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Isotopic Analysis of the In-Zinerator Actinide Management System

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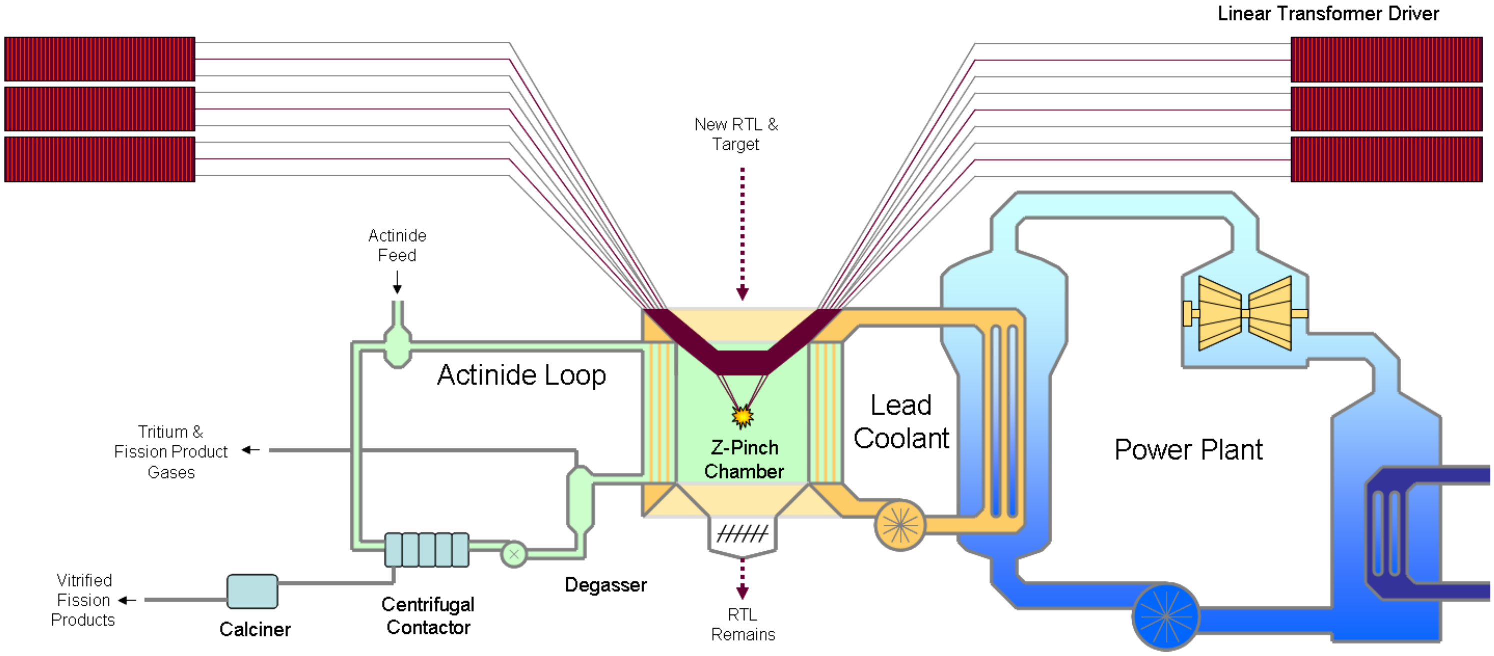
Overview

- In-Zinerator
- Problem Description
- Isotopic Inventory Tool – MCise
- Results
- Future Work

In-Zinerator

- Designed to reduce heat load, and radiotoxicity of nuclear waste from LWR



In-Zinerator - Features

- Sub-critical blanket with Z-pinch fusion
  - Fusion Source – 200 MJ D-T, 0.1 Hz
- Fuel - Actinides in eutectic liquid form
  - $(LiF)_2AnF_3$
  - Continuously reprocessed
- Coolant – Lead surrounding an annular of 5-cm fuel tubes
- Structural Material – Hastelloy-N

In-Zinerator - Challenges

- Fusion yield of Z-pinch
- Reactivity control
- Shock mitigation from x-ray pulses
- Heat Removal
- Safety and concerns from liquid fuel
- Tritium breeding
- Burnup and transmutation calculation

What is MCise?

- Monte Carlo Isotopic Simulation Engine
- Important Capabilities
  - Online extraction – FP removal
  - Continuous feed – Fuel replenishment

Background & Motivation

Control Volume

Neutron Flux (Φ), Residence Time (t_R)

$$\lambda_{eff} \equiv \int \phi(E)\sigma(E)dE + \lambda_{decay}$$

Mean reaction time

$$t_m = 1/\lambda_{eff}$$

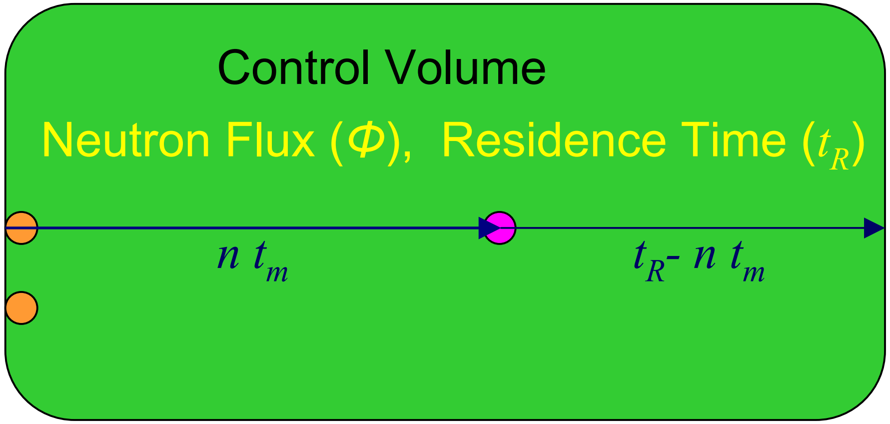
- Convert residence time to number of mean reaction times for this isotope

$$n_R = \frac{t_R}{t_m}$$

- Randomly sample number of mean reaction times before next reaction

$$n = -\ln \xi$$

Background & Motivation



Control Volume

Neutron Flux (Φ), Residence Time (t_R)

$n\ t_m$

$t_R - n\ t_m$

$$\lambda_{eff} \equiv \int \phi(E)\sigma(E)dE + \lambda_{decay}$$

Mean reaction time

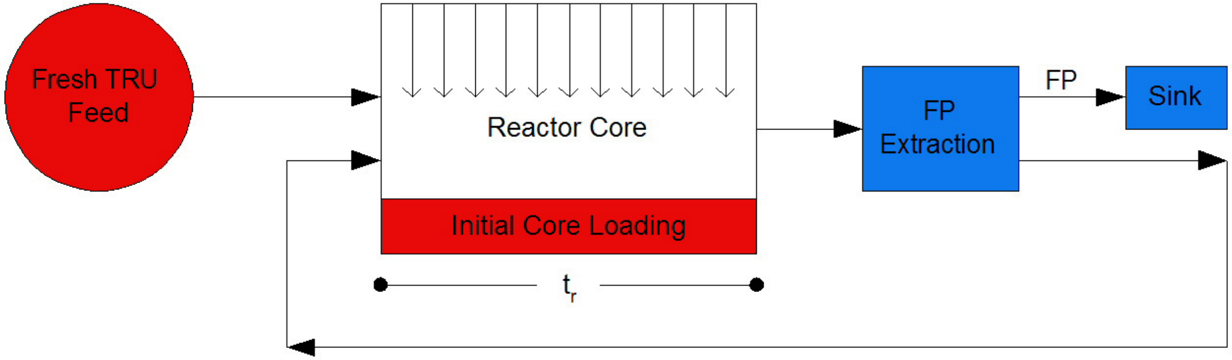
$$t_m = 1/\lambda_{eff}$$

- While $n_R > n$, reaction occurs.
  - Randomly sample a type of reactions
  - $t_R \Rightarrow t_R - n\ t_m$
  - Repeat until $n > n_R$
    - Particle leaves control volume (history ends?)

Comparison to Monte Carlo Transport

Element	**Transport**	**Inventory Analysis**
Source quanta	Neutral particles	Individual atoms
Characteristic dimension	Length of geometric cell	Residence time in control volume
Basic sampling quanta	Mean free paths between reactions (macroscopic cross-section)	Mean times between reactions (effective total transmutation & decay rate)
Primary particle characteristic	Energy	Isotopic identity

In-Zinerator MCise Model



- Flux obtained from MCNP
- t_R=100 days, T_{sim}=20000 days
- Two sources
  - Initial core loading - uniformly distributed in the core
  - Continuous feed - at the beginning of the core

Birth Time of Atom Sources

- Initial Core Loading – $t_{sim} = 0$
- Continuous feed
  - Feed rate at anytime must be equal to half of FP removal rate (dF/dt)
- Assume constant power level,

$$\dot{F} = \kappa P - \frac{\varepsilon \dot{C}}{I} F, \quad F(0) = 0$$

F = a total amount of FP [atoms]

P = a desired power level [enery/time]

κ = a number of FP released for energy released [atoms/energy]

ε = FP separation efficiency

I = a total initial inventory [atoms]

$\dot{C}$ = a processing capacity [atoms/time]

Birth Time of Atom Sources

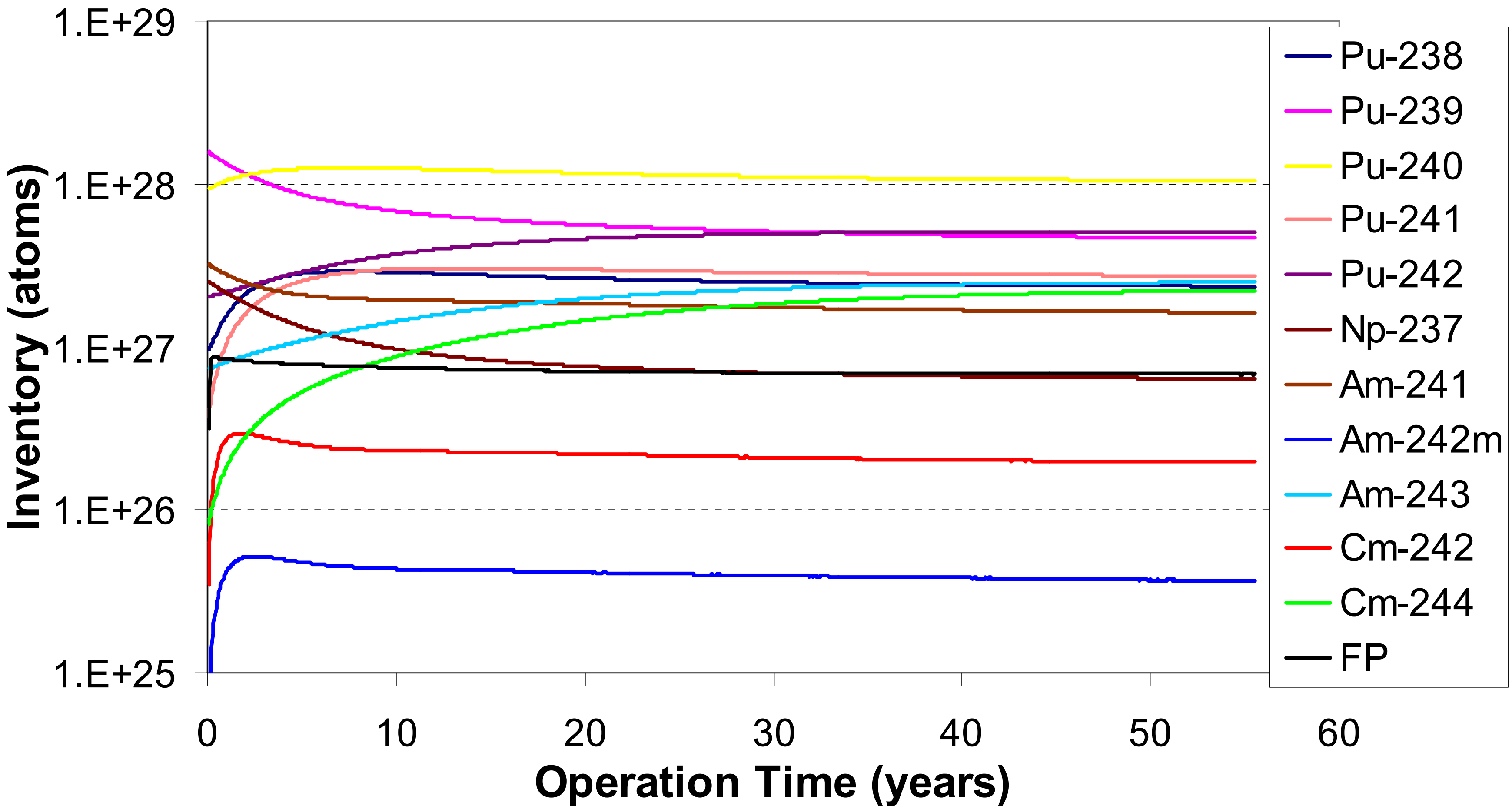
Inventory of FP at any time is given by

$$F(t) = \frac{\kappa P I}{\varepsilon \dot{C}}(1 - e^{-\varepsilon \dot{C} t / I})$$

Feed Rate is therefore given by

$$\frac{1}{2}\frac{\varepsilon \dot{C}}{I} F(t_{sim}) = \frac{\kappa P}{2}(1 - e^{-\varepsilon \dot{C} t_{sim} / I}), \quad 0 < t_{sim} < T_{sim}$$

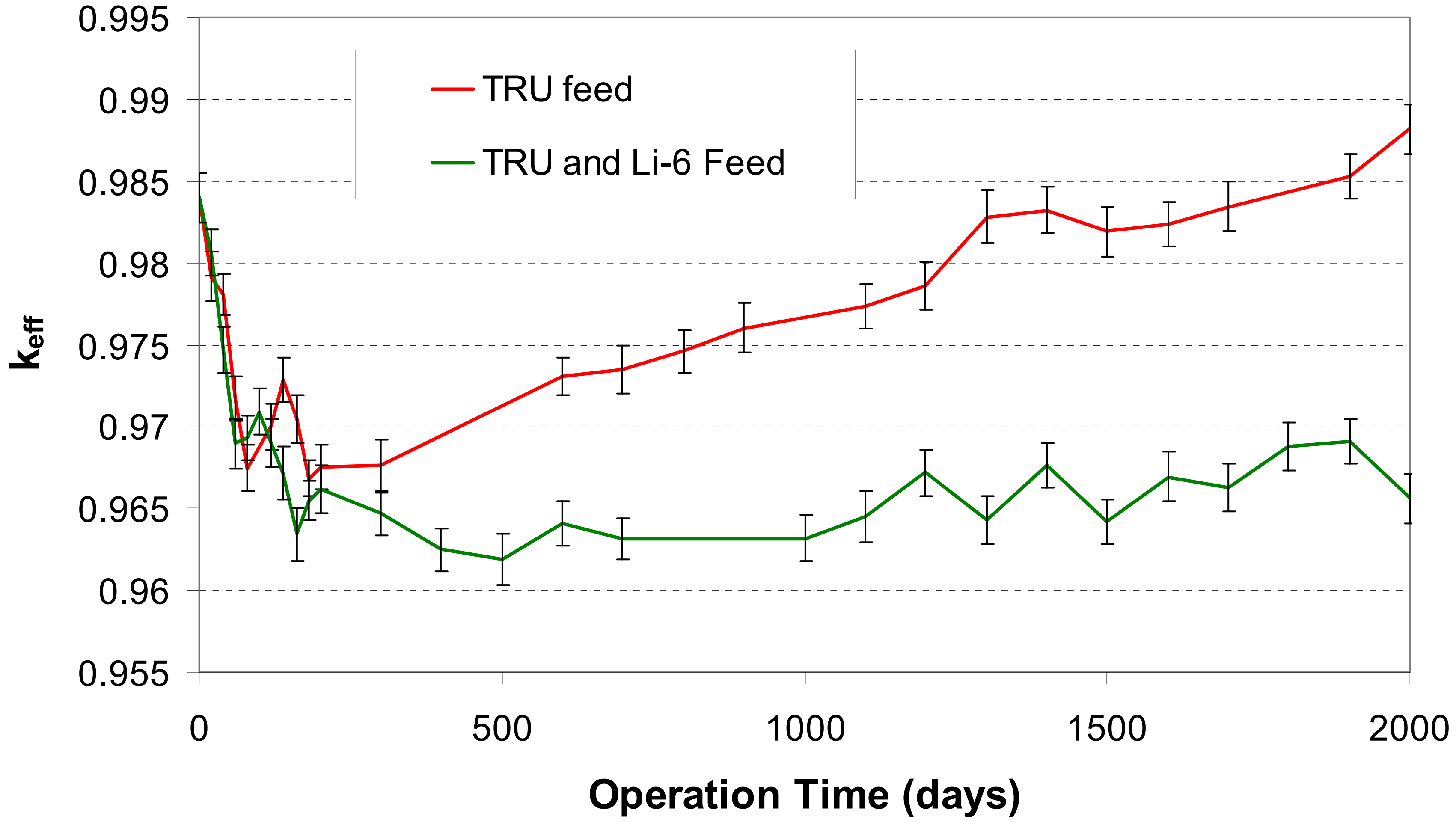
Results



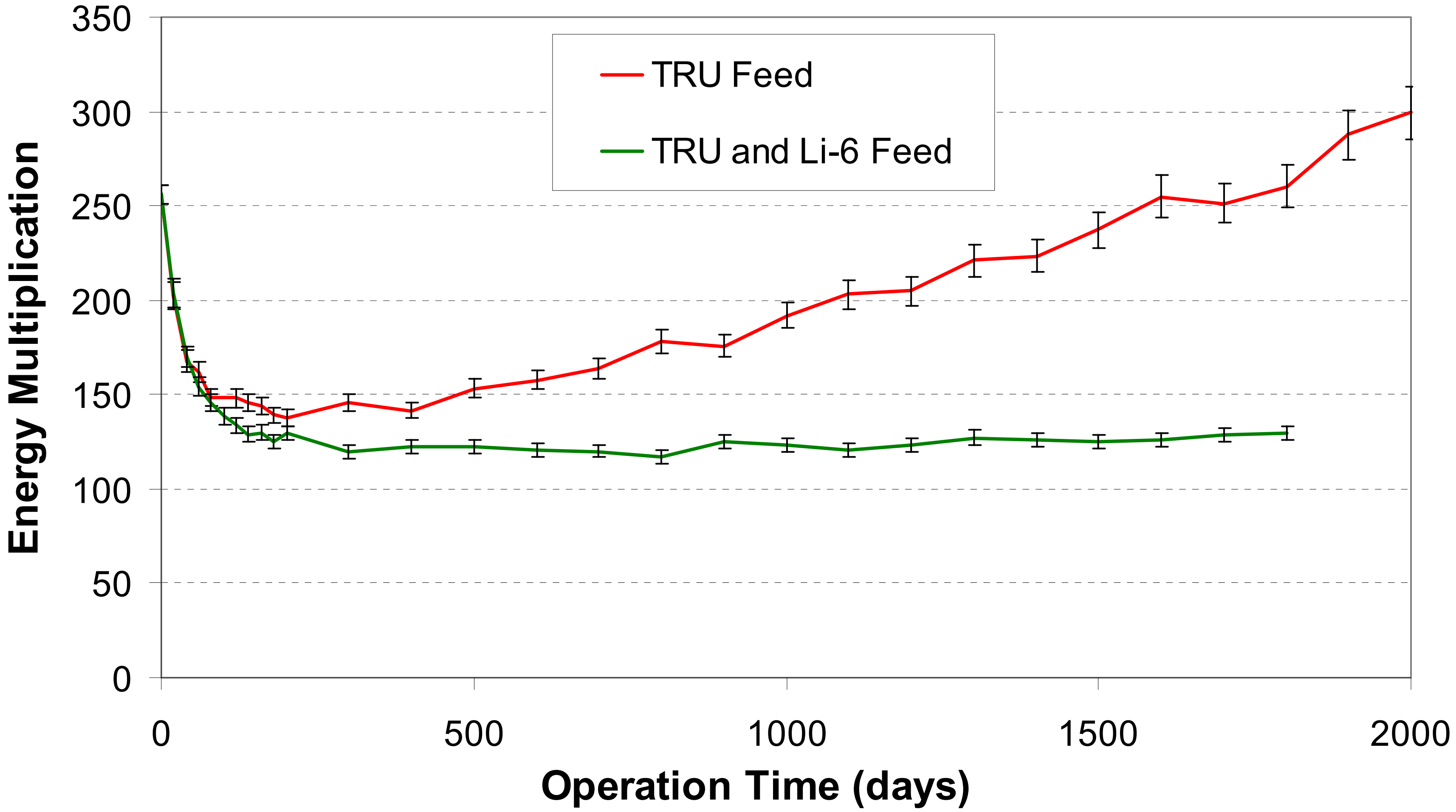
- Equilibrium achieved after ~ 30 years

Results

Criticality

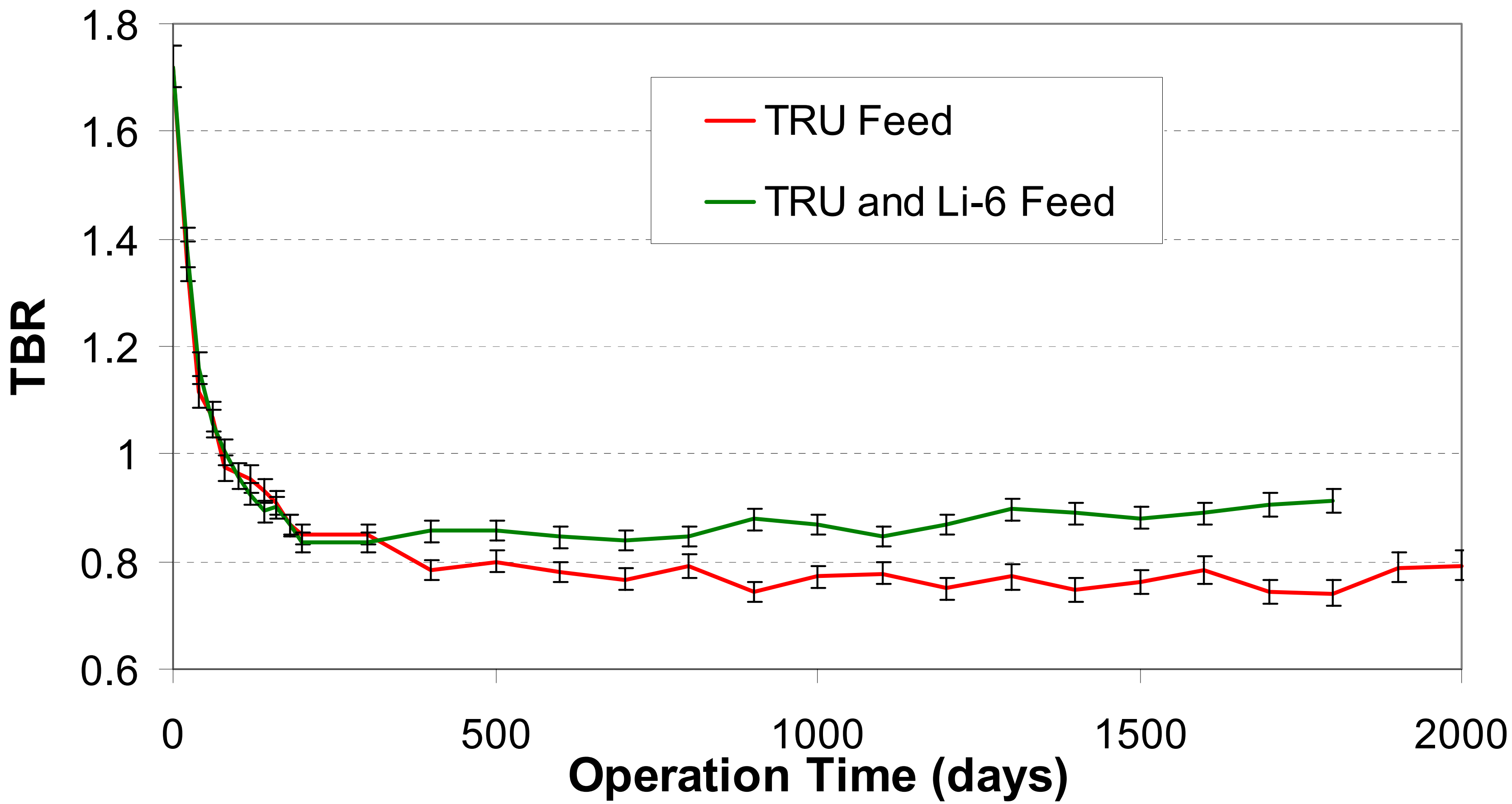


Results
Energy Multiplication

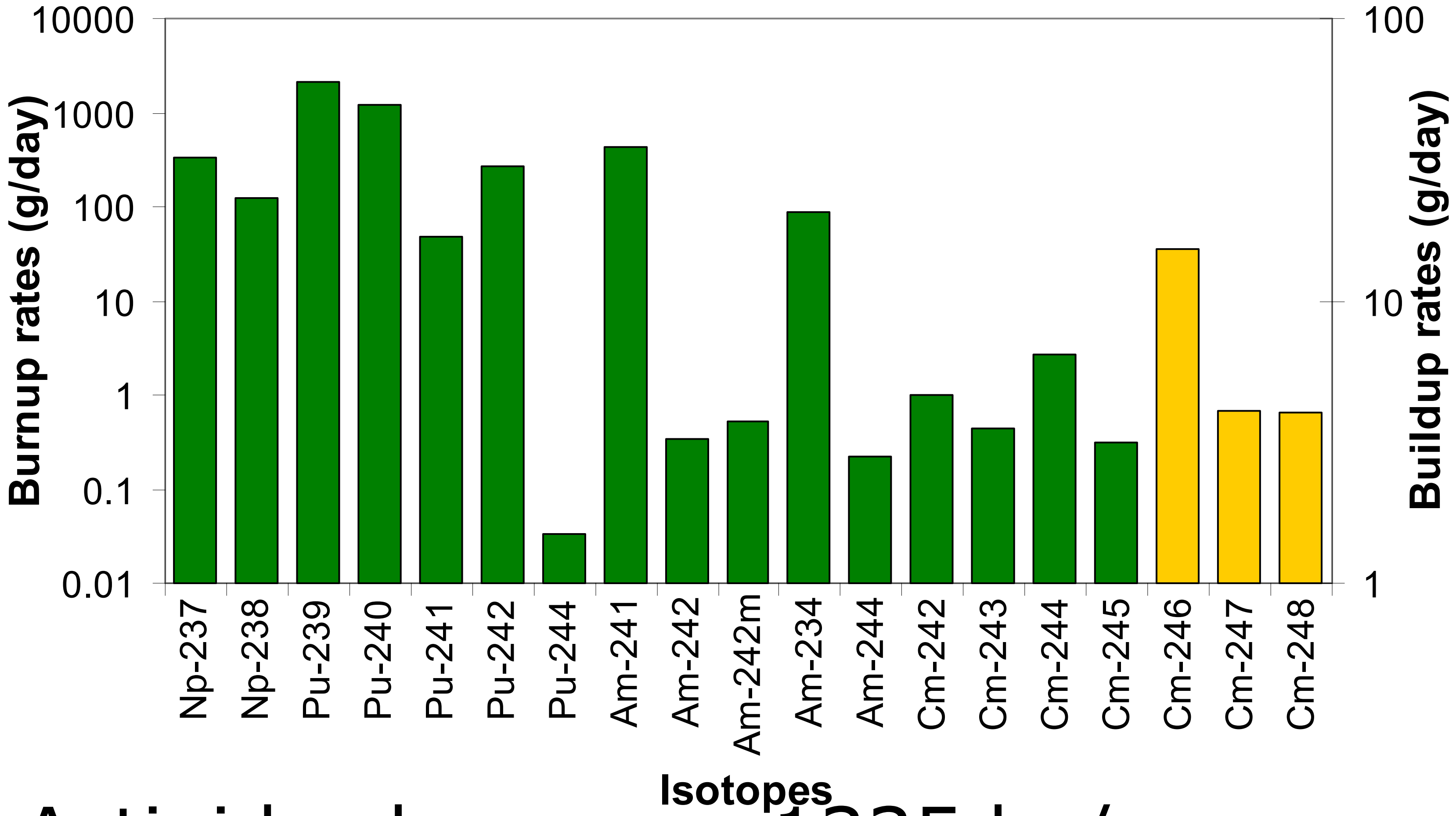


Results

Tritium Breeding Ratio



Results



- Actinides burnup = 1335 kg/ years

Future Work

- Need a tighter coupling between neutronics and isotopics
  - Imply reactivity control mechanism
- Iterative scheme between MCNP & MCise
  1. Use MCNP to find the reactivity control state, S_i, that achieves a desired energy multiplication for the current isotopic inventory state, I_i,
  2. Use the neutron flux from step 1 with MCise to determine isotopic distributions for the next time step, I_{i+1}.

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Question & Comments

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