INL/CON-24-77707-Revision-0

[Presentation] Long time scale Multiphysics simulation of spent nuclear fuel canister in MOOSE

April 2024

Changing the World's Energy Future

Rodrigo Gonzalez Gonzaga de Oliveira, Joshua Thomas Hanophy, Paolo Balestra, Derek R Gaston

Idaho National Laboratory

INL/CON-24-77707-Revision-0

[Presentation] Long time scale Multiphysics simulation of spent nuclear fuel canister in MOOSE

Rodrigo Gonzalez Gonzaga de Oliveira, Joshua Thomas Hanophy, Paolo Balestra, Derek R Gaston

April 2024

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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

PHYSOR 2024 – Apr 23, 2024

Rodrigo de Oliveira
Joshua Hanophy
Paolo Balestra
Derek Gaston

Long Time Scale Multiphysics Simulation of Spent Nuclear Fuel Canister in MOOSE

Overall project’s objective

- Problem:
  - PBRs generate spent fuel that is not as understood as typical LWR
  - It has also not been given due attention even though there are several reactor concepts using pebbles as fuel

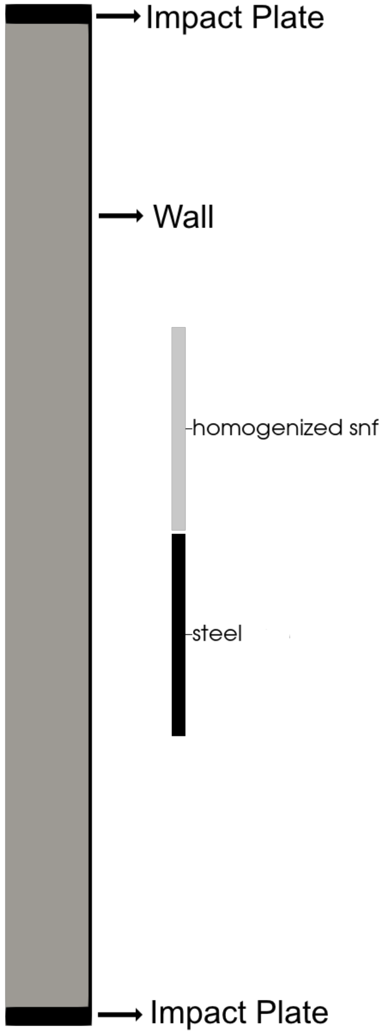
- Solution:
  - Model the backend fuel cycle of PBRs from reactor to disposal in a geological repository
  - Elucidate gaps currently available

Modeling approach

- 200 MW_{th} GPBR
- Reactor simulated with a recycle scheme, with a burnup limit of 140 MWd/kgU

↓

- Average discard pebble composition assumed for all pebbles
- Discard pebbles introduced into standard DOE canister
- Study canister disposal

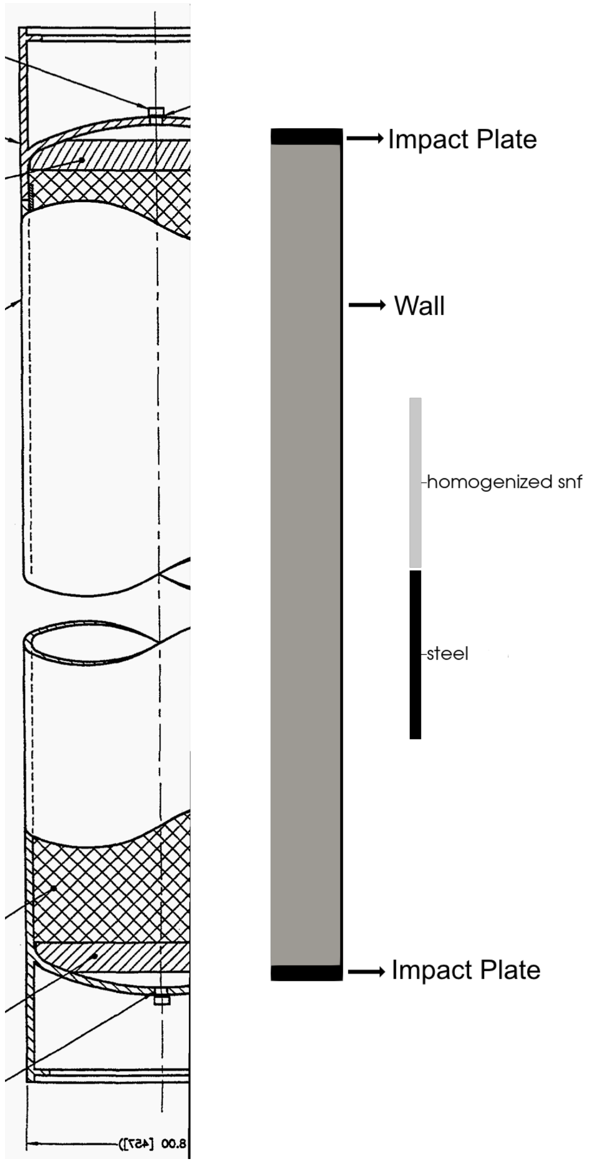


Assumptions and boundary conditions

- SNF pebbles are homogenized with helium coolant and treated as a porous medium

- Wall at ambient temperature
- Impact plates adiabatic to account for air gap

- Perform single physics calculations to find a reasonable starting point
- Use that as the starting point of a Multiphysics calculation



Choice of initial case

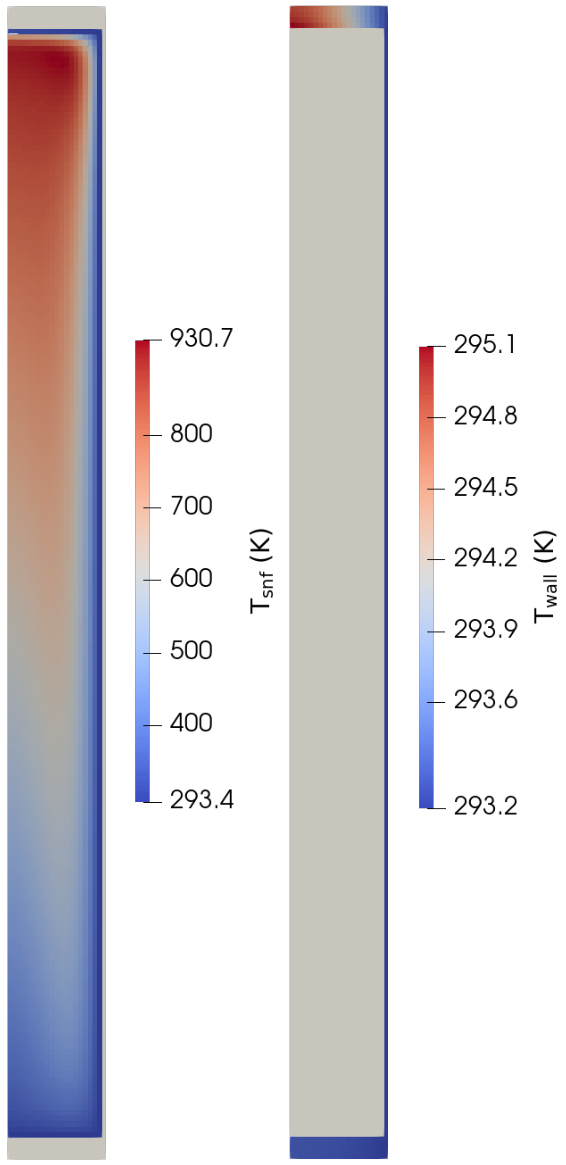
- Simulate decay over 10^9 s
- Simulate fluid flow at reasonable times
- Find an initial case that is “aggressive” enough to represent a cooling challenge.

~1 day → 10^5
~11 days → 10^6

Time (s)	Decay heat (W)	Pebble power (W)	T_{max} (K)
0	3056	1.46	
0.1	3022	1.44	
1	2815	1.35	
10	2218	1.06	
10^2	1571	0.751	
10^3	1029	0.492	
10^4	624.6	0.299	
10^5	449.8	0.215	1241
10^6	279.8	0.134	931
10^7	120.6	0.0576	
10^8	20.09	0.00960	
10^9	5.216	0.00249	

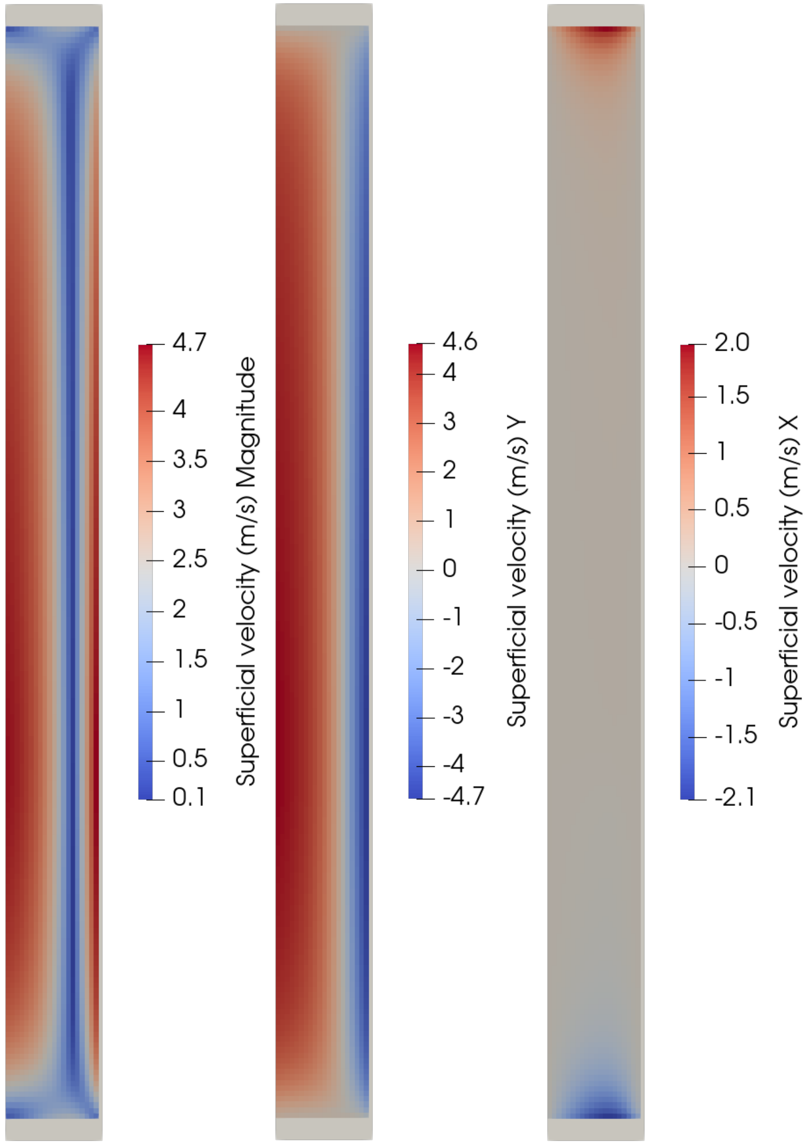
Temperature at t=0

- Boundary conditions imposes a steep temperature gradient
- Might have to rethink the adiabatic top boundary
- Most likely need to replace the wall boundary. Maybe a convective heat flux one… but at what heat transfer coefficient?



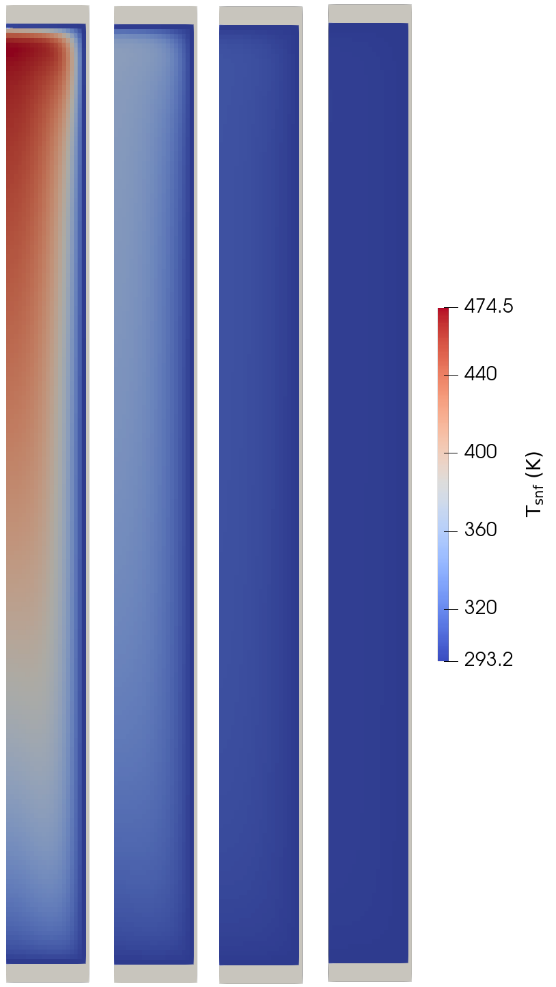
Velocity fields at t=0

- Clear natural circulation pattern
- Velocities rather high based on current heat source and BC



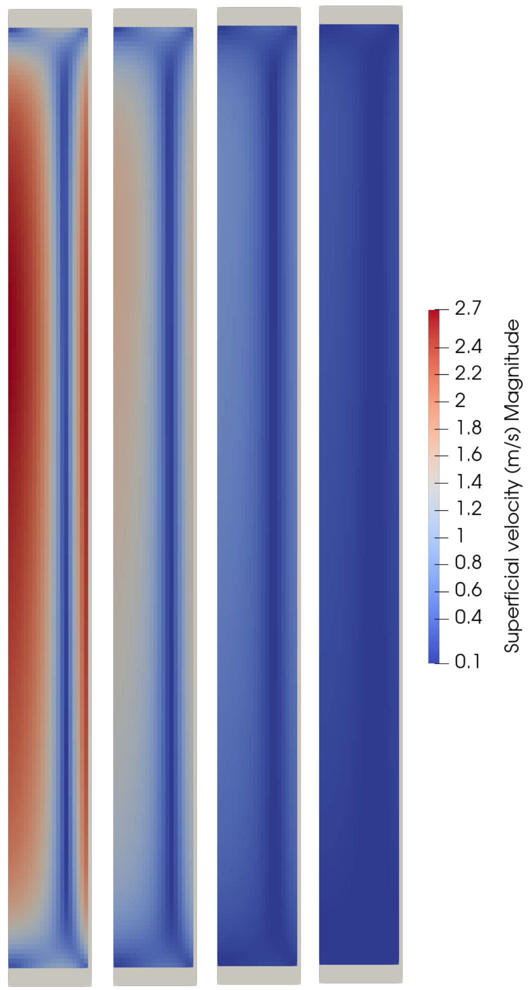
Temperature fields at t=1, 3.5, 54 and 219 years

- By the first year, temperature has already dropped significantly
- At 54 years or so, it's already approaching ambient temperature



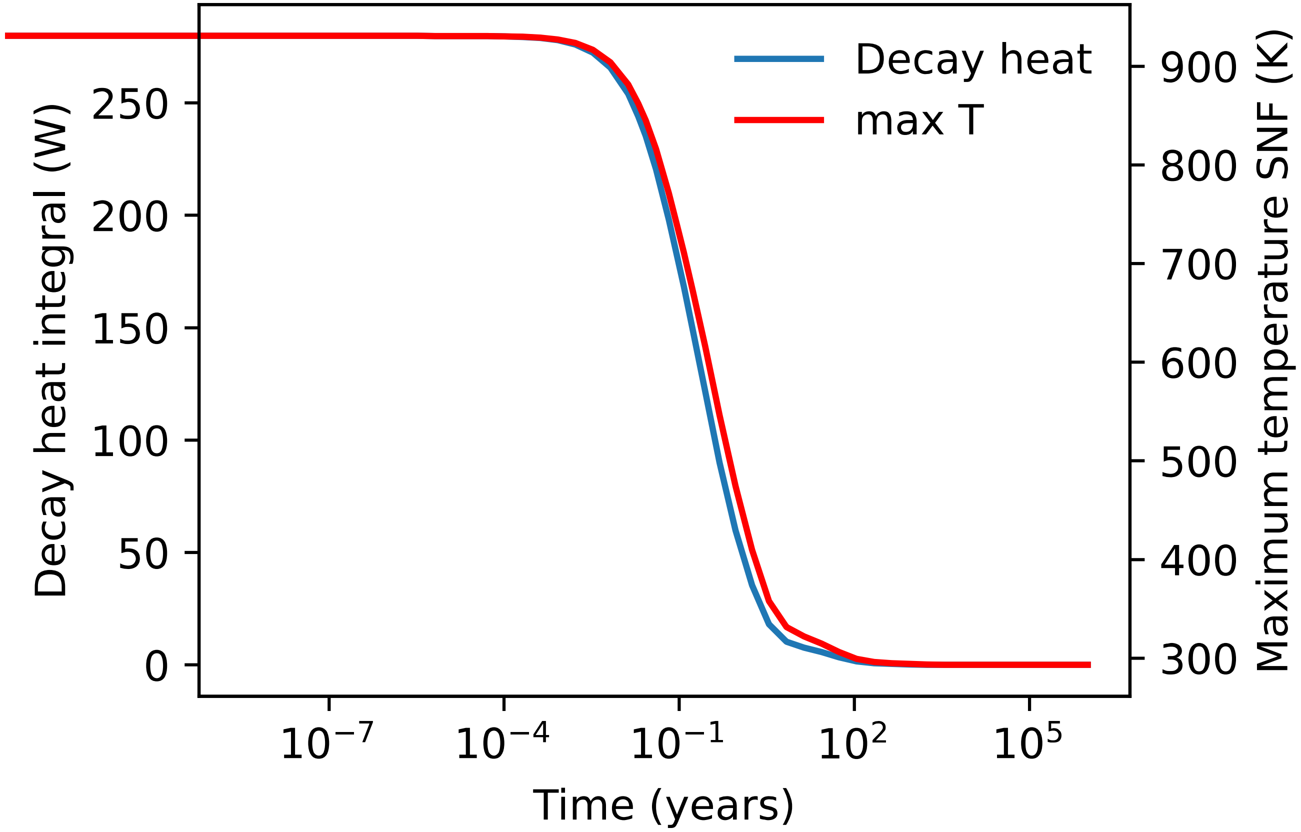
Velocity fields at t=1, 3.5, 54 and 219 years

- Velocities continue to be high after a year, suggesting that an improvement in BC and friction factors could significantly improve simulations of near future.



Approach to thermal equilibrium

- After 100 years, the maximum temperature in the canister has approached ambient temperature
- This independently confirms previous reports



Conclusions

- Thermal BC and friction factor specifications are a low-hanging fruit for improving studies of short-term behavior but not that important after ~100 years (or even earlier)
- MOOSE can simulate these scenarios quite well, with runtimes of the order of 20 minutes
- The final times steps are of the order of 10,000 years, requiring a well specified goal for the analysis
- MOOSE was not previously used to do this types of analysis, and this effort has revealed several aspects that need improvement

Acknowledgements

This research made use of Idaho National Laboratory's High Performance Computing systems located at the Collaborative Computing Center and supported by the Office of Nuclear Energy of the U.S. Department of Energy and the Nuclear Science User Facilities under Contract No. DE-AC07-05ID14517.

Work supported through the INL Laboratory Directed Research & Development (LDRD) Program under DOE Idaho Operations Office Contract DE-AC07-05ID14517.

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.