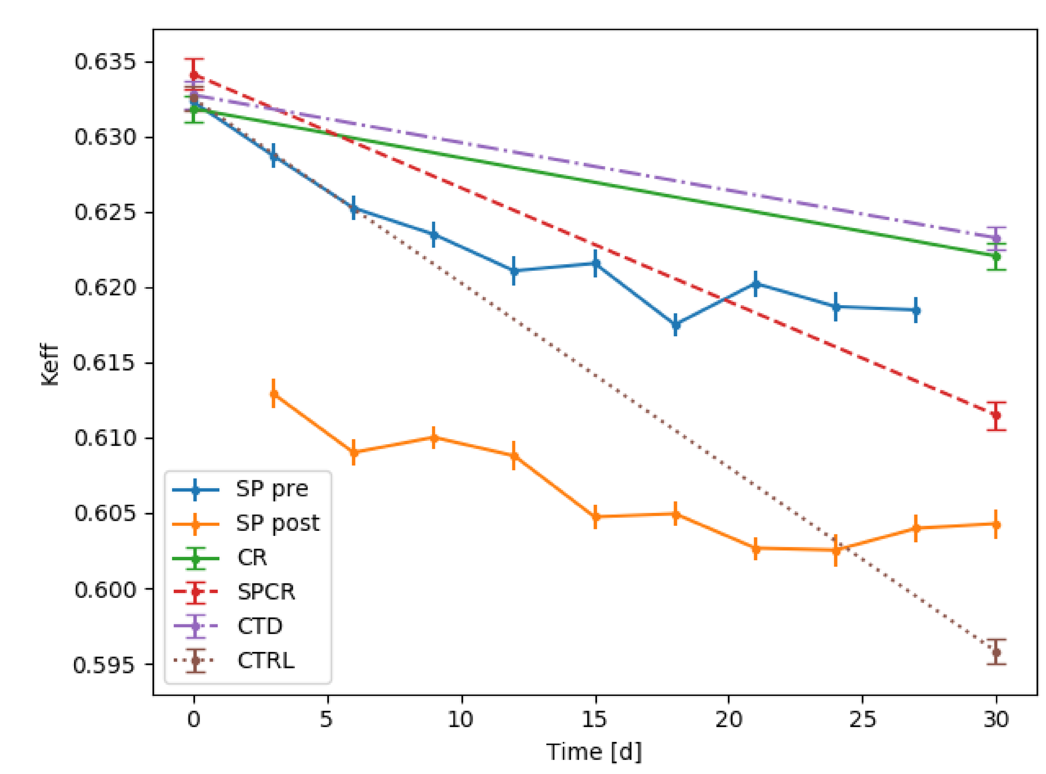


Figure 3: Continuous and batch models $k_{eff}$ over time when continuous uses a single step and average feed rates.

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 |

## Future Work

- Mass balancing of continuous reprocessing for full reactor
- Comparison of models for full reactor
- Depletion step size development over reactor lifetime

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## References

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