



Comparison Between Continuous and Batchwise Online Reprocessing in Serpent2



Luke Seifert, Madicken Munk

University of Illinois at Urbana-Champaign, Department of Nuclear, Plasma, and Radiological Engineering, Urbana, IL 61801

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: Geometry of toy model used in Serpent2 for continuous and batchwise reprocessing models.

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

Contact Information

- Email: seifert5@illinois.edu
- Phone: +1 865 279 0603

Reprocessing Models

Batchwise Reprocessing

- Iteratively perform depletion with external adjustments
- Small removals each depletion step is Steady Batch
- Full removal after set number of steps is Bulk Batch
- SaltProc used to run batchwise reprocessing for Serpent2

Table: 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]

$$\frac{dN_j}{dt}_{base} = \sum_{i \neq j} [(\gamma_{i \rightarrow j} \sigma_{f,i} \Phi + \lambda_{i \rightarrow j} + \sigma_{i \rightarrow j} \Phi) N_i] - (\lambda_j + \sigma_j \Phi) N_j \quad (1)$$

$$\frac{dN_j}{dt}_{net} = \frac{dN_j}{dt}_{base} - \lambda_{r,j} N_j + \sum_{mat} \lambda_{r,i \rightarrow j} N_i \quad (2)$$

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 .
- Φ 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 transmutation cross section of reaction $i \rightarrow j$.
- 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 .
- $\lambda_{r,i \rightarrow j}$ is the reprocessing constant for feed of material $i \rightarrow j$.
- Cycle Time Decay model treats reprocessing as decay

$$\lambda_r = \frac{\ln(2)}{\tau_{1/2}} \quad (3)$$

- Cycle Rate treats as linear fractional removal, same as Steady Batch

$$\lambda_r = \ln \left(\frac{1}{1 - X} \right) \quad (4)$$

- SaltProc Cycle Rate mimics batchwise reprocessing with continuous model

Table: Continuous Reprocessing Methods

Approach	Cycle Time	$\tau_{1/2}$	X [s ⁻¹]	λ_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

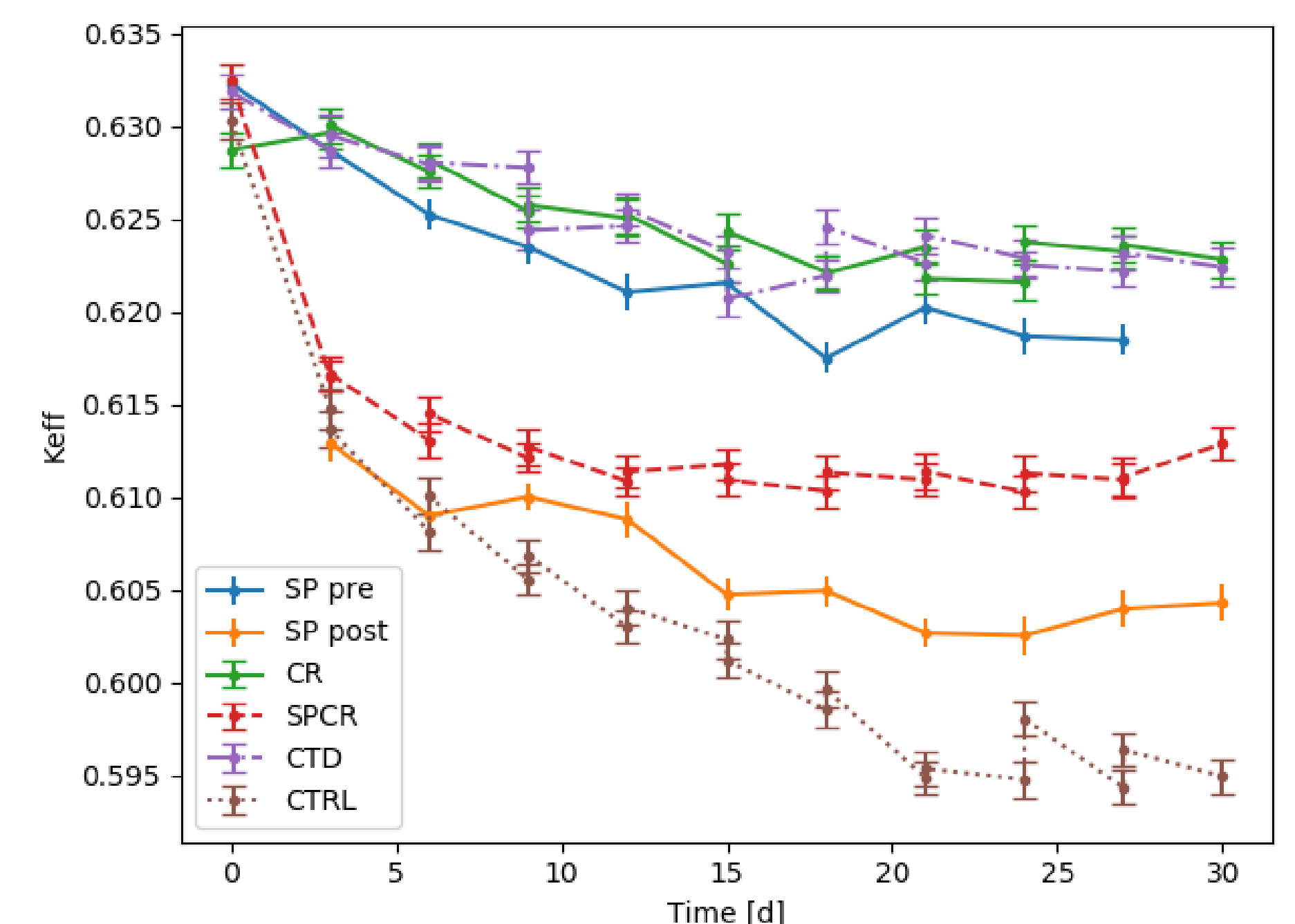


Figure: Continuous and batch models k_{eff} over time when using the matching depletion steps and feed rates.

Single Step

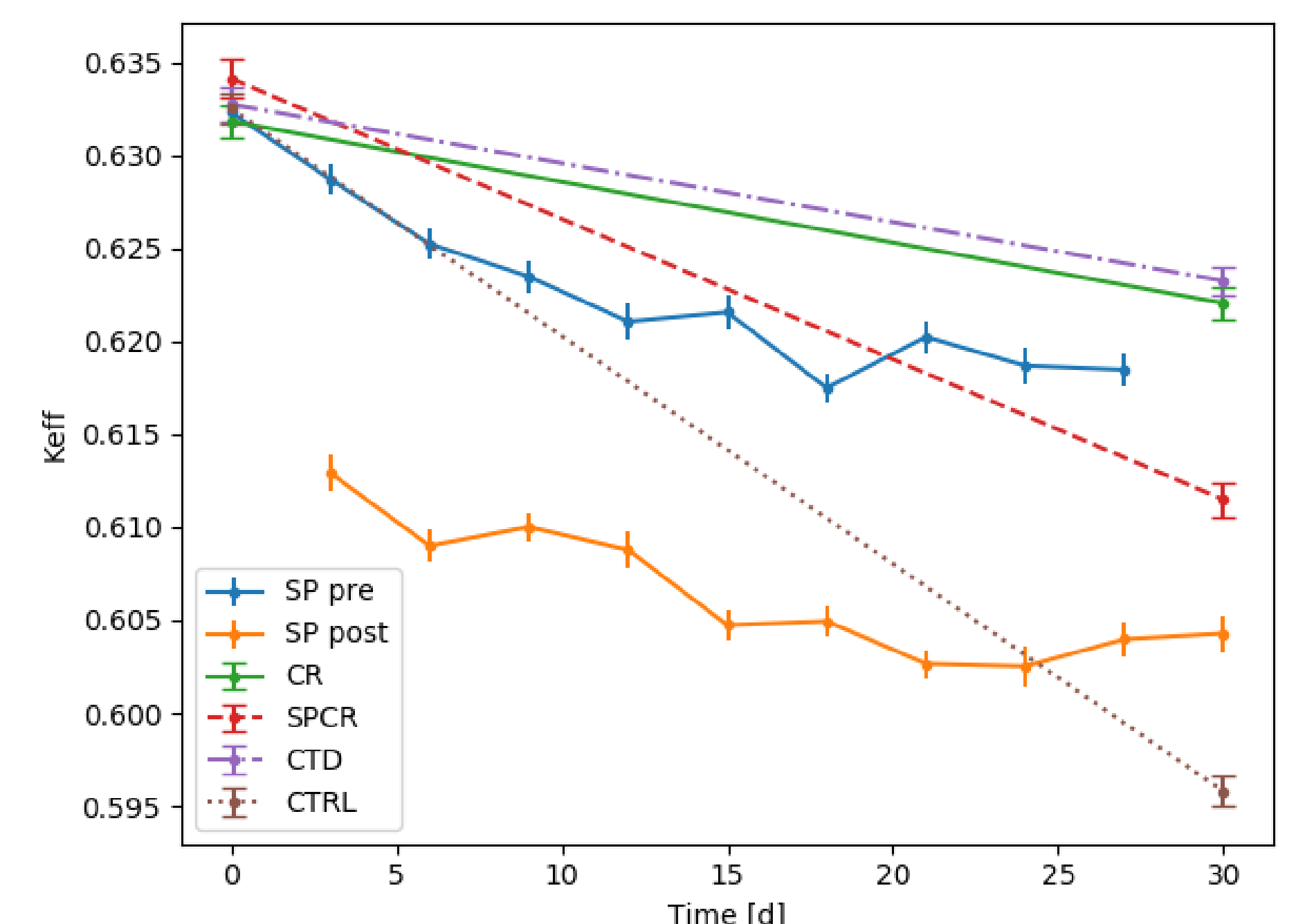


Figure: Continuous and batch models k_{eff} over time when continuous uses a single step and average feed rates.

Table: 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

Acknowledgements

This material is based upon work supported under an Integrated University Program Graduate Fellowship. The authors are grateful for this generous support.

The authors thank Kathryn Huff for her contribution and support of this work in its early stages.

References

- [1] M. Aufiero, A. Cammi, C. Fiorina, J. LeppÄdnen, L. Luzzi, and M. Ricotti. An extended version of the SERPENT-2 code to investigate fuel burn-up and core material evolution of the Molten Salt Fast Reactor. *Journal of Nuclear Materials*, 441(1-3):473–486, Oct. 2013.
- [2] B. R. Betzler, J. J. Powers, and A. Worrall. Molten salt reactor neutronics and fuel cycle modeling and simulation with SCALE. *Annals of Nuclear Energy*, 101:489–503, Mar. 2017.
- [3] A. Rykhlevskii, J. W. Bae, and K. D. Huff. Modeling and simulation of online reprocessing in the thorium-fueled molten salt breeder reactor. *Annals of Nuclear Energy*, 128:366–379, June 2019.