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Multiphysics Pebble-Bed Reactor Control Rod Withdrawal Study

RESULTS PRESENTED ARE PRELIMINARY AND SUBJECT TO CHANGE

DOE ART Gas-Cooled Reactor (GCR) Review Meeting
Virtual Meeting
July 25 – 27, 2023

ART
Advanced Reactor Technologies

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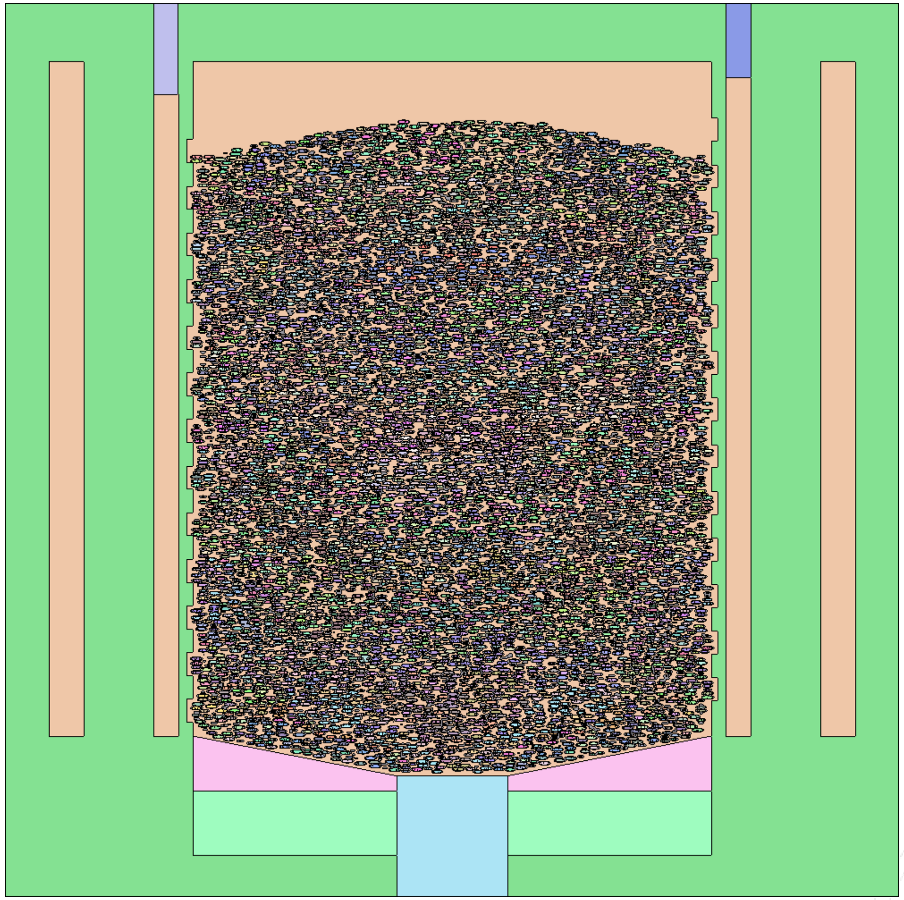
Content

- Purpose of the Study
- Workflow
- Gas-Cooled PBR Control Rod Withdrawal
- Fluoride-Cooled PBR Control Rod Withdrawal
- Future Work

Objectives

- Study Control Rod Withdrawal (CRW) and Ejection (CRE) events in Pebble Bed Reactors (PBR)
- Develop models that can predict how much of the core exceeds a given temperature limit and for how long.
- Compare gas- and fluoride cooled PBRs
- Perform a sensitivity analysis



Cases to be considered

Event	Number of CRs	Initial State	CR Speed (cm/s)
Control Rod Withdrawal	All	Full power	1
Control Rod Withdrawal	All	Cold zero power	1
Control Rod Ejection	1	Full power	10,000
Control Rod Ejection	1	Cold zero power	10,000

Workflow

- Cross-section generation
- Griffin-Pronghorn equilibrium core calculation
- CRW/CRE Griffin-Pronghorn transient simulation

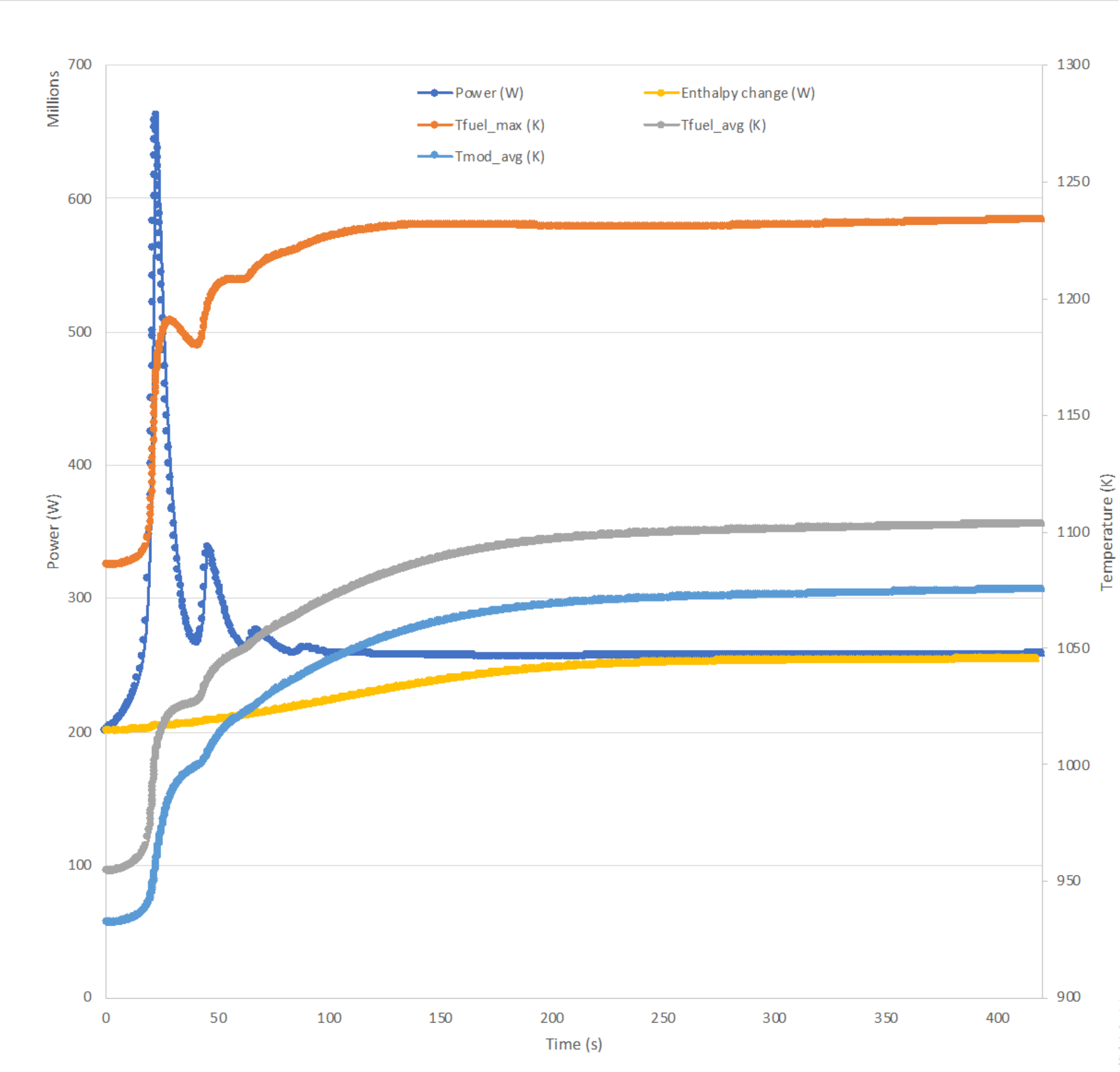
Advantages of model vs Point Kinetics

- Griffin-Pronghorn 2-D RZ multiphysics model can give information regarding:
  - How much of the core sees a temperature above a given limit?
  - For how long does it stay above that limit?
  - What is the heating rate of the fuel in that region?

- Less conservatism can enable a more competitive design

Gas-Cooled PBR Control Rod Withdrawal

- CR withdrawn at 1 cm/s
- Most of the reactivity added in the first minute
- Power peaks when reactivity insertion rate matches negative feedback rate from core heating
- Eventually stabilizes at a higher power
- Maximum fuel temperature much lower than fuel limits (~1900K)

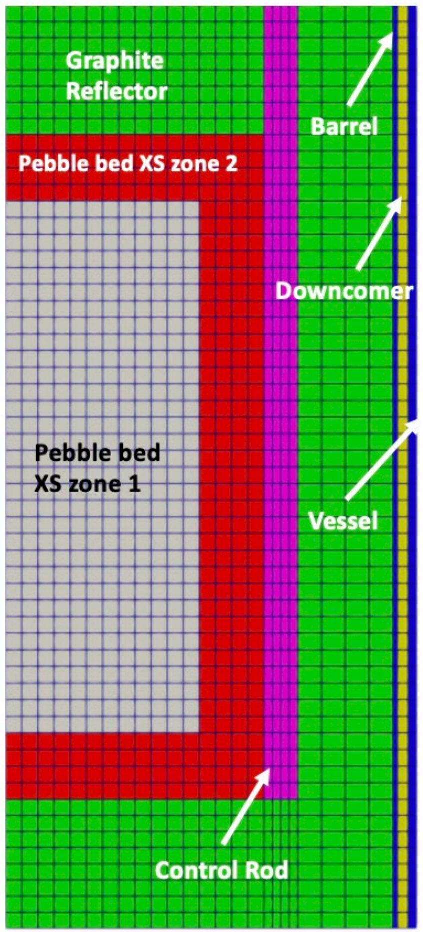


Sensitivity Analysis (ongoing work)

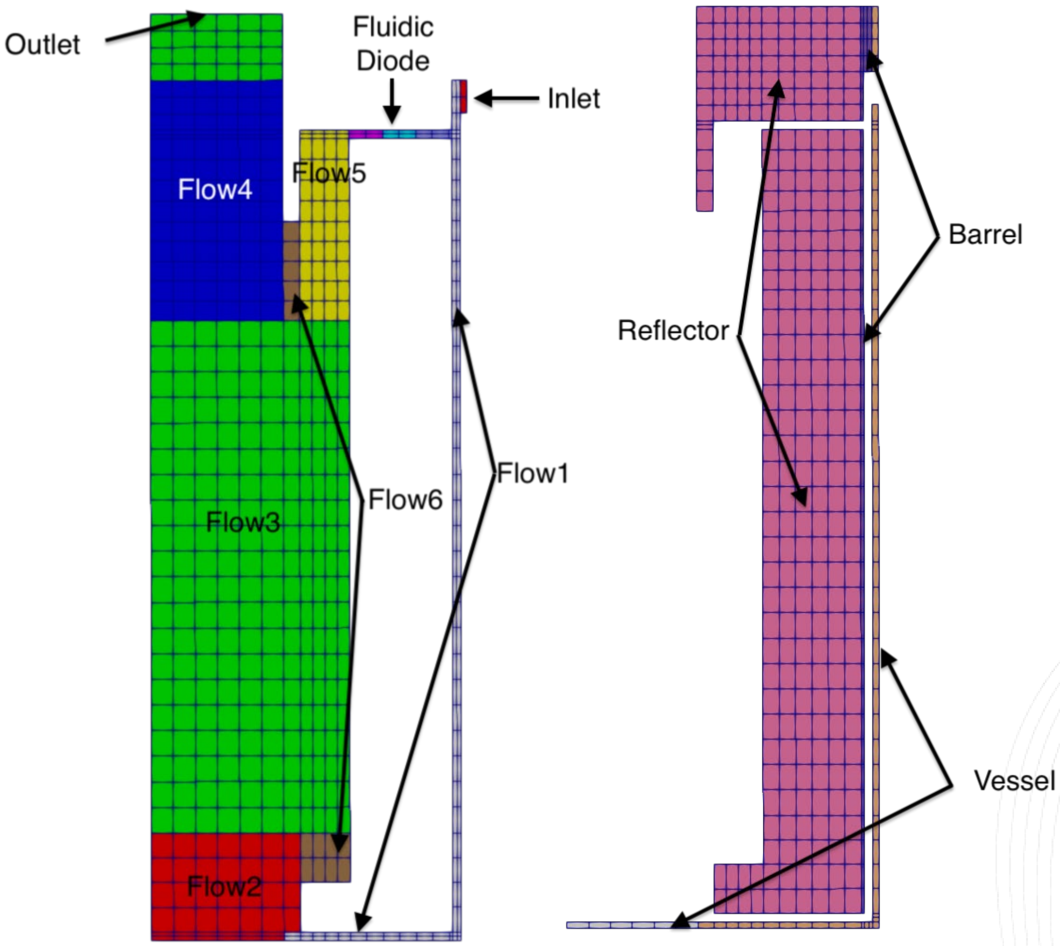
- Parameters to be perturbed:
  - Reactivity insertion (move CR position)
  - Reactivity coefficients (potentially via volume fractions in each burnup group and cross-sections)
  - Thermal properties
  - Kinetics parameters (CRE only)

Fluoride-Cooled PBR Model

- Very similar model to gas-cooled PBR
- 2-D RZ Griffin model
- 2-D RZ Pronghorn model
- 1-D spherical Pronghorn TRISO models
- Control Rods modeled as "gray curtain"
- Additional feedback from fluid density
- Fluidic diode to allow onset of natural convection



Griffin mesh

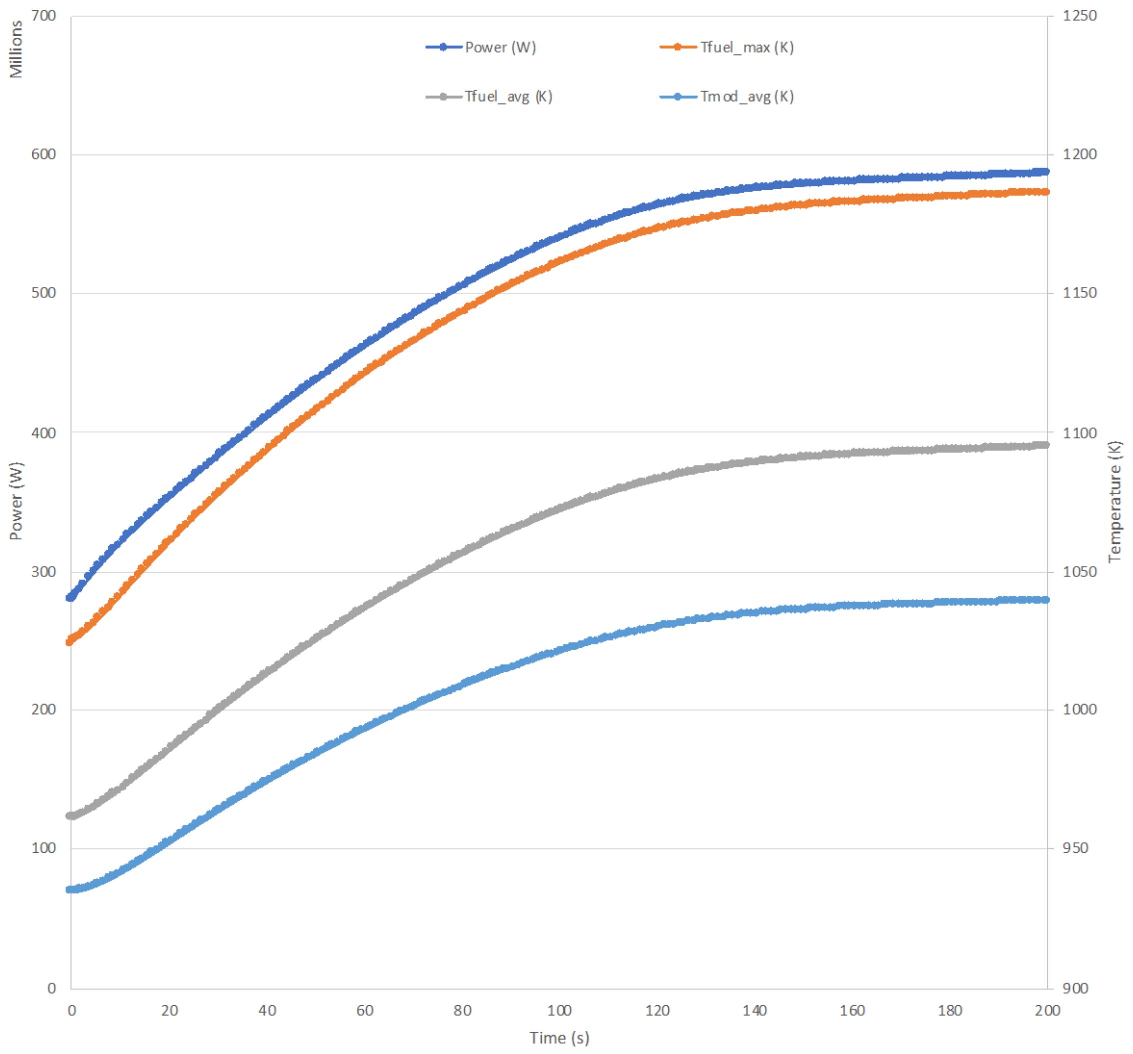


Pronghorn meshes
(porous medium vs solid conduction)

Original model and pictures from: Ortensi, Javier, Mueller, Cole, Terlizzi, Stefano, Giudicelli, Guillaume Louis, and Schunert, Sebastian. 2023. "Fluoride-Cooled High-Temperature Pebble-Bed Reactor Reference Plant Model". United States. https://doi.org/10.2172/1983953. https://www.osti.gov/servlets/purl/1983953.

Fluoride-Cooled PBR Control Rod Withdrawal

- Much stronger temperature feedback due to FLiBe density changes
- Power/temperature stabilize above nominal conditions
- But no overshoot observed



Conclusions & Ongoing Work

- Gas- and Fluoride-Cooled PBR 2D R-Z multiphysics models developed
- Preliminary CRW simulations performed for hot and cold conditions
- Ability to determine how much of the core exceeds temperature limits and for how long
- Ongoing Sensitivity Analysis work

Questions?