INL/MIS-23-73515-Revision-1

Multiphysics Pebble-Bed Reactor Control Rod Withdrawal Study

July 2023

Changing the World's Energy Future

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Idaho National Laboratory

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http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

July 27, 2023

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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

Contributors

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- Etc.

Content

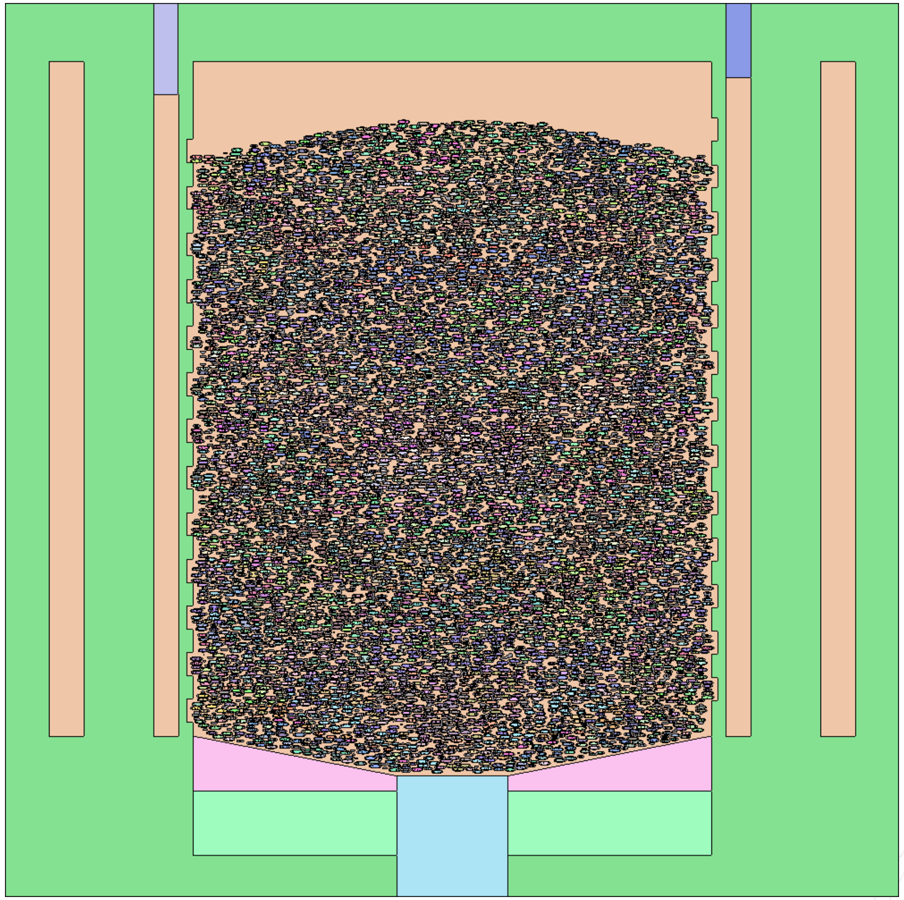
- Purpose of the Study
- Workflow
- Gas-Cooled Pebble-Bed Reactor (PBR) Control Rod Withdrawal (CRW)
- Fluoride-Cooled PBR CRW
- Future Work

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
  - Local energy deposition rate

- Compare gas- and fluoride-cooled PBRs (gPBR-200 and gFHR).



Target Cases

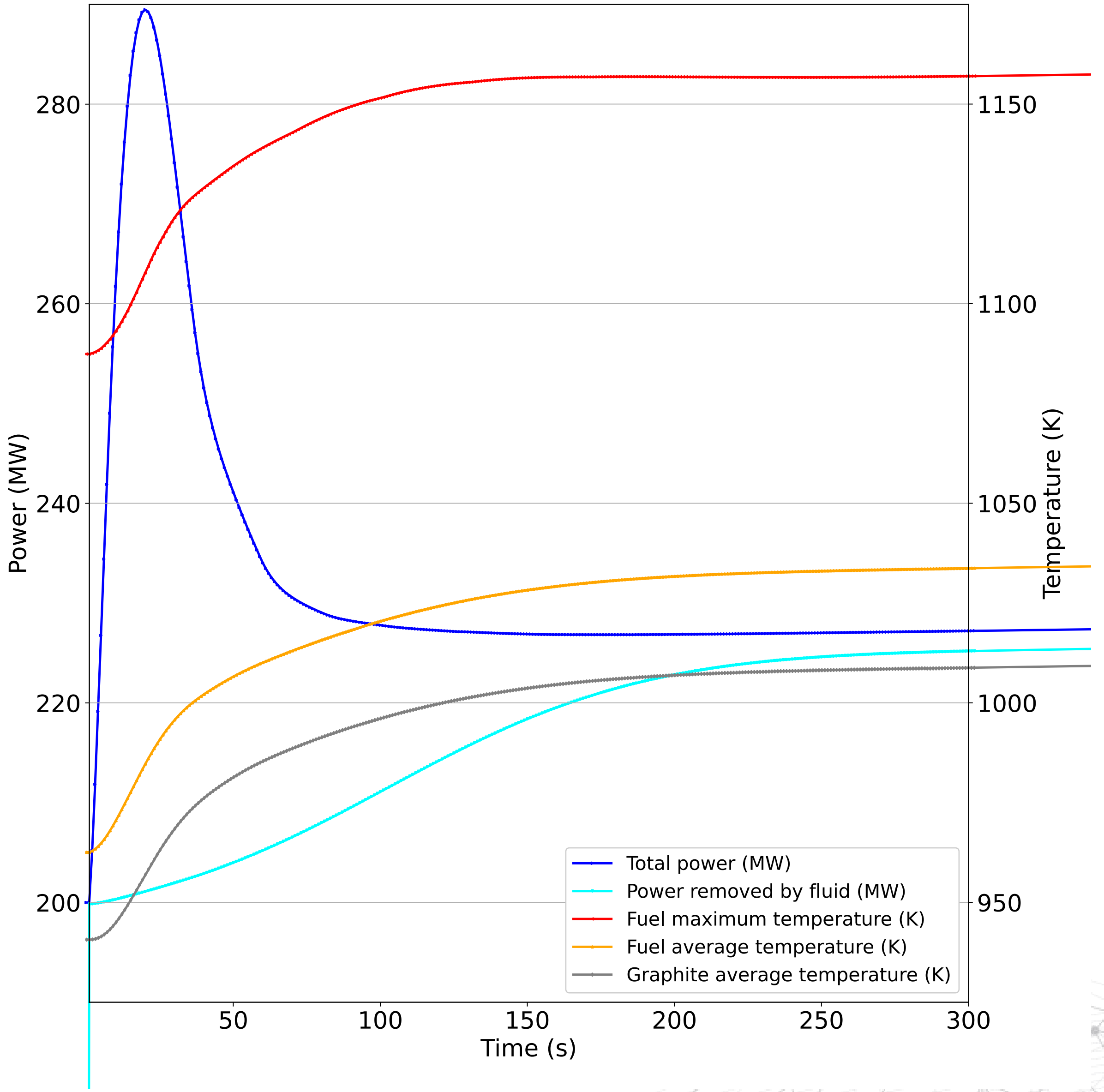
Event	Number of CRs	Initial State	CR Speed (cm/s)
Control Rod Withdrawal	All	Full power	1
Control Rod Withdrawal	All	“Cold” zero power	1
Control Rod Ejection	1	Full power	Comparable with PBMR-400 benchmark
Control Rod Ejection	1	“Cold” zero power	Comparable with PBMR-400 benchmark

Workflow (hot full-power CRW)

1. Cross-section generation
2. Griffin-Pronghorn equilibrium core calculation
3. Griffin adjoint calculation (to compute dynamic reactivity during CRW)
4. CRW/CRE Griffin-Pronghorn transient simulation

gPBR-200 CRW (hot full-power)

- CR withdrawn at 1 cm/s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

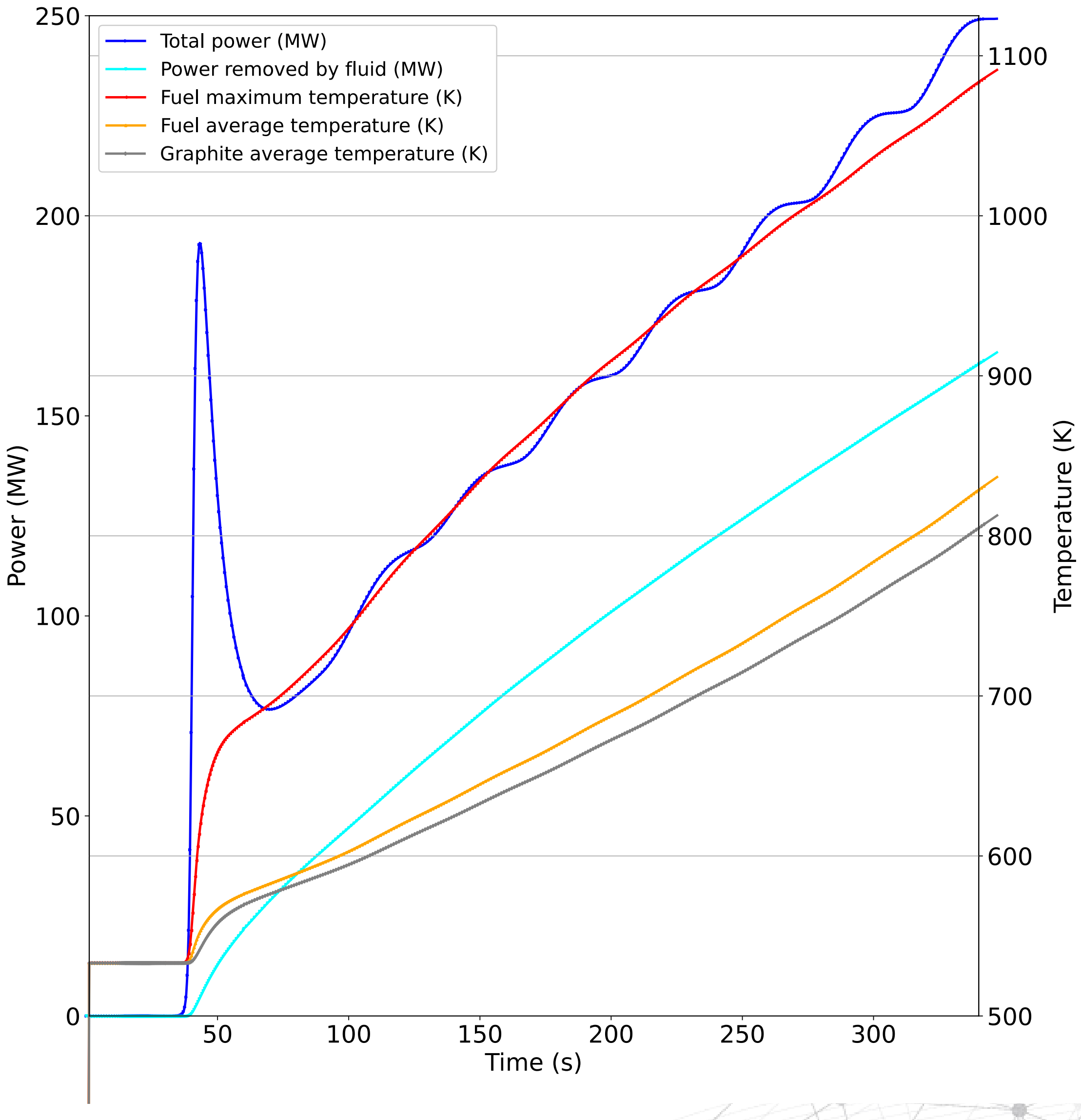


Workflow (cold zero-power CRW)

1. Cross-section generation
2. Griffin-Pronghorn equilibrium core calculation
3. Griffin zero-flux calculation to saturate poisons
4. Griffin-Pronghorn cold steady-state calculation
5. Griffin adjoint calculation (to compute dynamic reactivity during CRW)
6. CRW/CRE Griffin-Pronghorn transient simulation

gPBR-200 CRW (cold zero-power)

- CR withdrawn at 1 cm/s
- Reactivity inserted in ~ 10 minutes
- Power increases during the first ~ 45s from 1W to almost 200MW
- Strong temperature feedback quickly brings it back down
- Continuous reactivity increase results in much slower power and temperature increase
- Small oscillations due to slight cusping effects in the control rod model (exhibited by lack of smoothness in the reactivity curve)



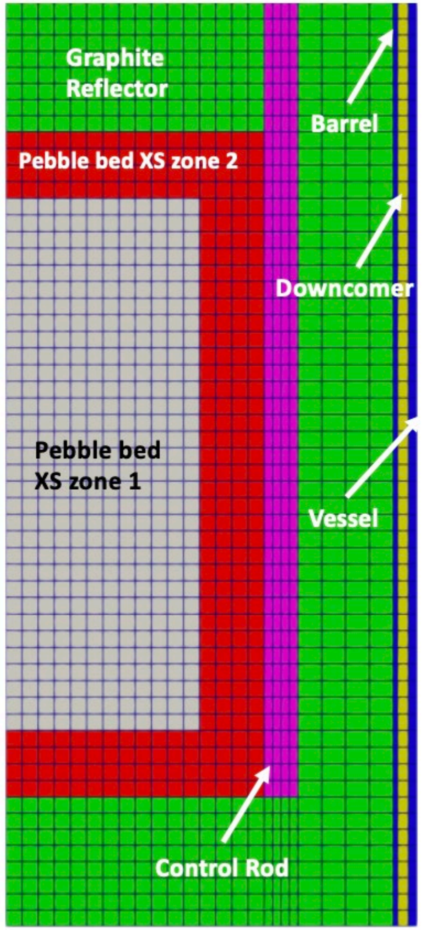
Advantages of model vs Point Kinetics

- 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?

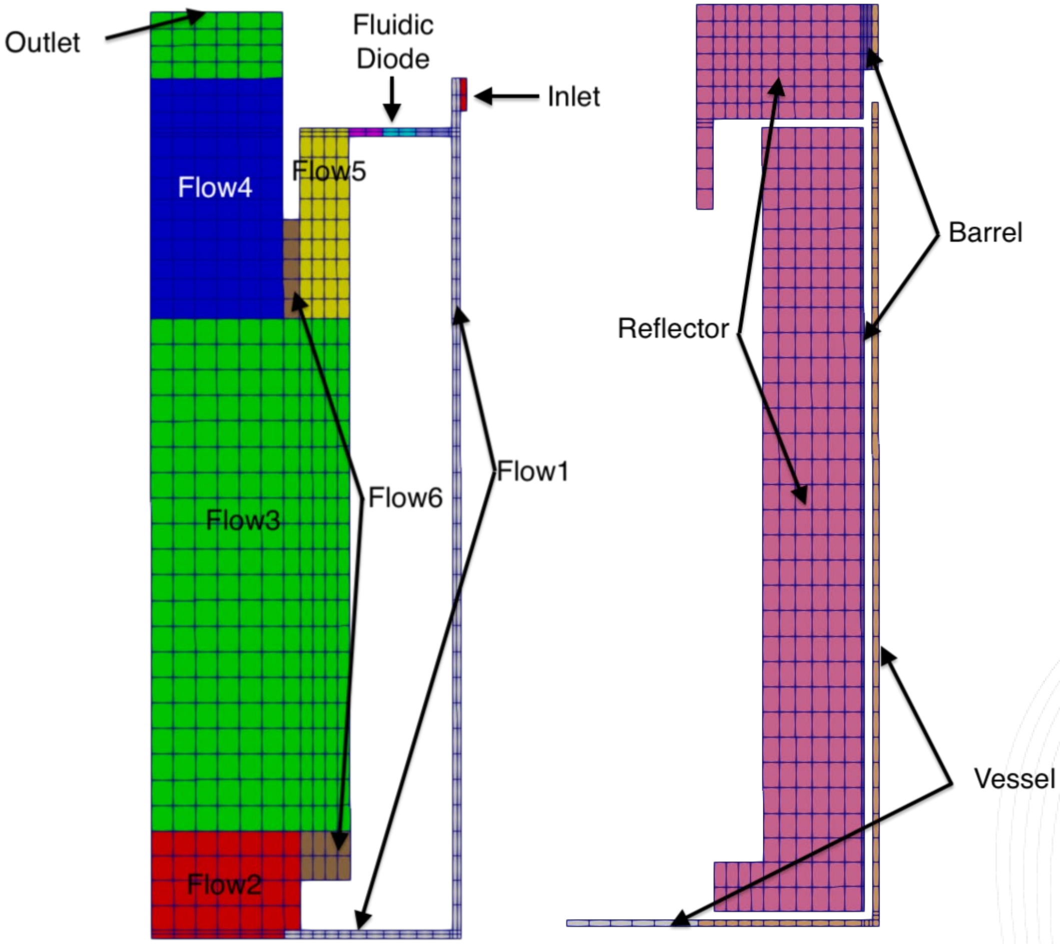
- Less conservatism can enable a more competitive design

Fluoride-Cooled PBR Model (gFHR)

- 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

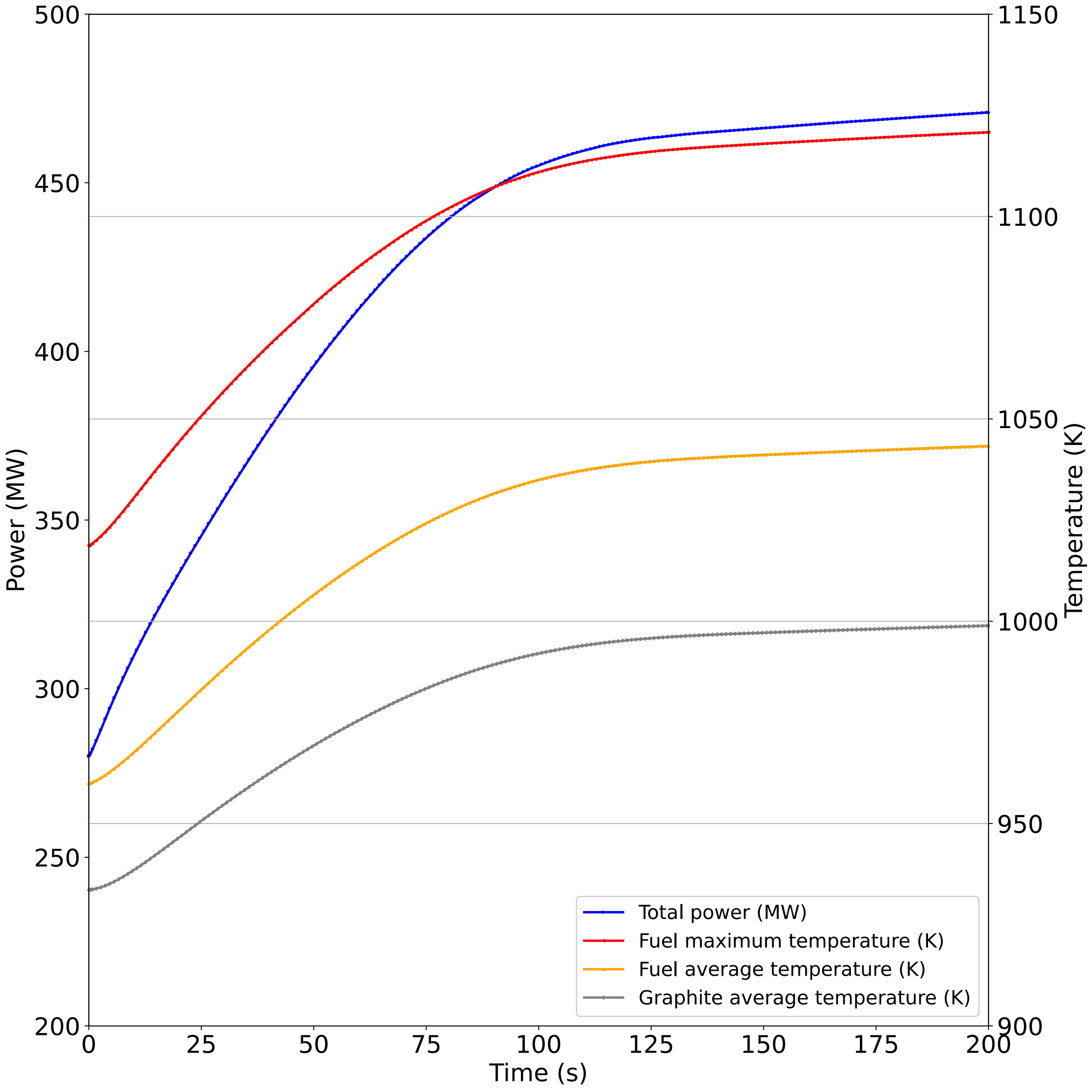


Pronghorn meshes
(porous medium vs solid conduction)

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.

gFHR Control Rod Withdrawal

- Additional temperature feedback due to FLiBe density changes
- Higher power density results in faster heating
- Power/temperature stabilize above nominal conditions
- But no overshoot observed



Conclusions & Future 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 and Future Work:

- Control Rod Ejection
- Fuel performance (estimation of TRISO failure probability)
- Sensitivity Analysis

Questions?

Backup Slides

Griffin Reactivity Curve

- Static reactivity computed with Griffin at equilibrium core conditions
- No visible cusping (exhibited by lack of smoothness in the reactivity curve)
- Partly because the difference in cross-section between the B4C segment and the follower is not huge
- More challenging with Gas-Cooled PBR
- Adaptive local mesh refinement will help