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Monte Carlo Based Pebble Bed Run-in Scenarios Calculator for Optimization Studies

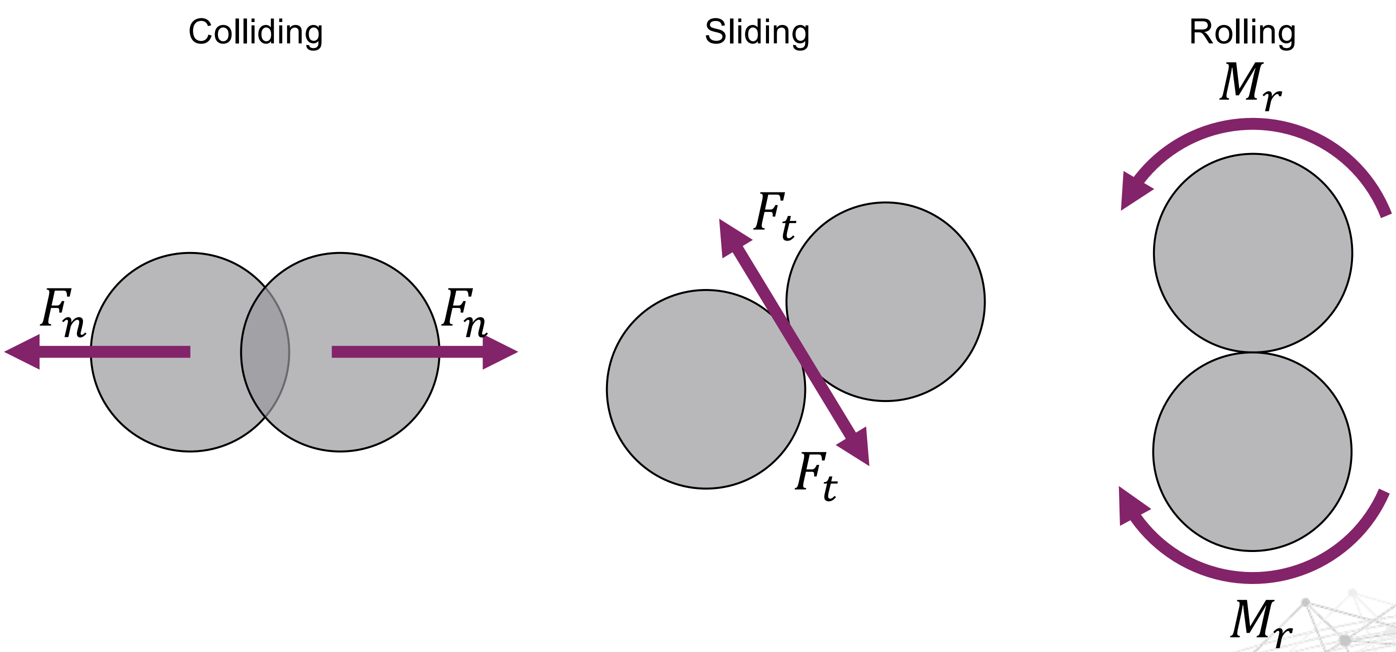
Advanced Reactor Technologies
GAS-COOLED REACTORS

Introduction

- The running-in phase of a pebble-bed reactor (PBR) is a complex time-dependent problem
  - Involves the use of multiple fuel types, graphite pebbles and a ramp-up of power
- Modeling this problem using high-fidelity simulation tools allows us to examine multiple physical phenomena that is important to PBR operations
  - Determination of when to add equilibrium fuel, when to increase power, etc. have impacts on quantities of interest like discharge burnup, time to full power, pebble power peaking etc.
- Understanding pebble movement can improve simulation capabilities, reducing the need for modeling assumptions
  - Knowledge of pebble movement can then be used in burnup calculations

Discrete Element Method

- Each pebble is modeled as an individual element, forces and torques acting on each pebble determine their motion.



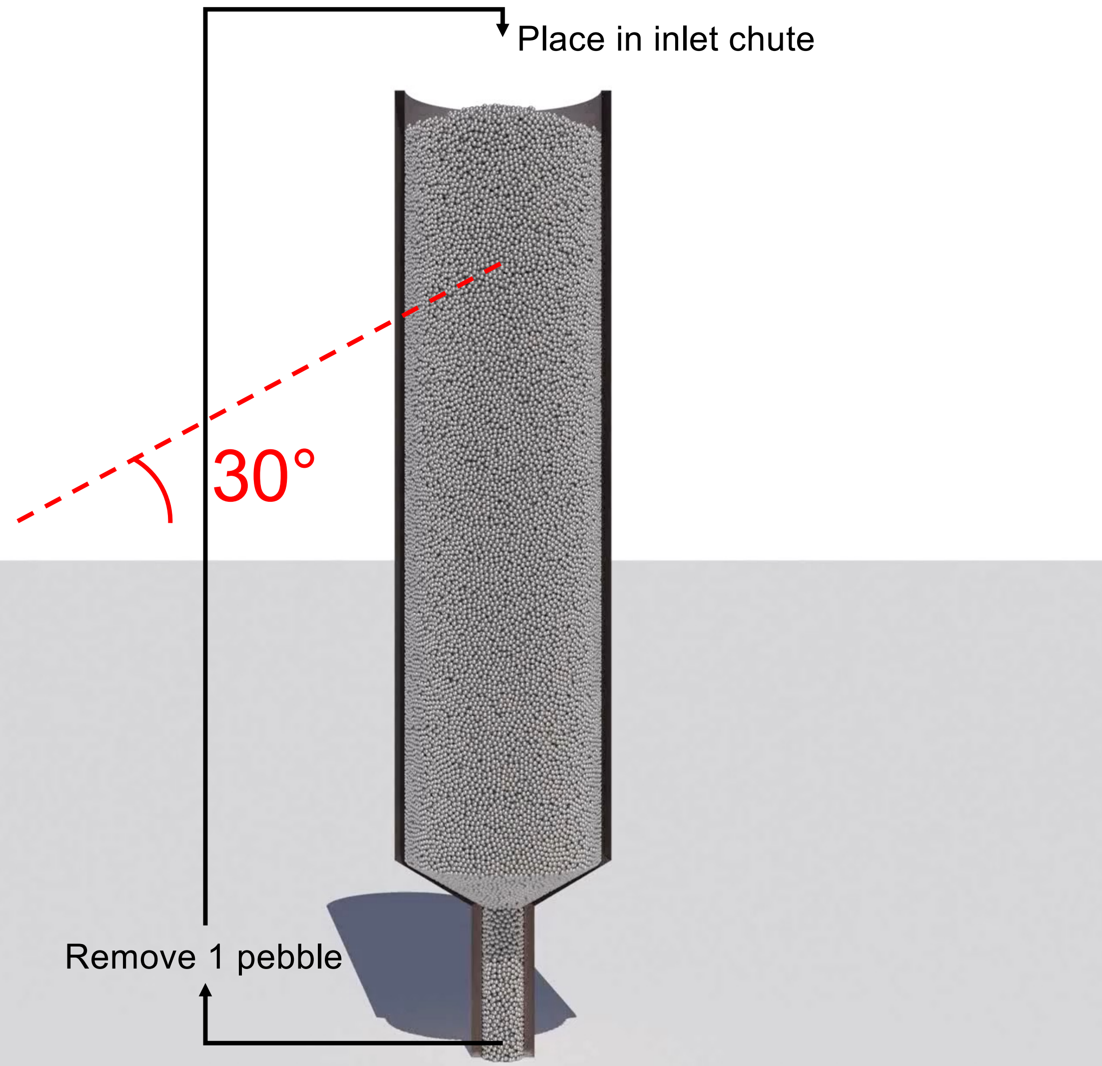
Run-In Analysis

- Modeling a general pebble bed reactor (dimensions and parameters from open-source literature)
- Filled with 220,000 pebbles

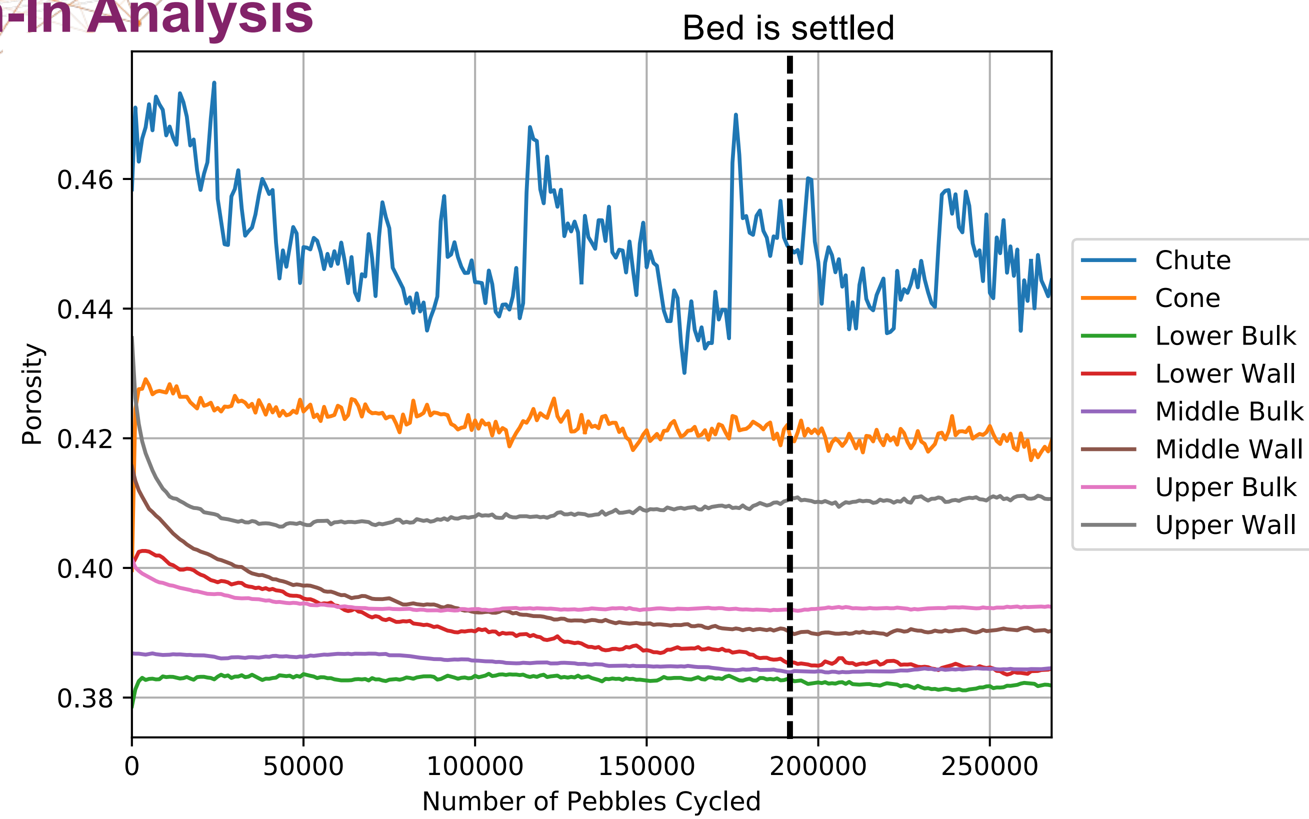
Pebble are generated in random sheets

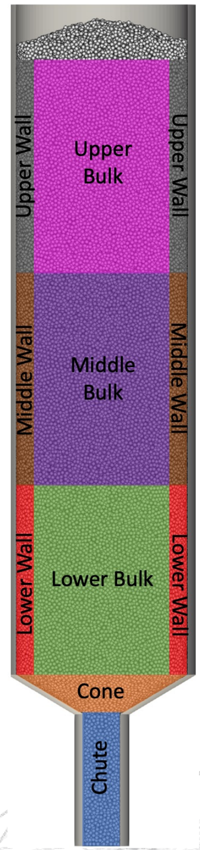
Run-In Analysis

- Modeling a general pebble bed reactor (dimensions and parameters from open-source literature)
- Filled with 220,000 pebbles
- Begin to cycle pebbles, cycle until all pebbles are cycled once. Pebbles are cycled at 60 peb/s



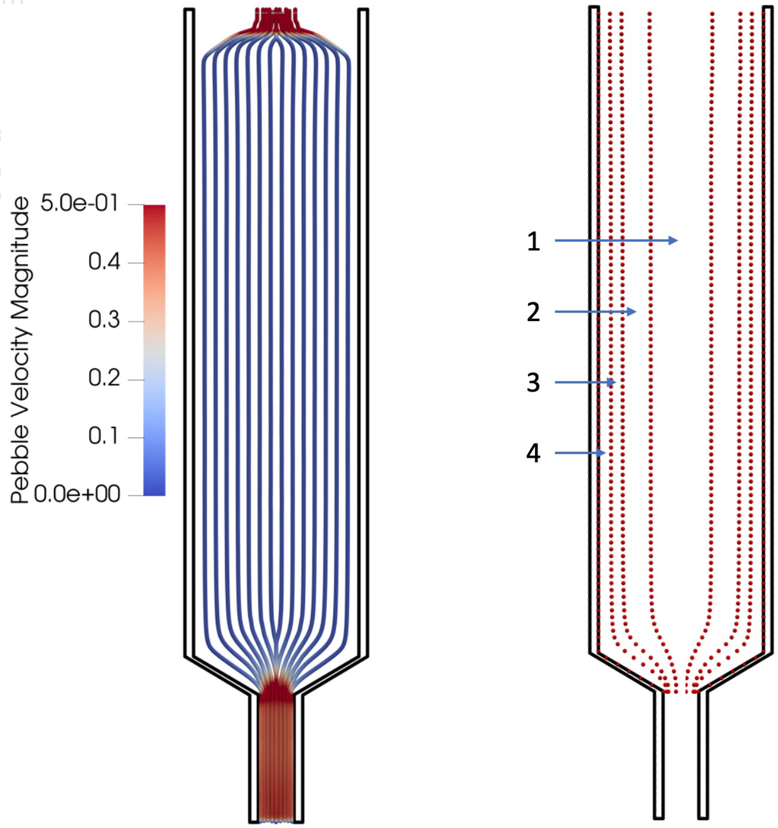
Run-In Analysis





A bed will mechanically settle in ~125 days at 1 peb/min cycling rate

Run-In Analysis



Channel	Relative Pebble Flow Rates	Relative Pebble Velocity
1	1.0	1.0
2	2.48	1.0
3	1.48	0.98
4	1.52	0.89

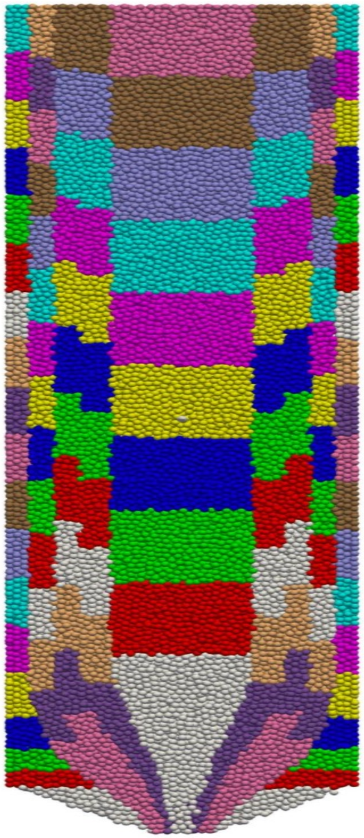
Algorithm for Performing Run-In Analysis

- Python module wrapped around Serpent to simulate pebble movement through the core
  - Divide the core into channels and axial volumes

Algorithm Outline

- Generate critical core configuration

1. Perform burn-up step
2. Shift pebbles down
3. Recycle/discharge pebbles
4. Update power, temperature, pebble type, etc.



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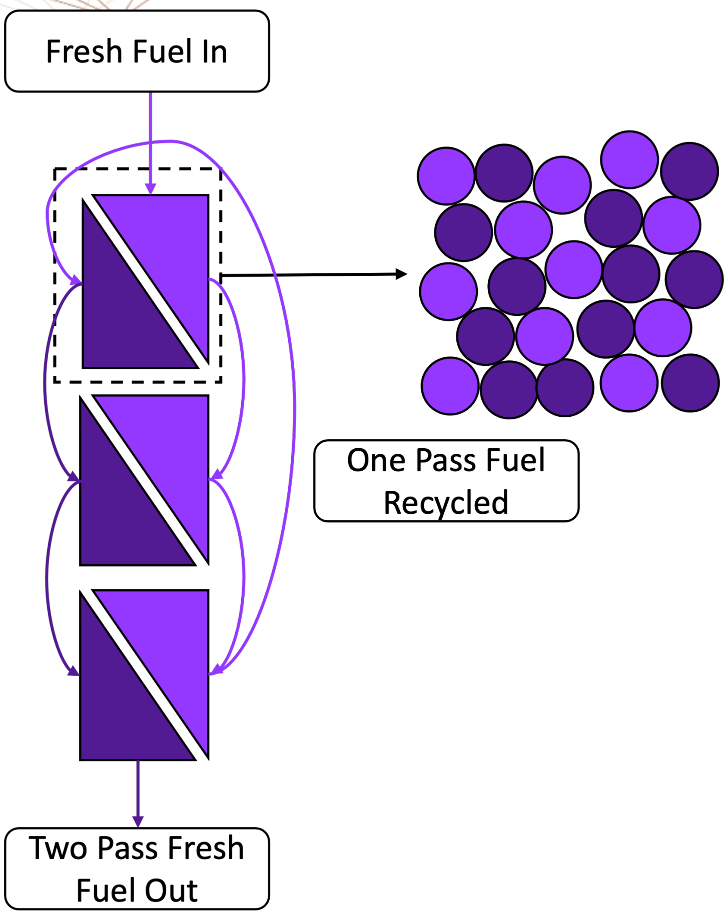

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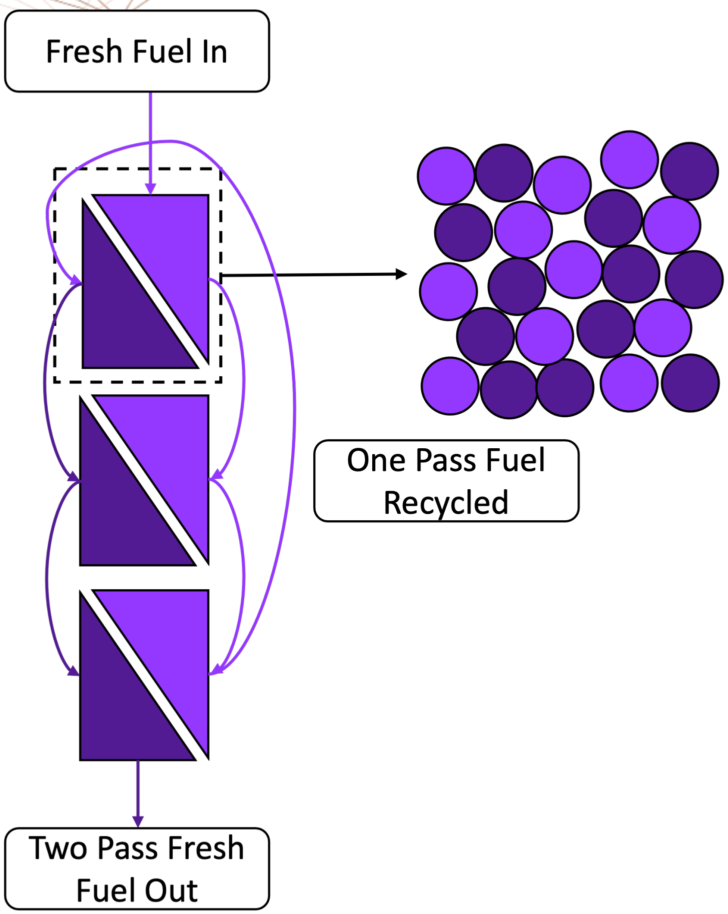
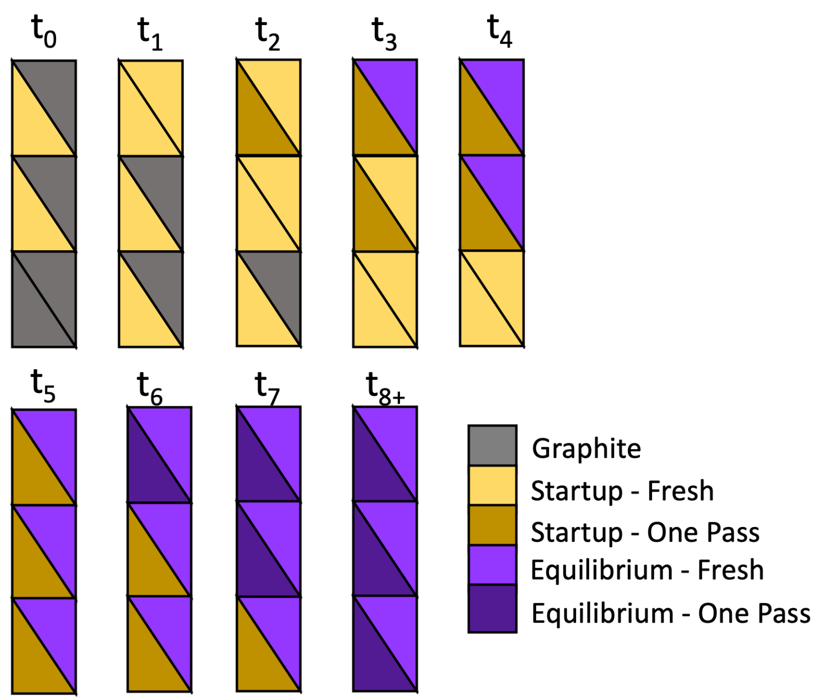
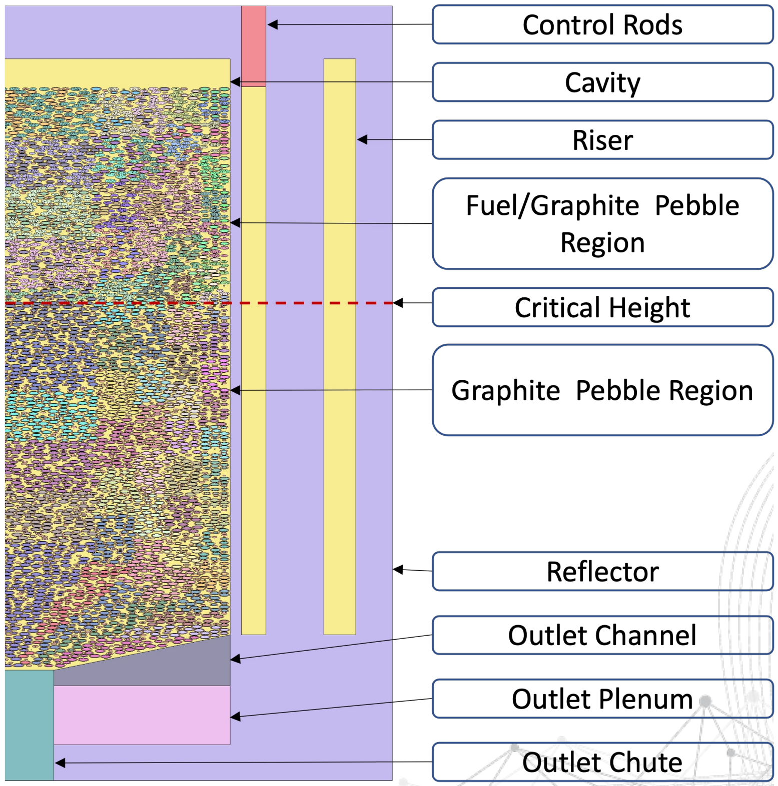




Run-In Analysis Problem Statement

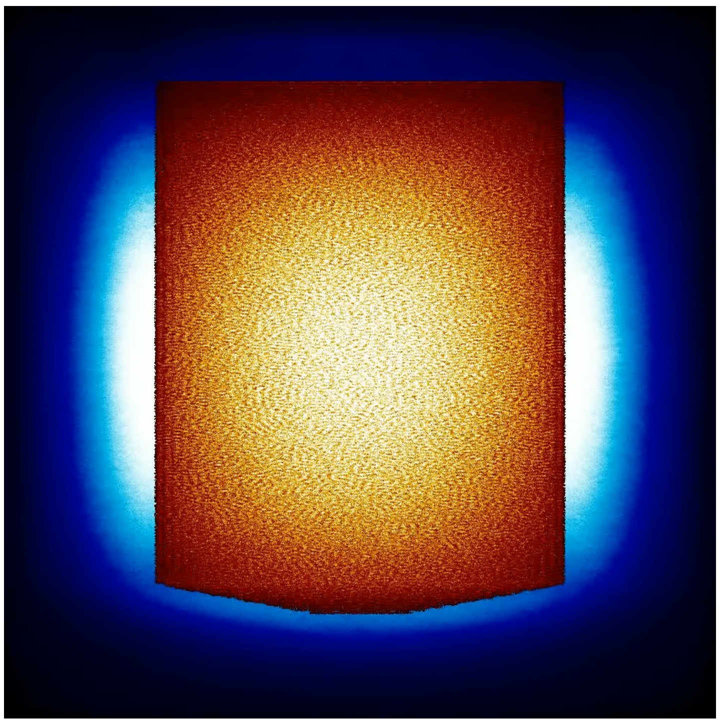
- Examine the ability to obtain an equilibrium core
  - Jump-in equilibrium
  - Run-in scenario
- Run-in scenario follows a constant power ramp
  - Startup fuel: 5.0 wt% U-235
  - Equilibrium fuel: ~15.5 wt% U-235
    - Introduced at 90 days
  - No additional graphite added

Days	Power (MW)	Fuel Temp (K)	Mod. Temp (K)
0	1	300	300
30	25	400	300
60	50	500	400
90	75	600	400
120	100	700	500
150	150	800	500
180	175	800	650
210	200	800	650

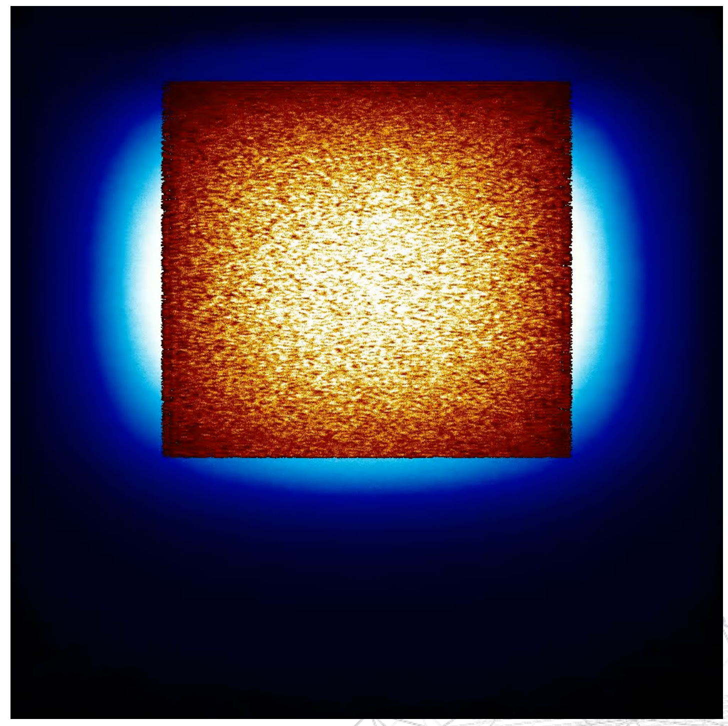


Thermal Flux During Run-In

Jump-in equilibrium

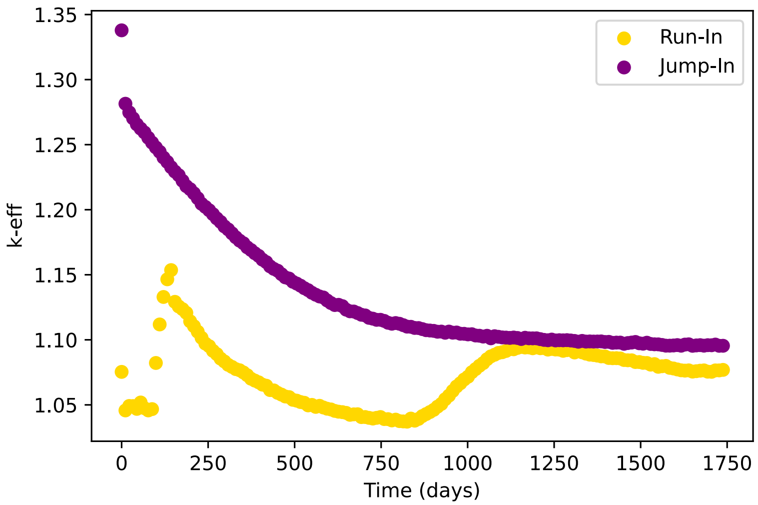


Run-in scenario



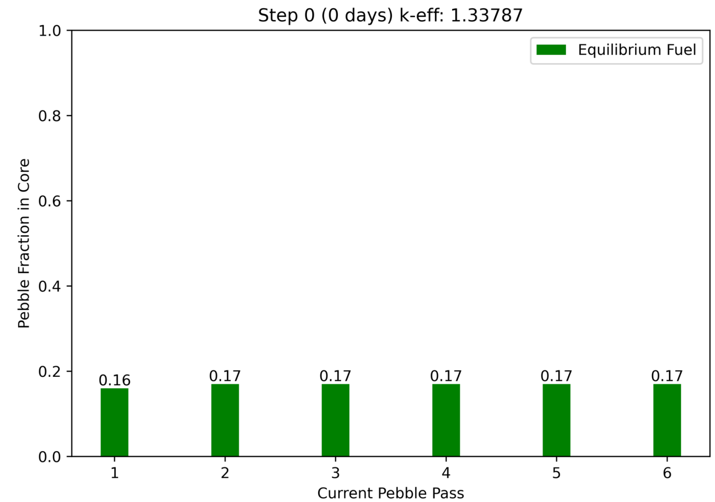
Run-In Analysis – Part I

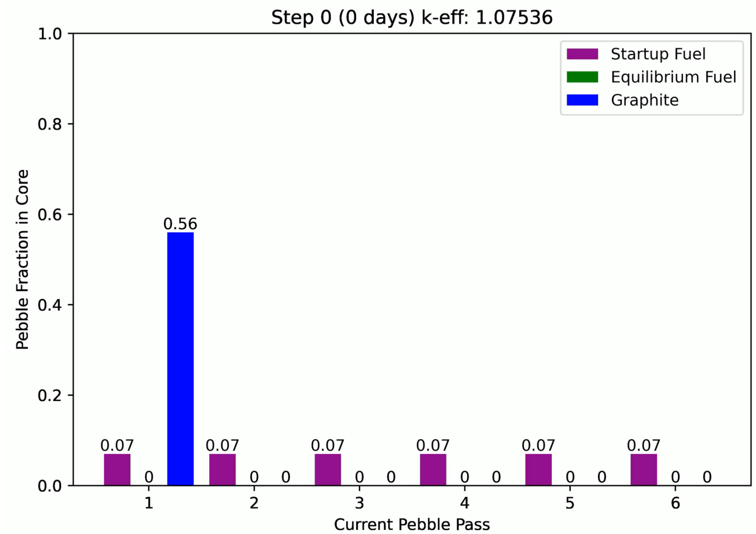
- Jump-in equilibrium started with all fresh fuel and was used as a pseudo-validation technique
  - Roughly 1/6 of the discharged pebbles are replaced each pass
- Run-in scenario reaches full power at 210 days (**90%** of the graphite pebbles are removed)
  - Initial peak in k-eff is due to addition of equilibrium fuel
  - Increase is due to final removal of startup fuel and replacement with equilibrium fuel
  - Decline is due to uneven number of pebbles in each pass



Run-In Analysis – Part II

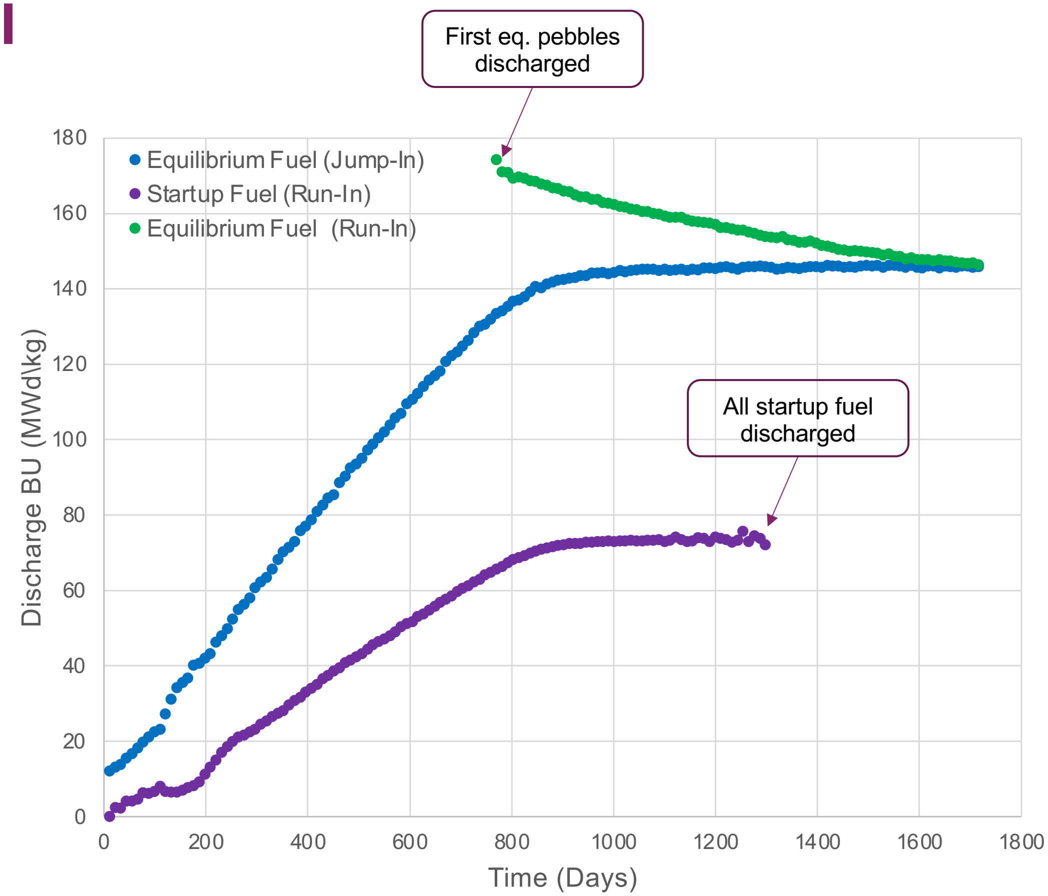
- Beginning (Steps 1 – 8)
  - Mixture of graphite and startup fuel
  - Replace graphite with startup fuel
- Transition (Steps 9 –100)
  - Replacement of remaining graphite and startup fuel with equilibrium fuel
- Pseudo-Equilibrium (Steps 100+)
  - All startup fuel is removed
  - Equilibrium fuel begins convergence to final equilibrium
- Unbalance in pebbles per pass is dueto the introduction of equilibrium fuel too early





Run-In Analysis – Part III

- Pebbles passed through **six** times before discharge
- Equilibrium fuel initially has a higher discharge BU
  - Compensating for the start-up fuel during run-in
- Jump-in and Run-in equilibrium fuel begins to converge to similar burnup



Conclusions & Future Work

- Discrete Element Method simulation was used to determine a realistic equilibrium core pebble packing layout and pebble flow channels.
- Developed an algorithm which can perform the PBR run-in scenario by depleting the core, shuffling & refueling pebbles, and removing spent pebbles.
  - Preliminary results show the run-in scenario converging on an equilibrium core configuration
  - These results provide a proof of concept for the approach
- Optimization of run-in
  - Based on fuel utilization or time to full power
- Addition of a multi-physics element
  - Coupling with neutronic and thermal-hydraulic NEAMS tools to allow criticality search and temperature feedback calculations

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