INL/MIS-23-72126-Revision-0

AGR-3/4 Post-Irradiation Examination

April 2023

John D Stempien, Adriaan Anthony Riet

Changing the World's Energy Future

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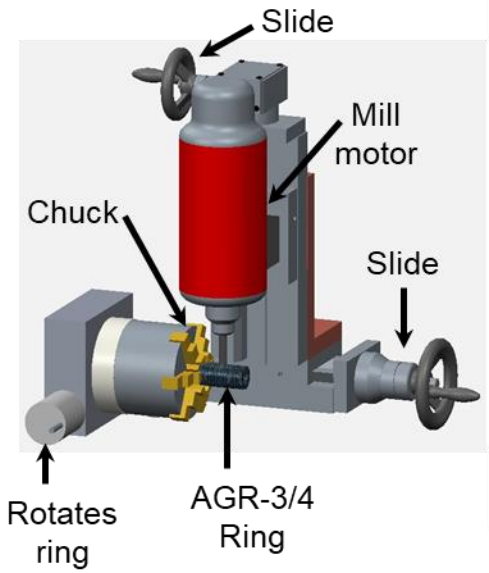
TRISO Fuel PIE Technical Lead

AGR-3/4 Post-Irradiation Examination

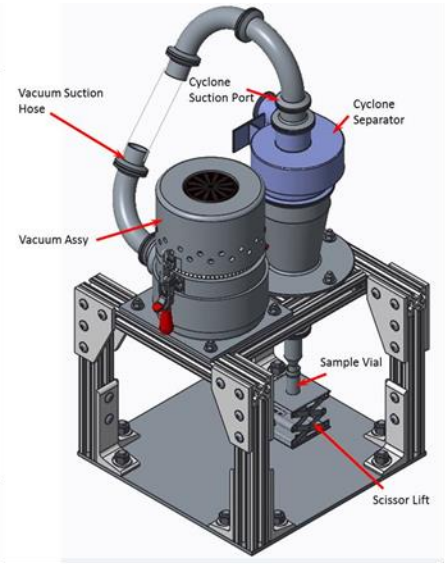
ART Advanced Reactor Technologies
GAS-COOLED REACTORS

Physical Sampling for Fission Product Concentration Profiles in Graphite and Graphitic Matrix

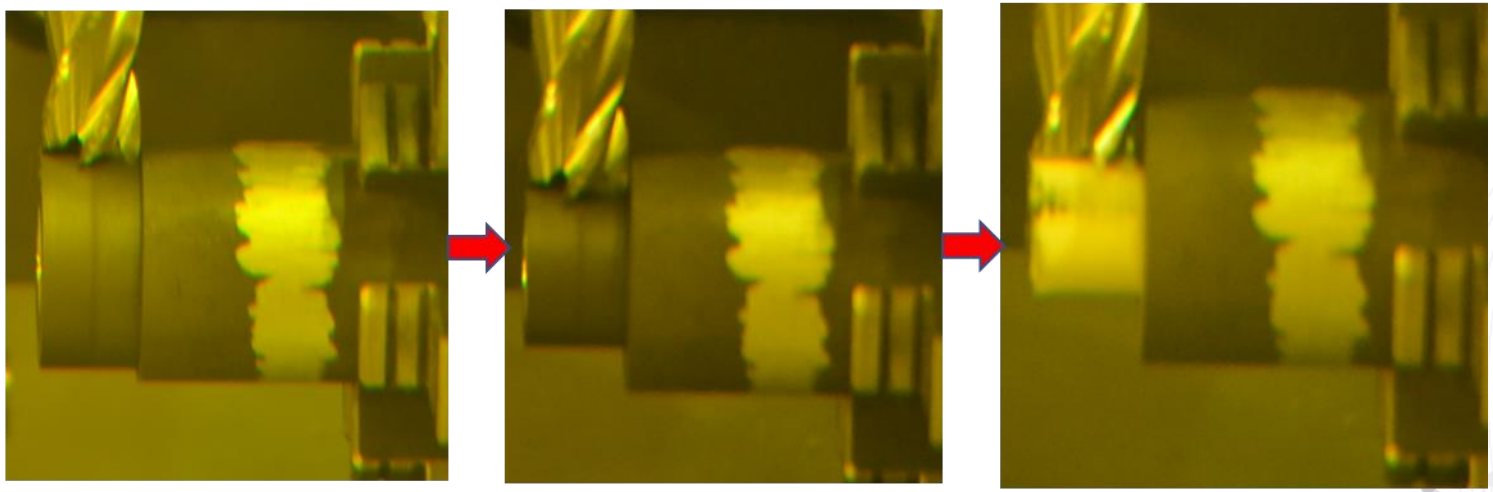
- Machining samples from the graphite rings to measure fission product radial profiles within rings
  - Progressively remove radial segments from rings at one or two axial locations
  - Collected material is gamma scanned and burn-leached for Sr-90 analysis
  - Refine models, compare to PGS, and derive transport parameters (e.g., diffusion coefficients) for FPs in graphite



Material Removal



Fines Collection

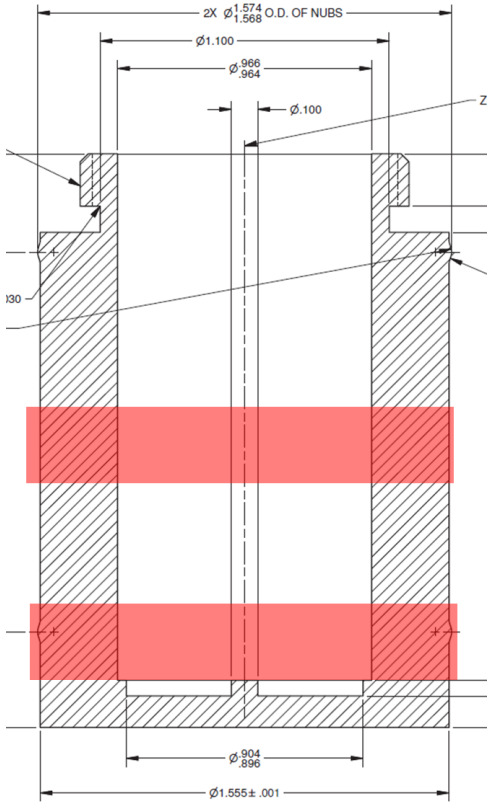


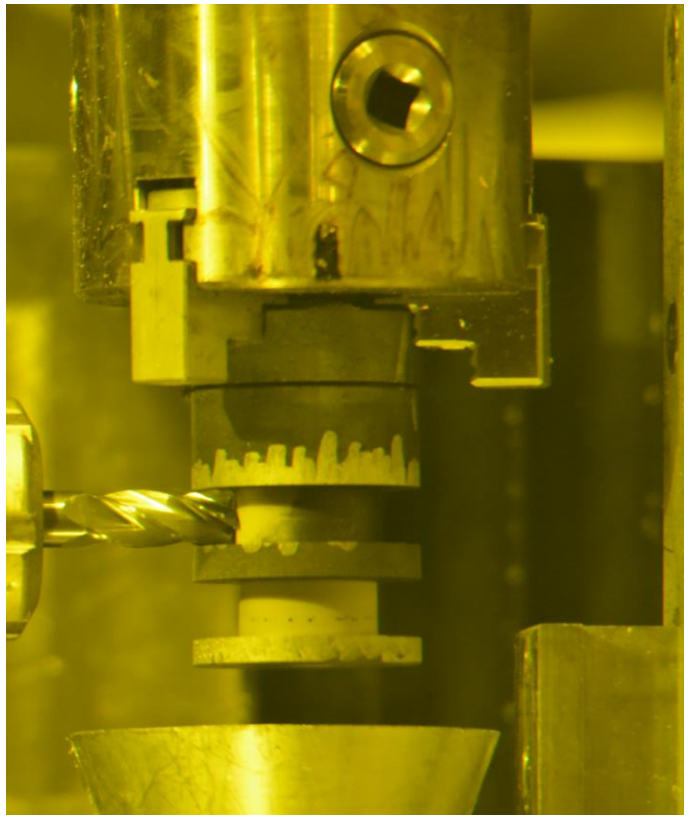
Images of IR-08 at beginning, middle, and end of sampling

Capsule 4 Rings (disassembled fuel body)

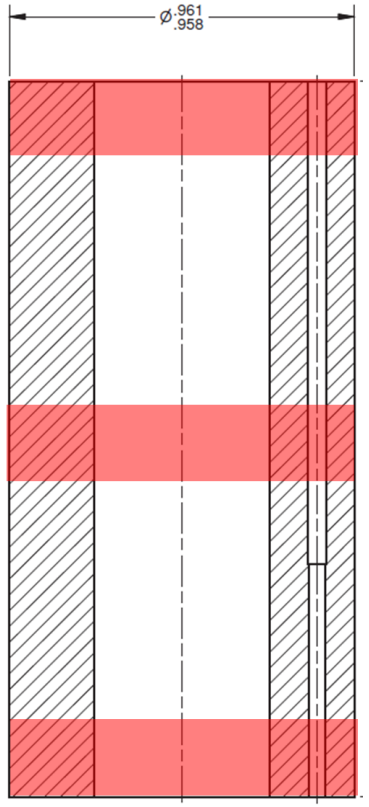
- Destructively sampled in FY22 after recommendation in Summer 2021 to analyze for axial transport
- Samples sent to Pacific Northwest National Laboratory in April 2022
- Expect results in late FY22 or Q1 in FY23

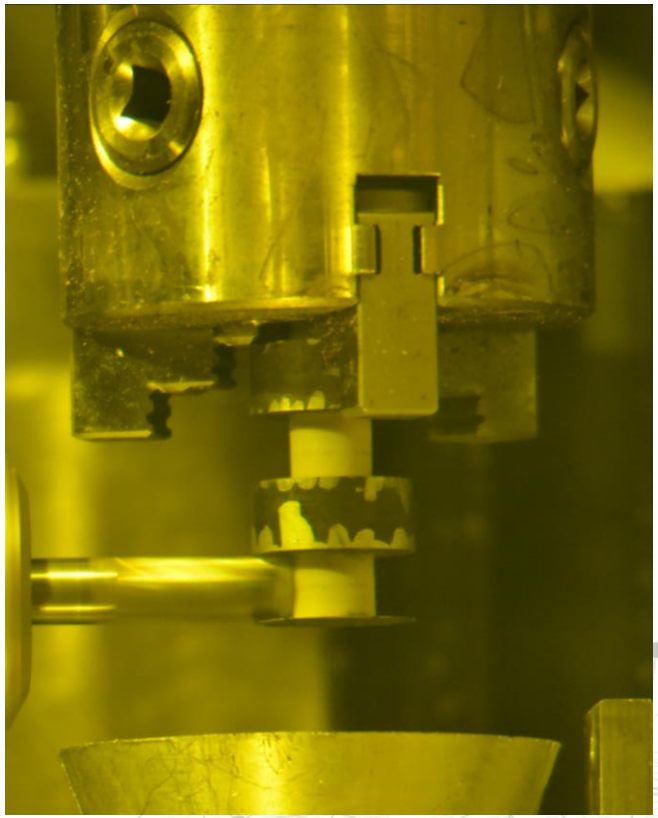
Outer Ring Samples Taken at Two Locations





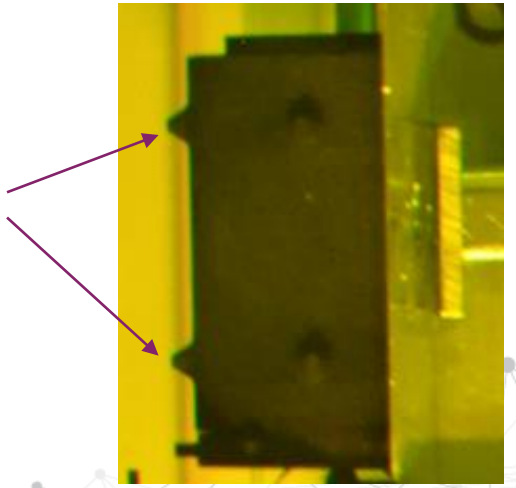
Inner Ring Samples Taken at Three Locations





Selected Conclusions from Ring Sampling

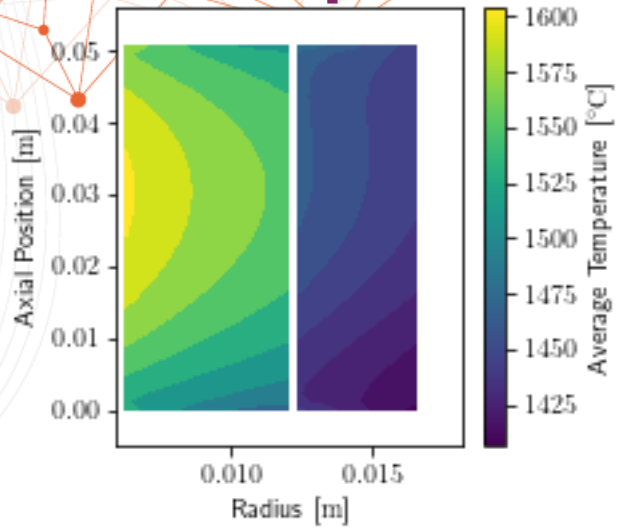
- Elevated concentrations of Ag, Cs, Eu, and Sr were detected on the outer surfaces of some IRs and ORs. Suggests a short-circuit pathway may exist whereby gas-phase fission product transport occurred in the gaps between the compacts and the rings.
- Ag-110m profiles had seemingly unpredictable shapes and significant variations from one sample to another. This will adversely affect the extraction of diffusivities.
- Cs-134 profiles compare reasonably with the AGR-3/4 model (more on that in A. Riet's presentation)
- Eu-154 and Sr-90 profiles have similar shapes suggesting transport is governed by similar mechanisms
- Outer ring nubs often had elevated fission product concentrations particularly of Sr-90. Suggests short-circuit transport. Also suggests some transport of Sr-90 as gaseous Kr-90 precursor and volatile intermediate Rb-90.
- Fundamental differences in transport within PCEA versus IG-110 versus graphitic matrix were not evident

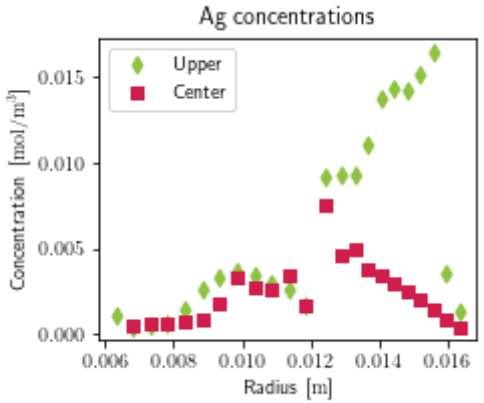


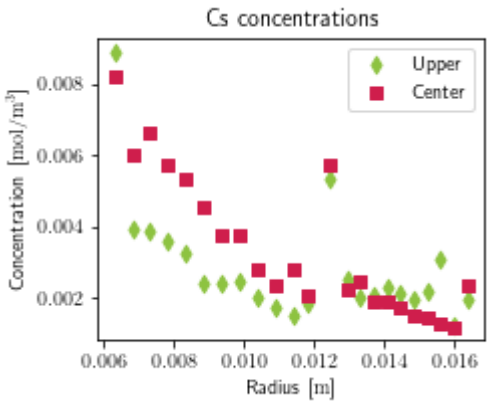
Graphite Ring Transport

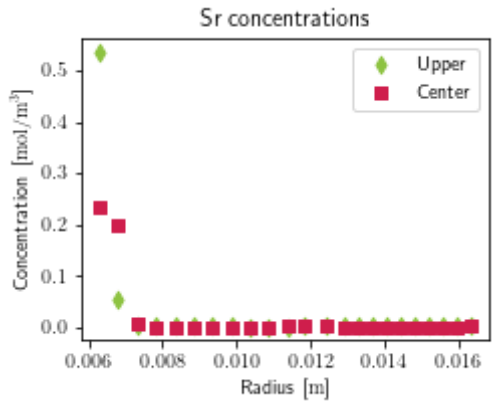
- Stubborn problem – dealing with the exponentials related to sorption isotherms will likely require a specialized FEM kernel to prevent divergence
- For now, we're using an integrated model developed in collaboration with the NEAMS campaign's work to model transport through the capsules
  - Model is partially derived from Paul Humrickhouse's HTR 2018 paper, but with TRISO release modeled directly in BISON instead of PARFUME, allowing for higher fidelity release predictions
  - Avoids modeling the inventory in the gas gaps directly

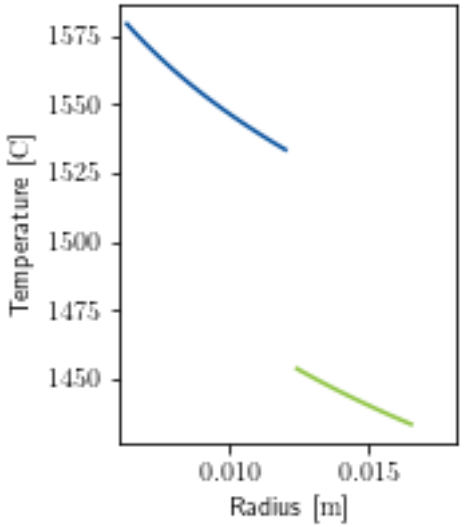
Capsule 3

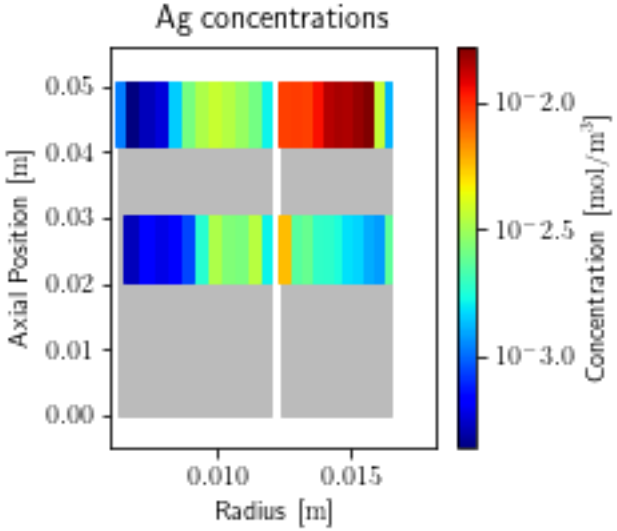

Axial Position [m]
Radius [m]
Average Temperature [°C]

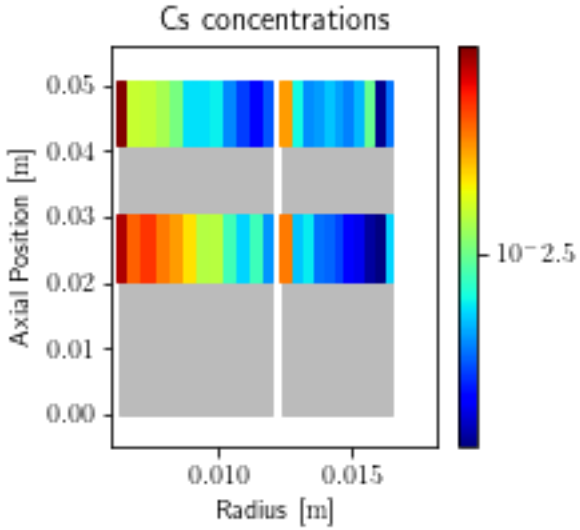

Ag concentrations
Upper
Center
Concentration [mol/m³]
Radius [m]

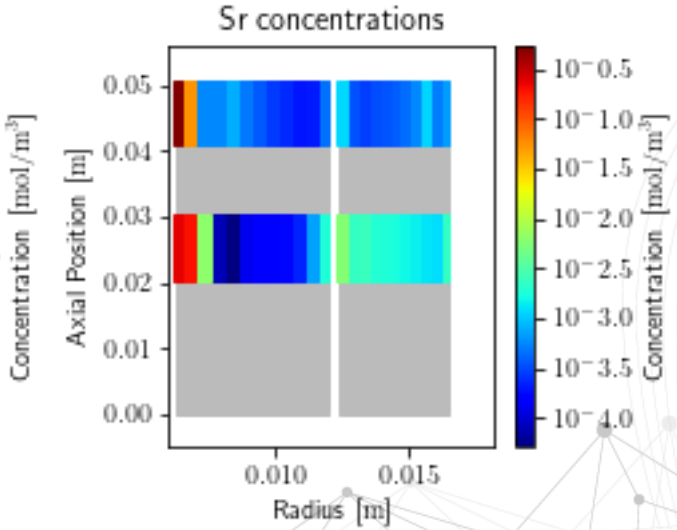

Cs concentrations
Upper
Center
Concentration [mol/m³]
Radius [m]


Sr concentrations
Upper
Center
Concentration [mol/m³]
Radius [m]

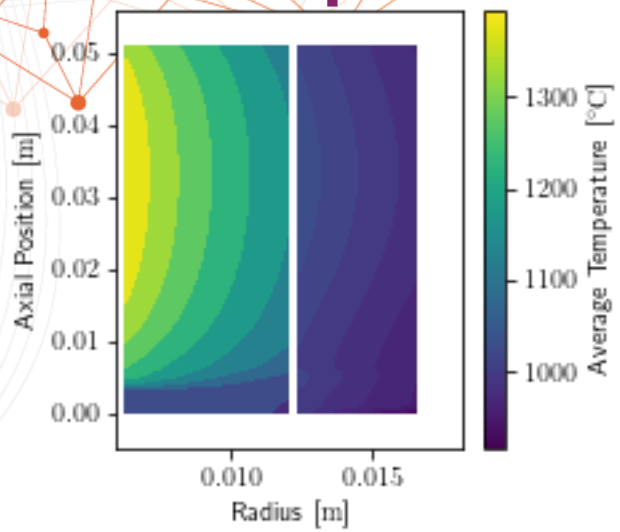

Temperature [C]
Radius [m]


Ag concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]


Cs concentrations
Axial Position [m]
Radius [m]


Sr concentrations
Concentration [mol/m³]
Axial Position [m]
Radius [m]
Concentration [mol/m³]

Capsule 4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Radius [m]
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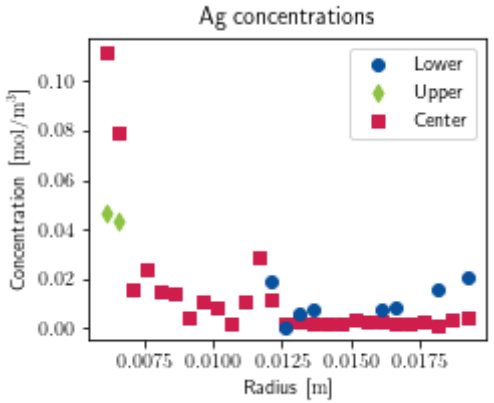
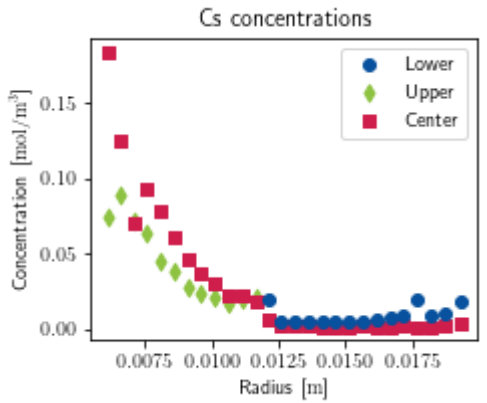
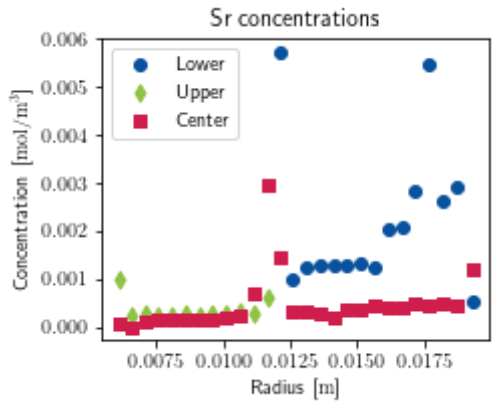
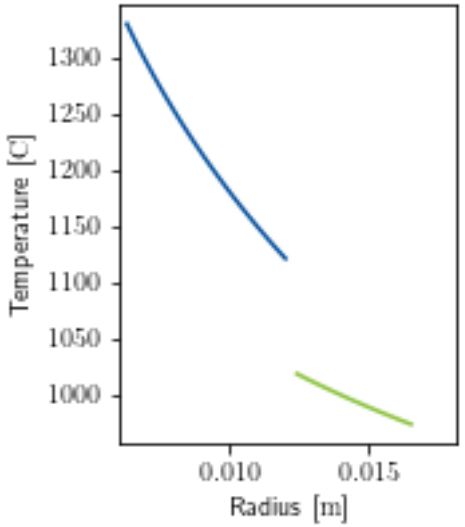
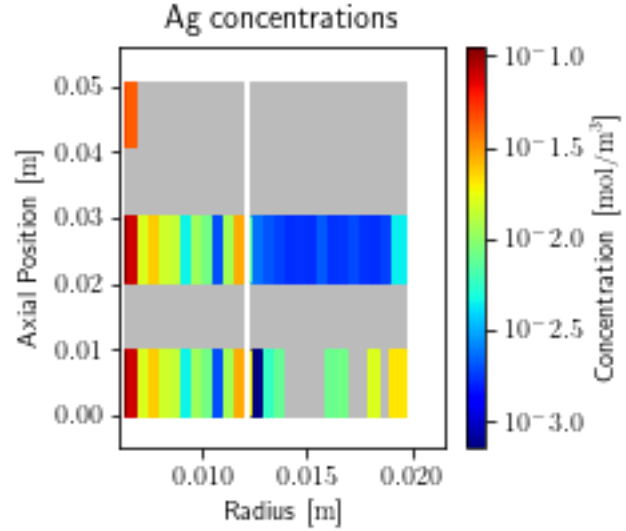
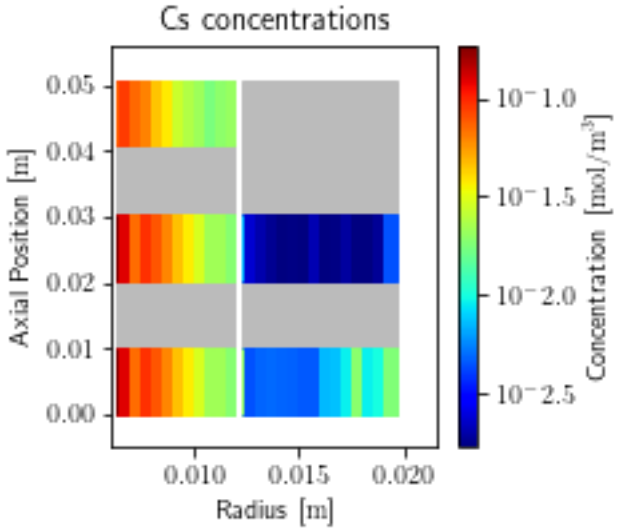

Ag concentrations
Lower
Upper
Center
Concentration [mol/m³]
Radius [m]

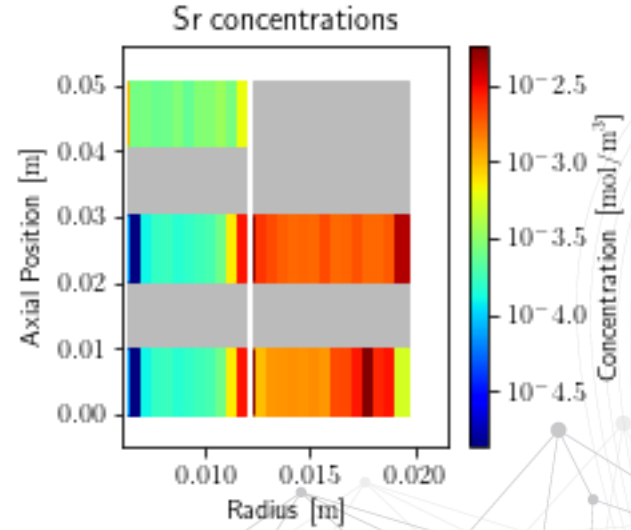

Cs concentrations
Lower
Upper
Center
Concentration [mol/m³]
Radius [m]


Sr concentrations
Lower
Upper
Center
Concentration [mol/m³]
Radius [m]

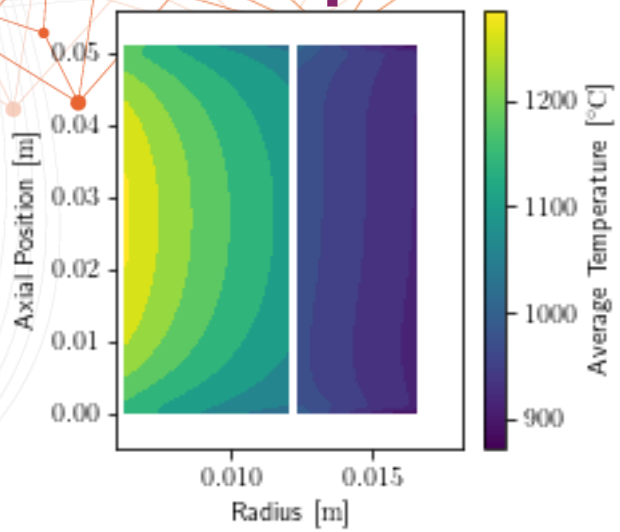

Temperature [C]
Radius [m]

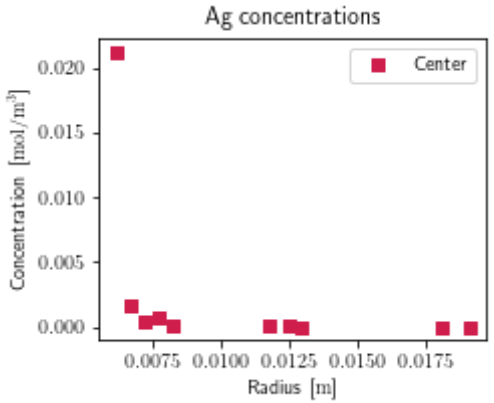

Ag concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

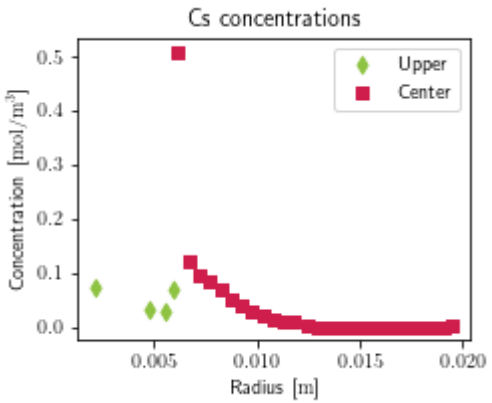

Cs concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

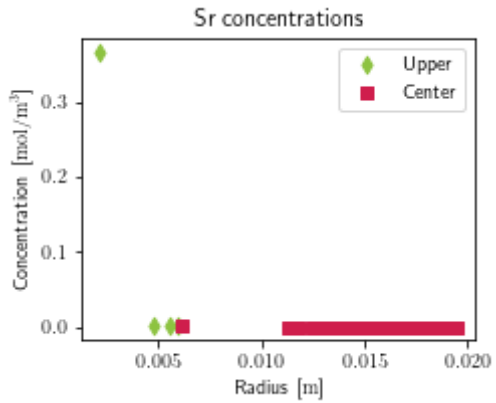

Sr concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

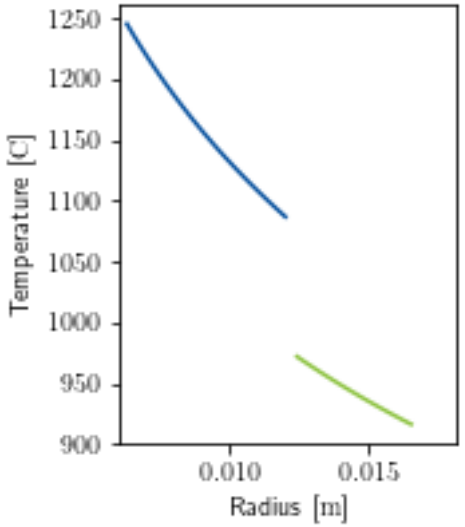
Capsule 5

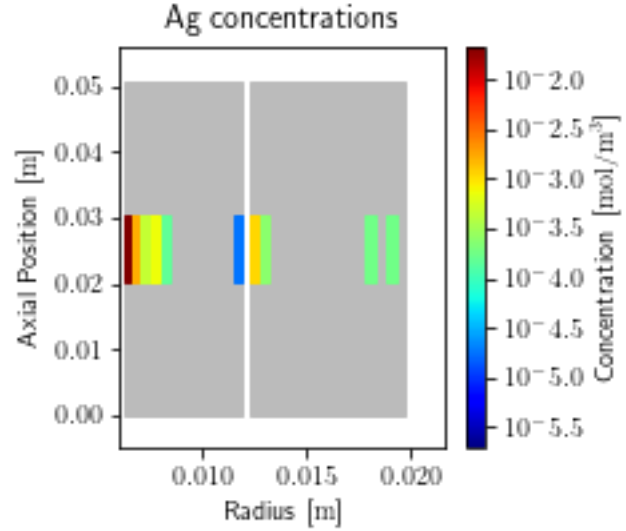

Axial Position [m]
Radius [m]
Average Temperature [°C]

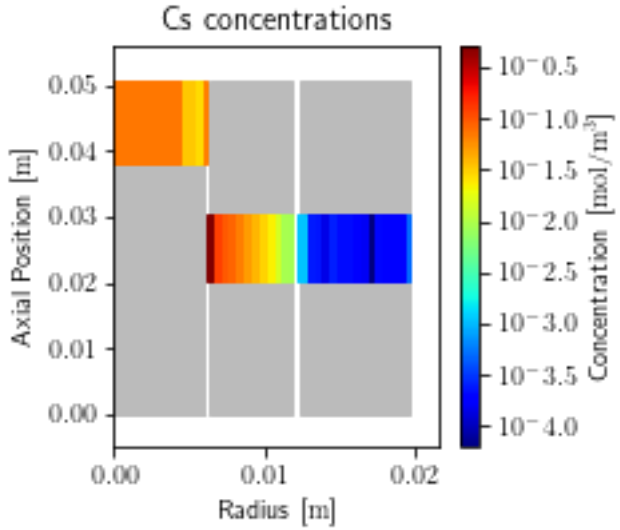

Ag concentrations
Center
Concentration [mol/m³]
Radius [m]

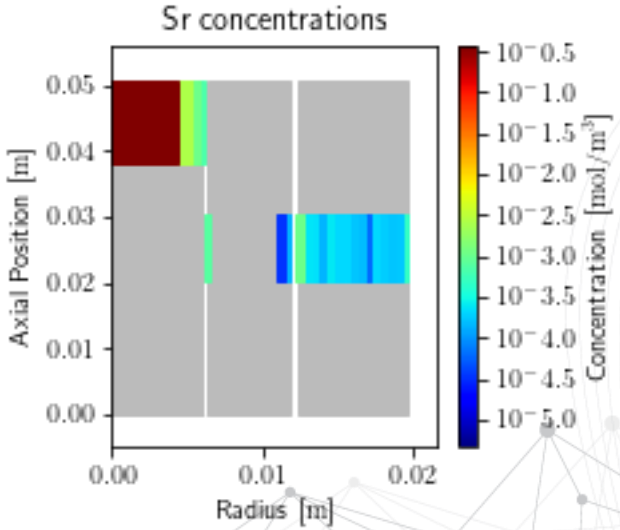

Cs concentrations
Upper
Center
Concentration [mol/m³]
Radius [m]


Sr concentrations
Upper
Center
Concentration [mol/m³]
Radius [m]

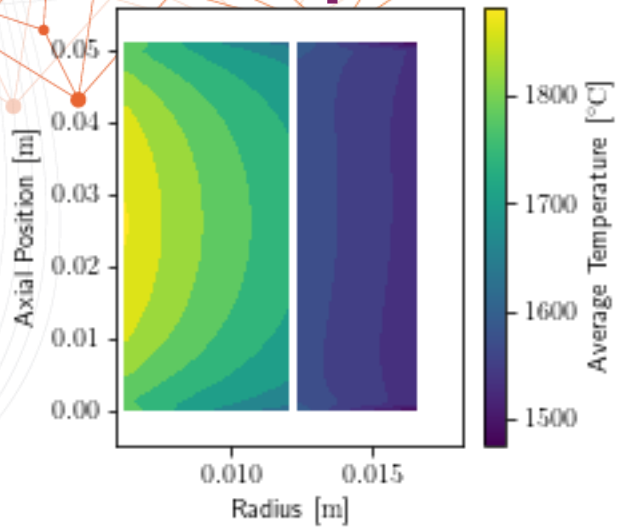

Temperature [C]
Radius [m]


Ag concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]


Cs concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]


Sr concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

Capsule 7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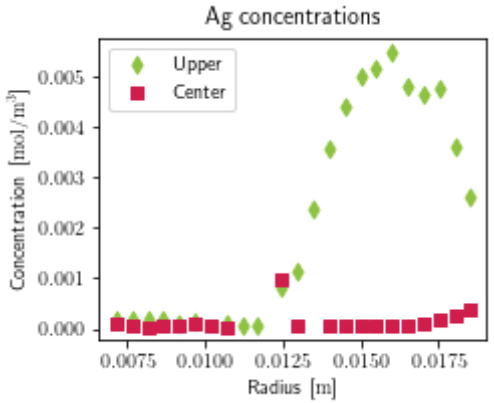
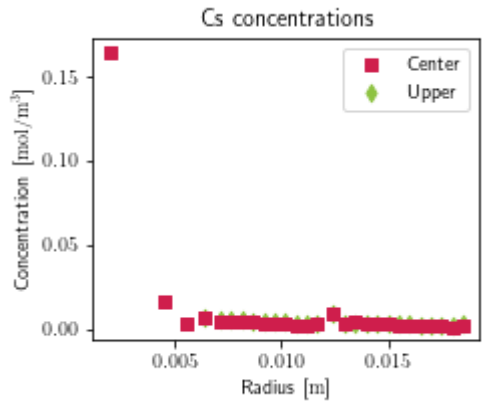
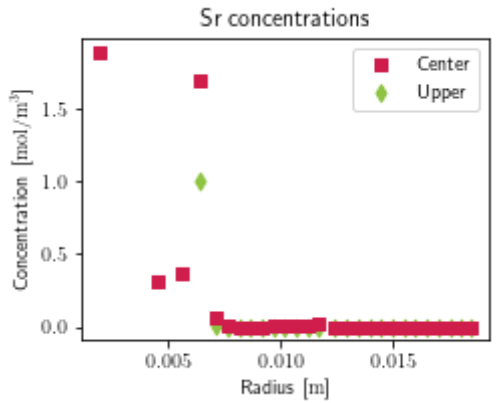
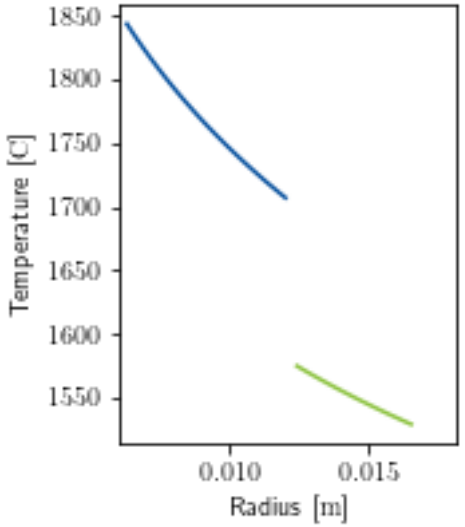
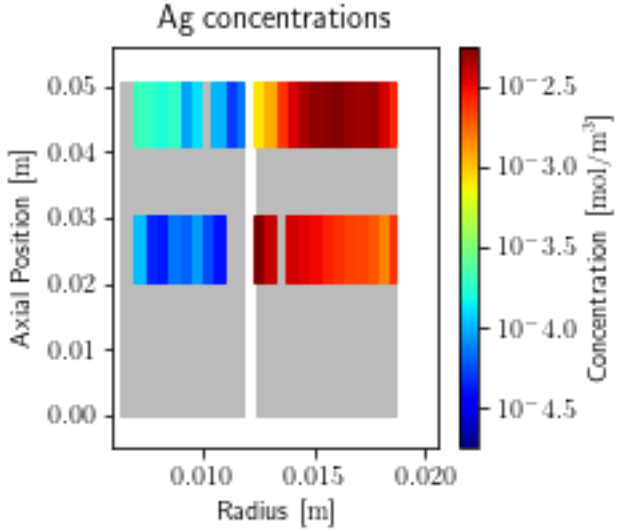
Radius [m]
Average Temperature [°C]

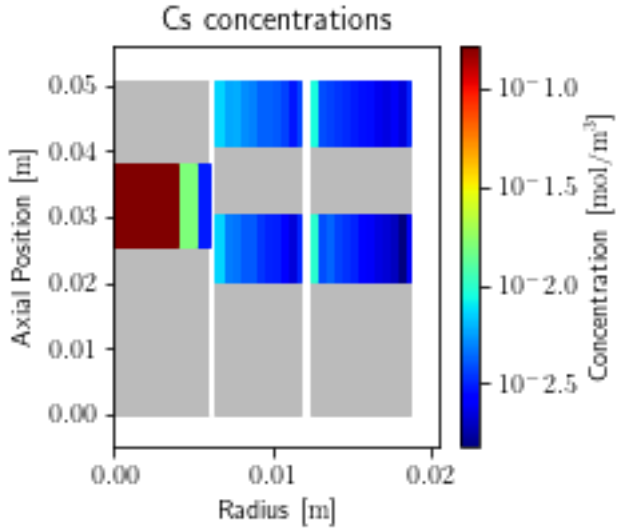

Ag concentrations
Upper
Center
Concentration [mol/m³]
Radius [m]

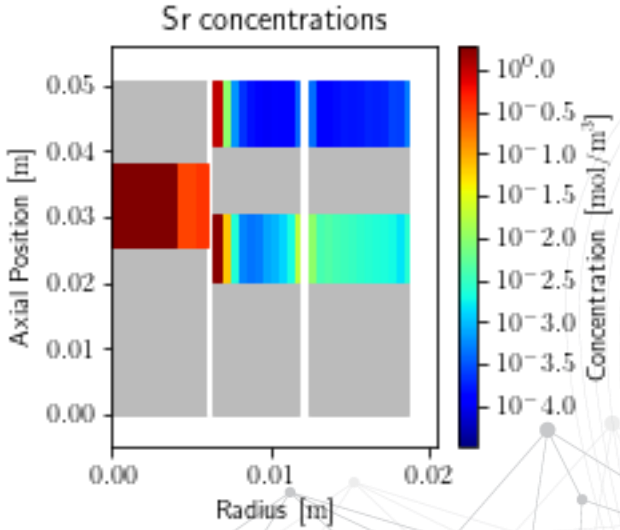

Cs concentrations
Center
Upper
Concentration [mol/m³]
Radius [m]


Sr concentrations
Center
Upper
Concentration [mol/m³]
Radius [m]

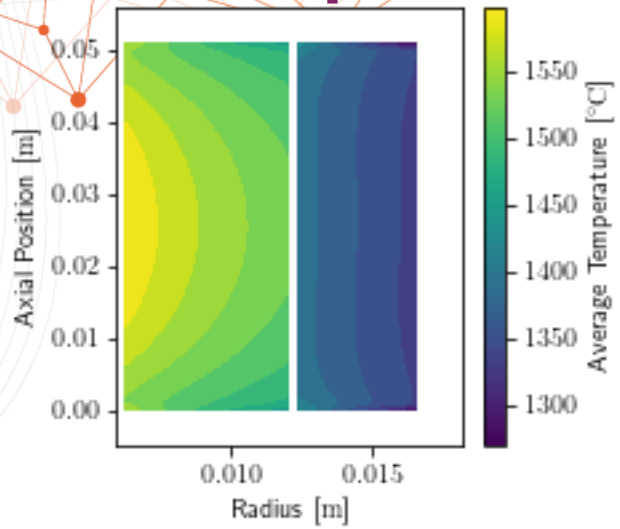

Temperature [C]
Radius [m]


Ag concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]


Cs concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]


Sr concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

Capsule 8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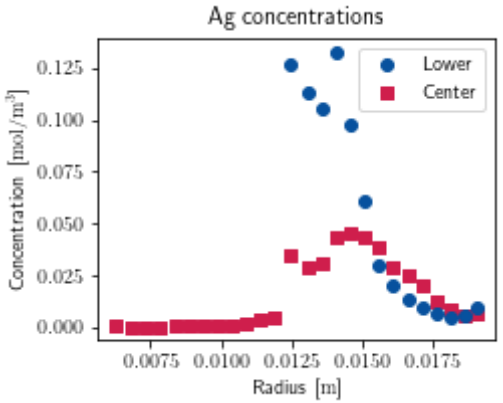
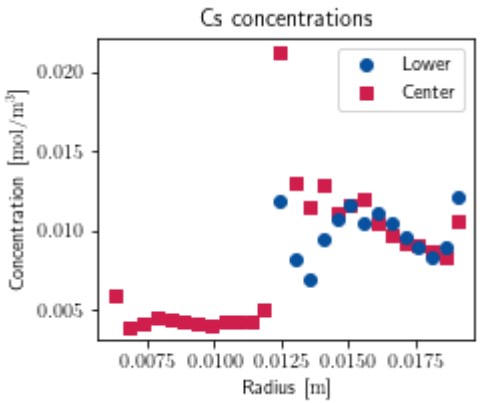
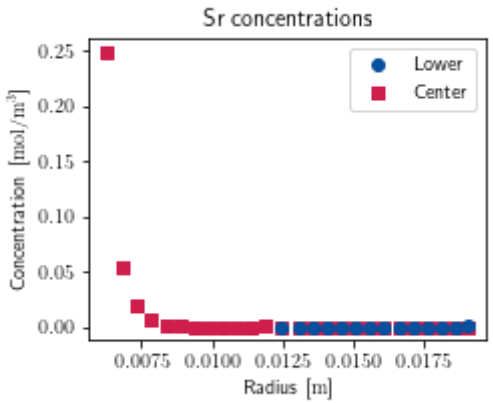
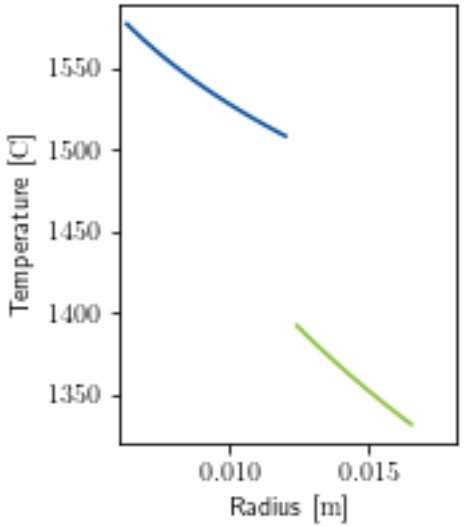
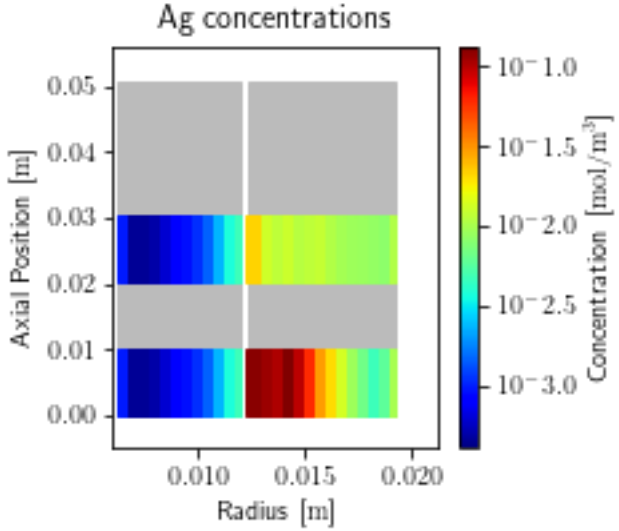
Average Temperature [°C]

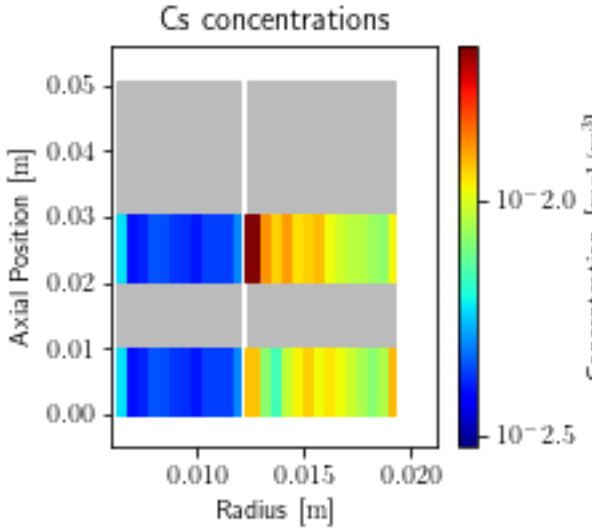

Ag concentrations
Lower
Center
Concentration [mol/m³]
Radius [m]

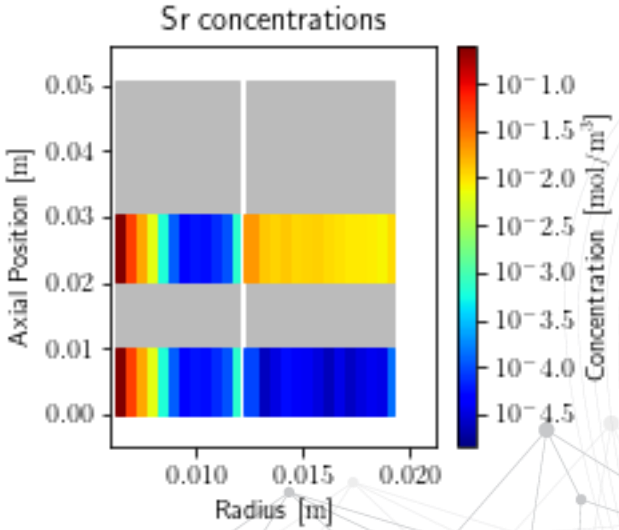

Cs concentrations
Lower
Center
Concentration [mol/m³]
Radius [m]


Sr concentrations
Lower
Center
Concentration [mol/m³]
Radius [m]

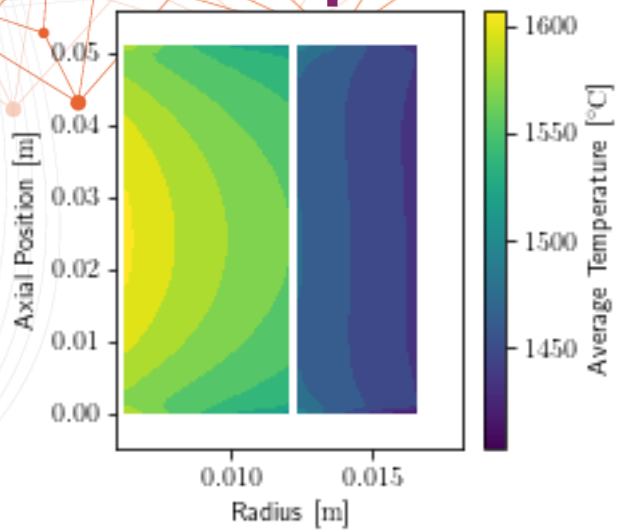

Temperature [C]
Radius [m]

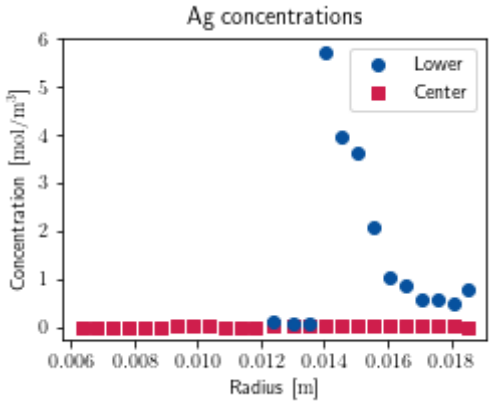

Ag concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

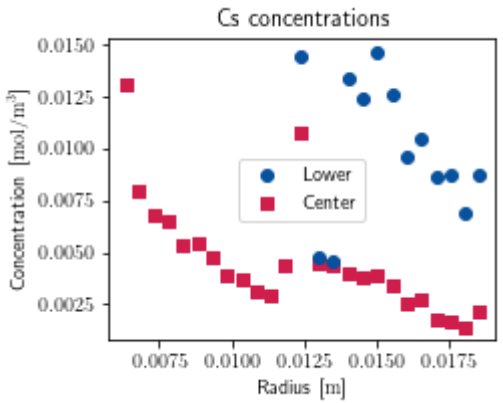

Cs concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

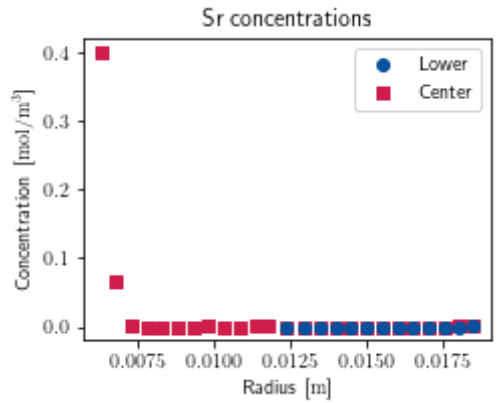

Sr concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

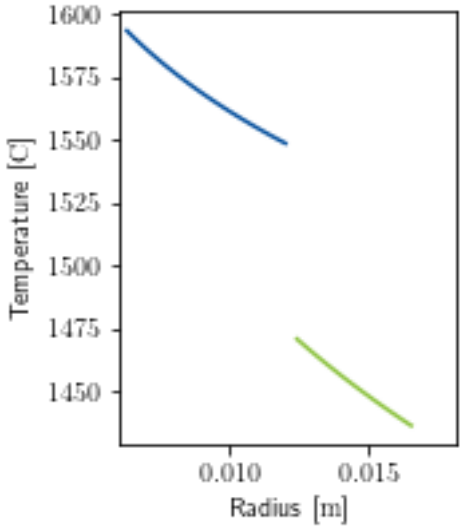
Capsule 10

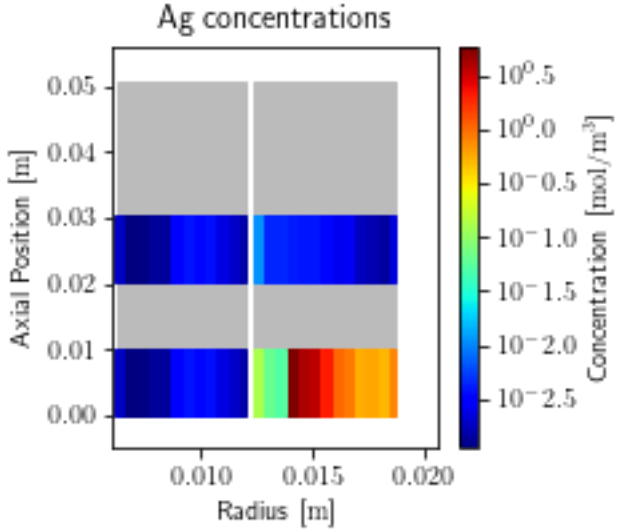

Axial Position [m]
Radius [m]
Average Temperature [°C]

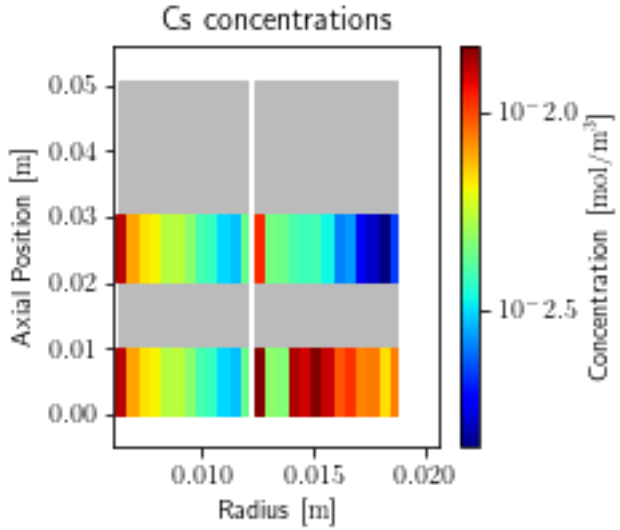

Ag concentrations
Lower
Center
Concentration [mol/m³]
Radius [m]

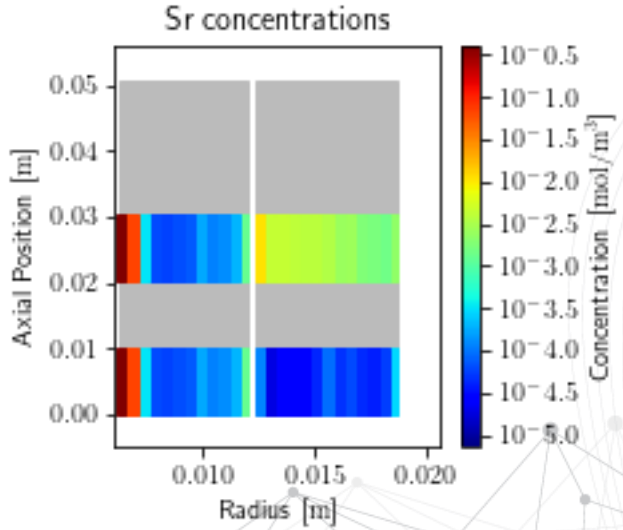

Cs concentrations
Lower
Center
Concentration [mol/m³]
Radius [m]


Sr concentrations
Lower
Center
Concentration [mol/m³]
Radius [m]

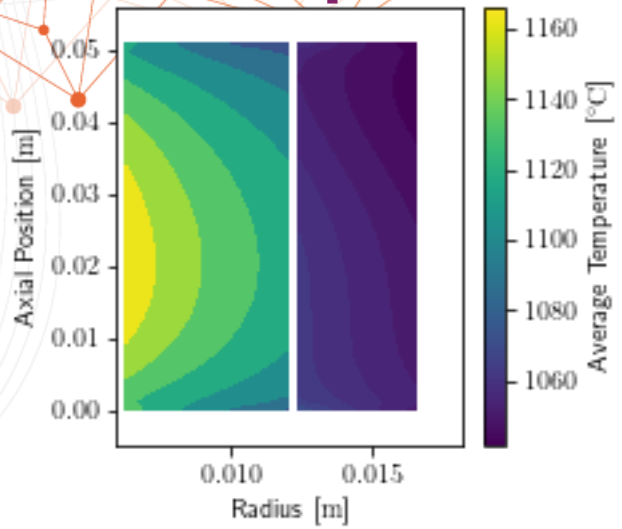

Temperature [C]
Radius [m]

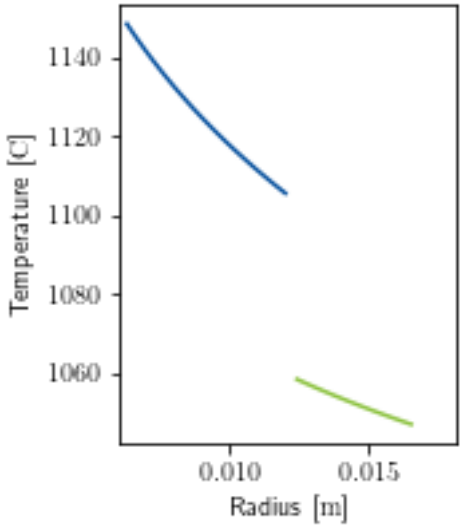

Ag concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]


Cs concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

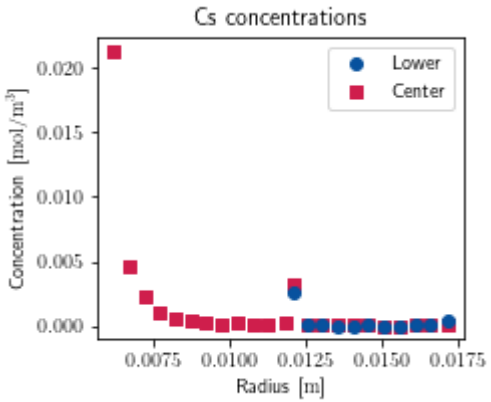

Sr concentrations
Axial Position [m]
Radius [m]
Concentration [mol/m³]

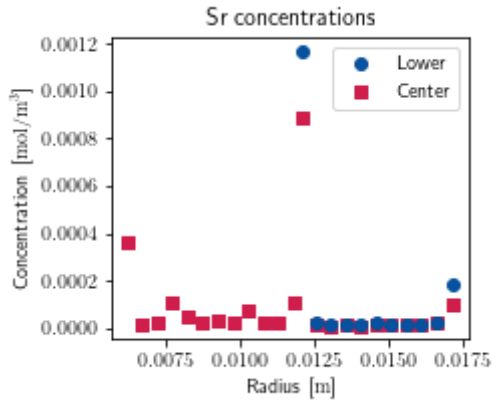
Capsule 12

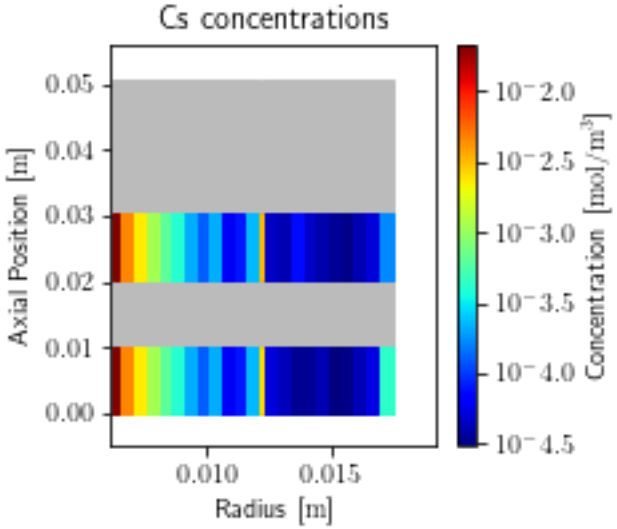


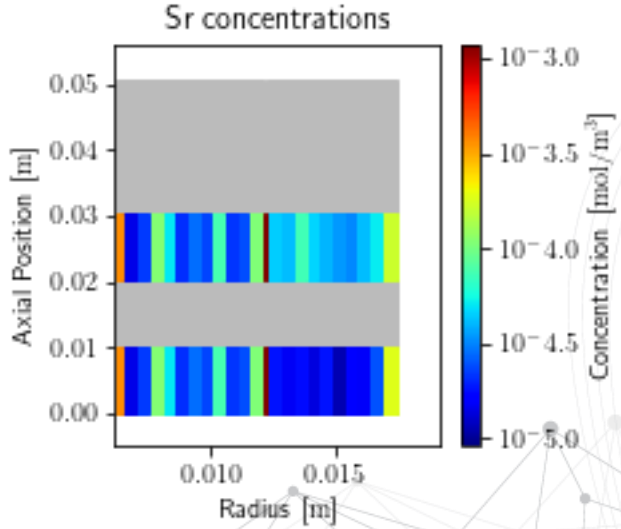


No Silver Detected



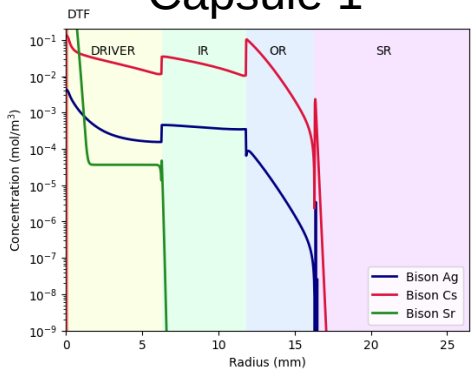




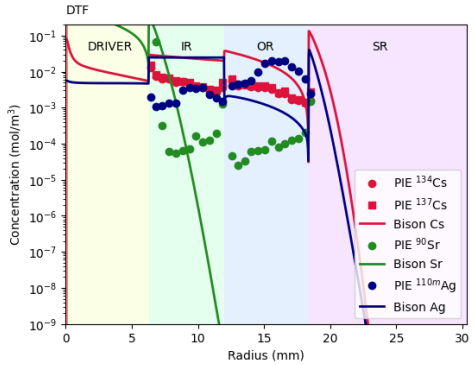


BISON Model (IAEA TECDOC 978 Properties) Comparison

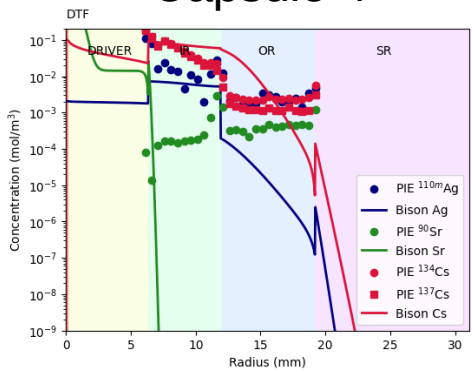
Capsule 1



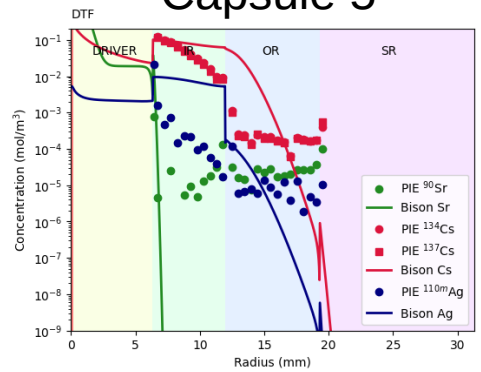
Capsule 3



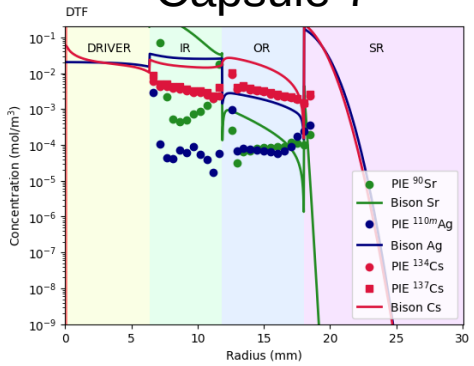
Capsule 4



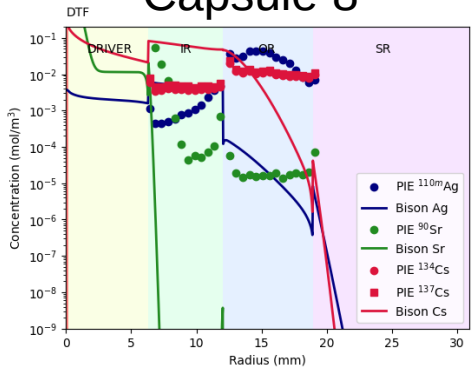
Capsule 5



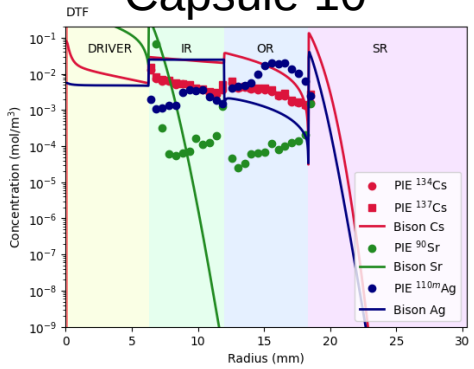
Capsule 7



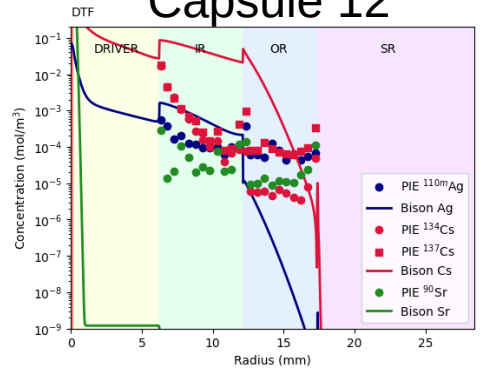
Capsule 8



Capsule 10



Capsule 12



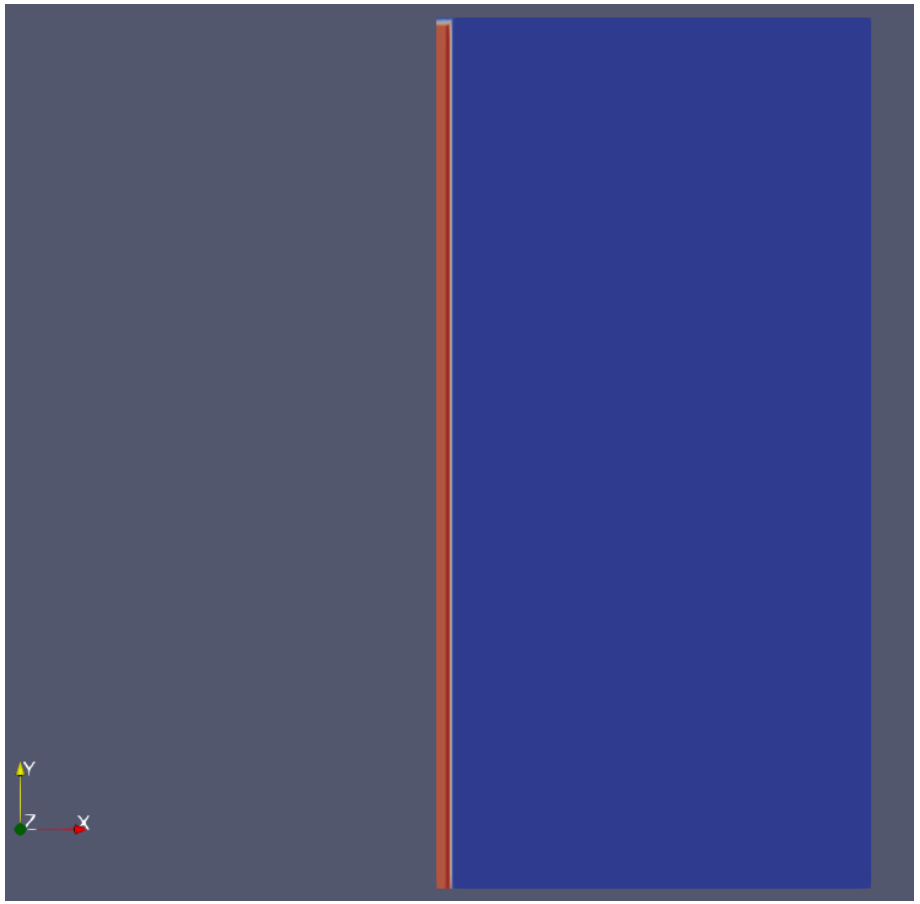
FACS Heating Tests

- Fission gas and condensable releases from the FACS Heating tests are now available
- Fitting with BISON model underway, much simpler physics to compare to
- Assumptions:
  - 2-D, radially symmetric diffusion
  - Isotopes at the beginning of the heating test are all located in the DTF particle region, uniformly distributed
  - Simple Arrhenius diffusion, no trapping (for now)
- Fitting released inventory as a function of time, normalized to the maximum measured inventory release
- Free surface boundary conditions on top and outside of compact, insulating boundary on bottom and center

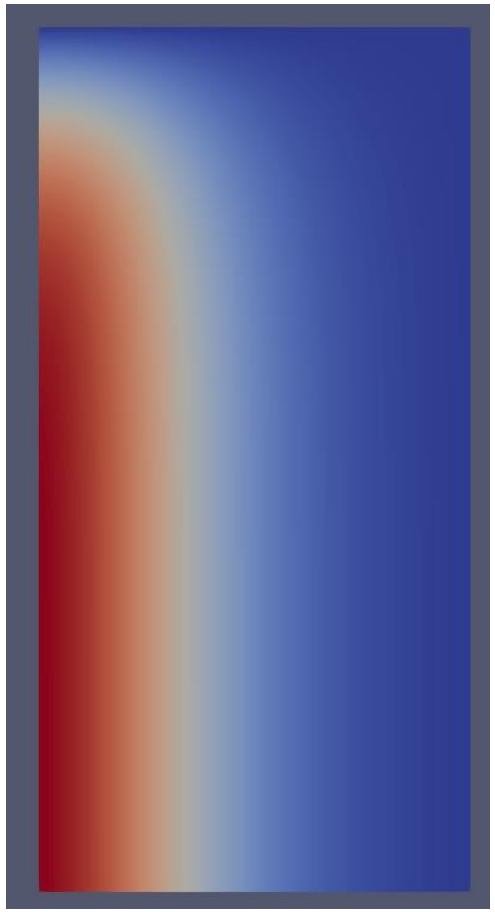
FACS Heating Test Modeling

Compact 3-1 Xe-133 release

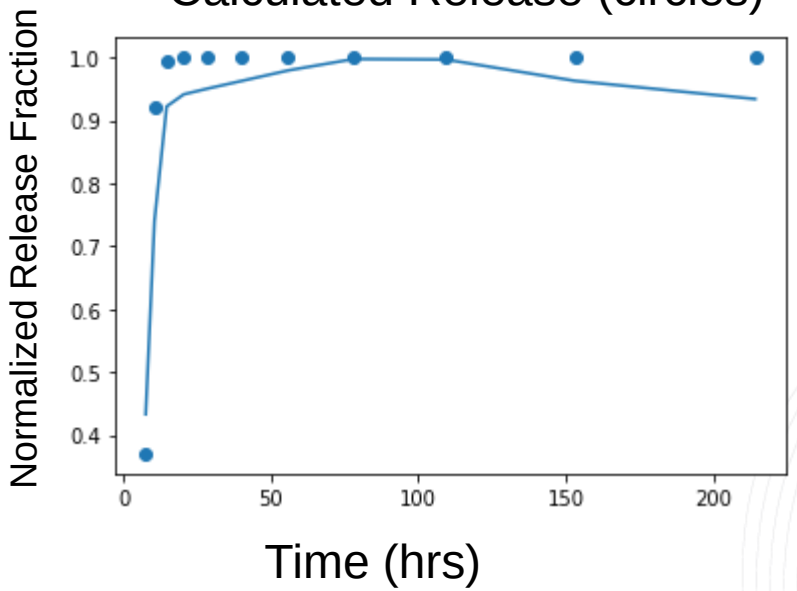
Initial profile (half cylinder)



Final concentration profile



Measured Release (line)
vs
Calculated Release (circles)



FACS Heating Test Modeling

- Goal is to calculate effective diffusivities for fission gases and condensables for each measured compact
- Comparisons of effective diffusivity between compacts not likely to yield fruitful results

Proposed Next Steps

- Fit Heating test and reirradiated heating test data
- Feed matrix diffusivities into NEAMS Bison Model, compare results (sanity check)

Idaho National Laboratory