Multi-Physics Modelling for Nuclear Engineering and other Applications

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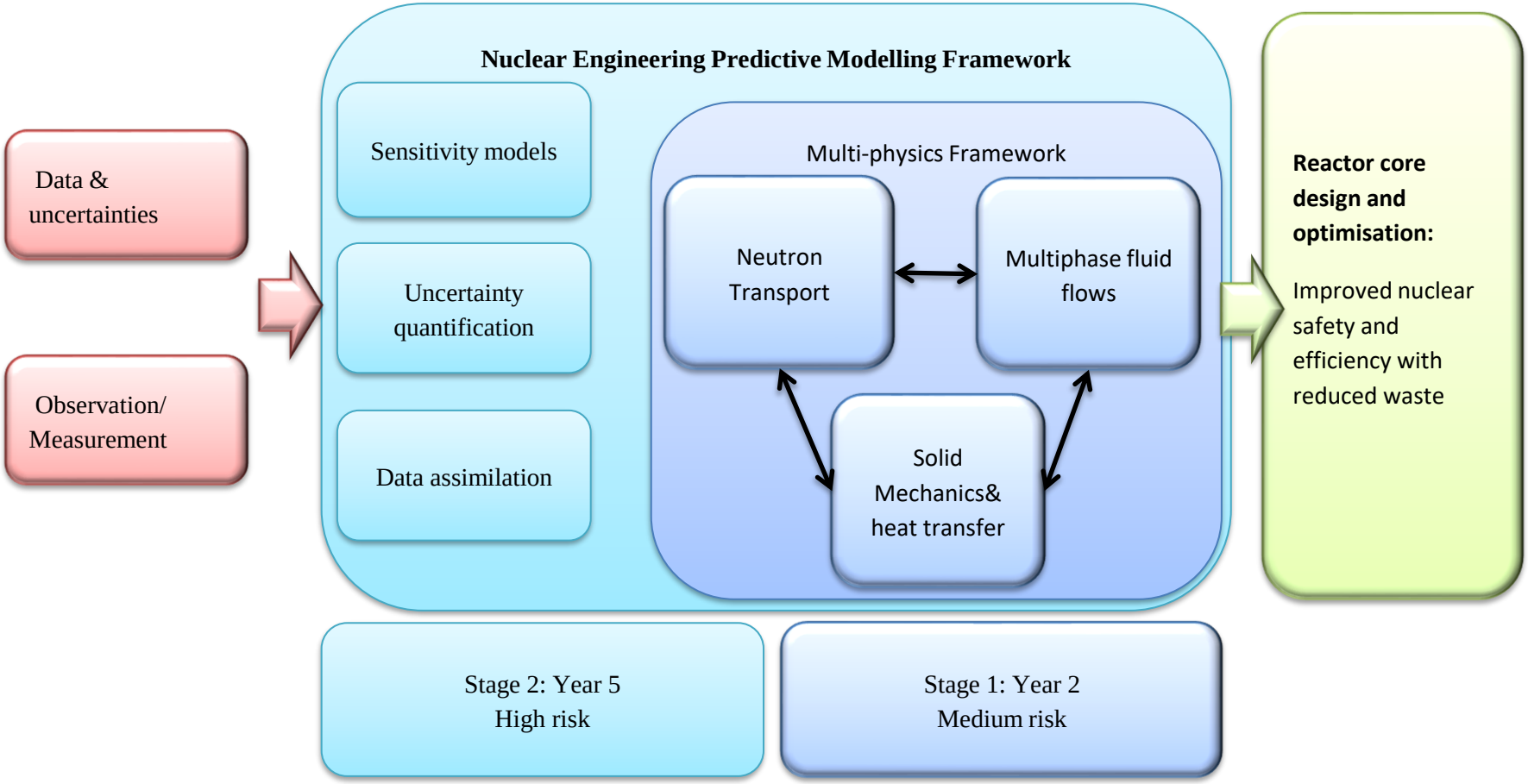
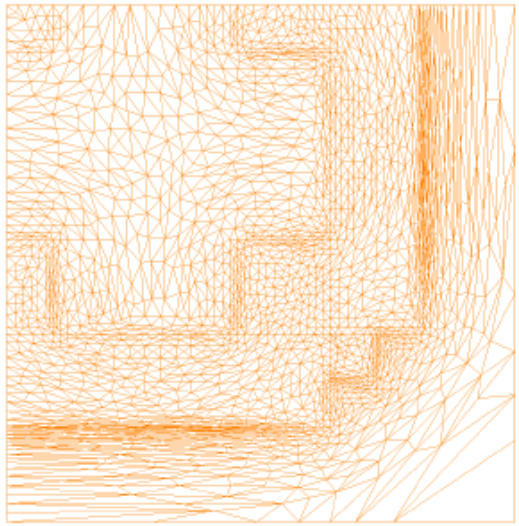
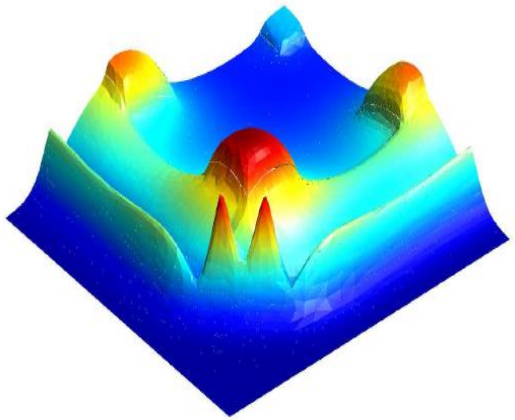
Outline of Presentation

- Overview of coupled physics modelling of radiation transport and fluid flow
- Neutron transport methods: mesh adaptivity, sensitivity analysis, reduced order models
- Coupled physics models: Reactor Physics, Environmental modelling , UVC disinfection
- Future directions
- Work uses several frameworks: FETCH, Wyvern and Firedrake – contributions from several institutions


Nuclear Engineering Predictive Modelling Framework
Data & uncertainties
Observation/ Measurement
Sensitivity models
Uncertainty quantification
Data assimilation
Multi-physics Framework
Neutron Transport
Multiphase fluid flows
Solid Mechanics& heat transfer
Reactor core design and optimisation:
Improved nuclear safety and efficiency with reduced waste
Stage 2: Year 5
High risk
Stage 1: Year 2
Medium risk

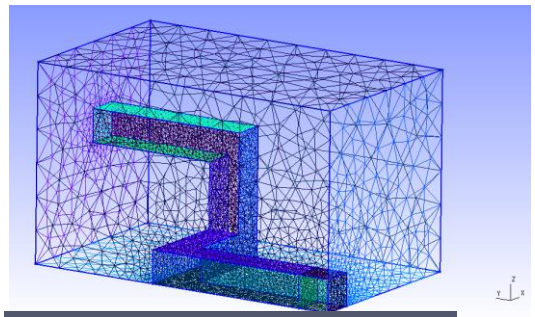
Neutron Transport Solver

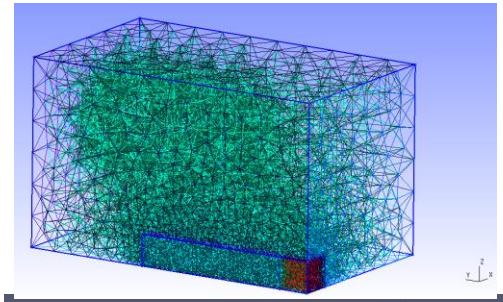


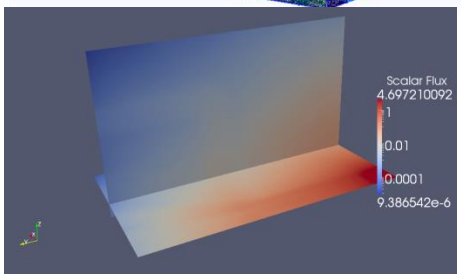


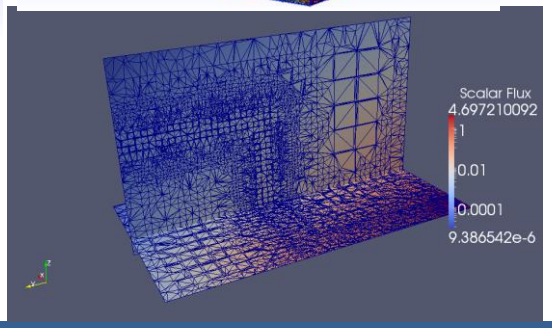
NT models: unique combination of advanced numerical methods:

- Adjoint-based Self adaptive resolution
- Adjoint sensitivity models
- Parallel solvers
- Reduced order models

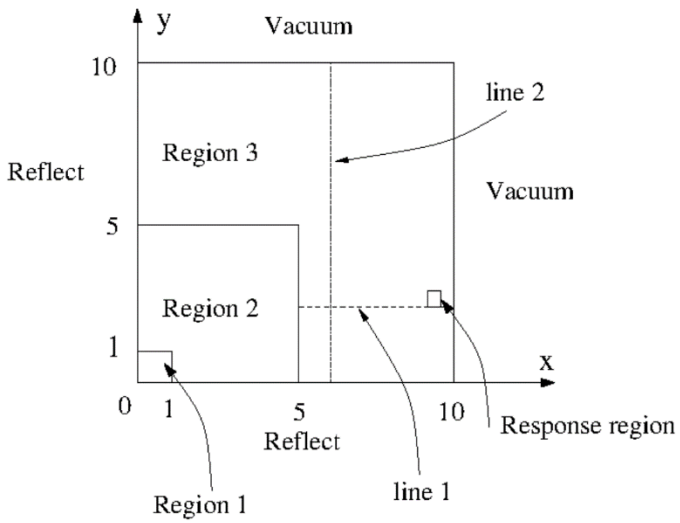


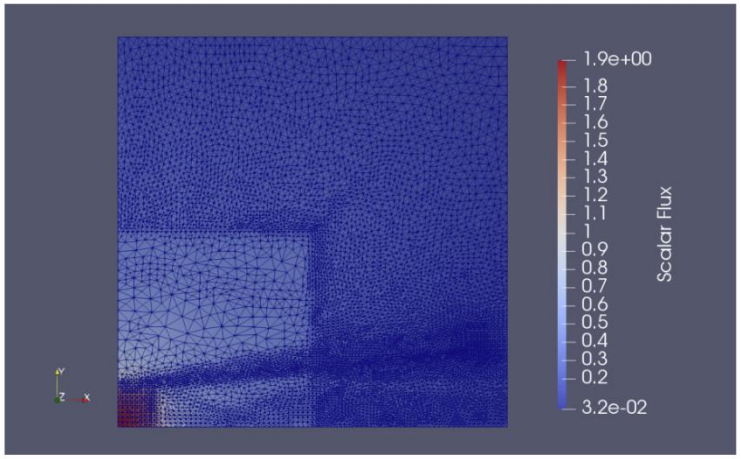




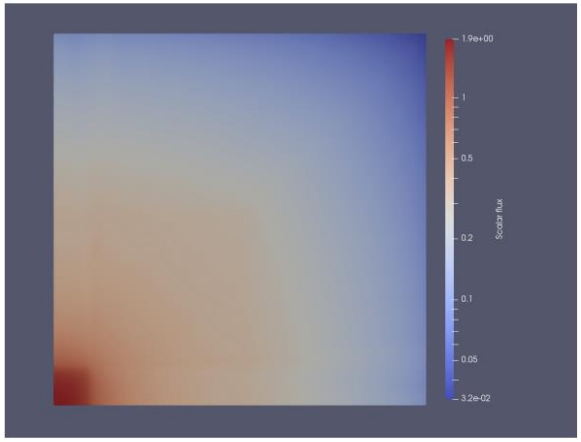


Adjoint Sensitivity & mesh Adaptivity

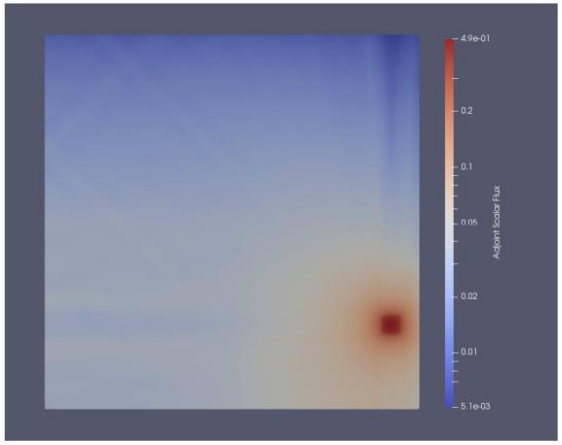




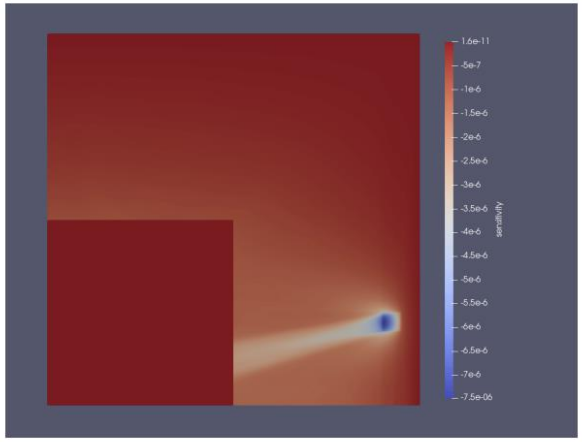
Adapted Mesh



Scalar flux

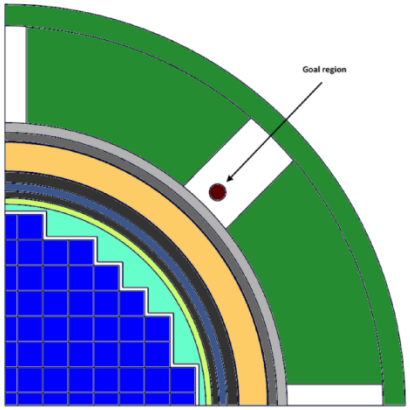


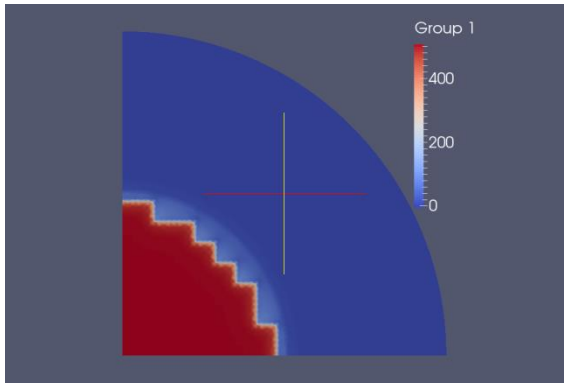
Adjoint Flux

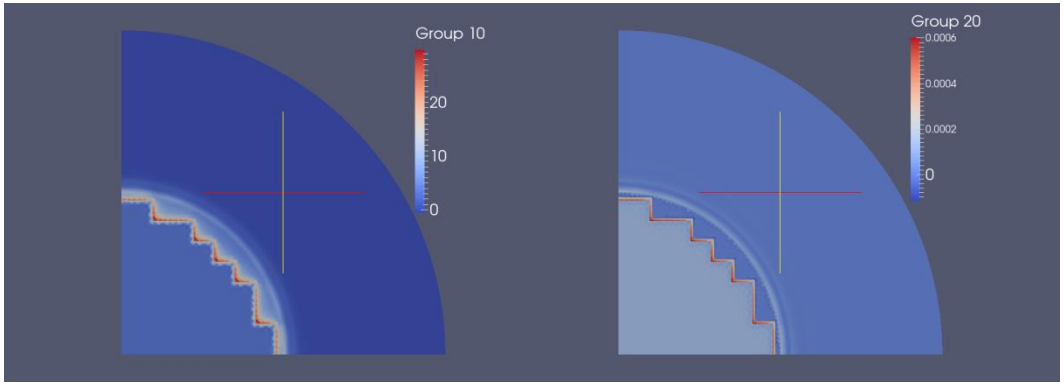


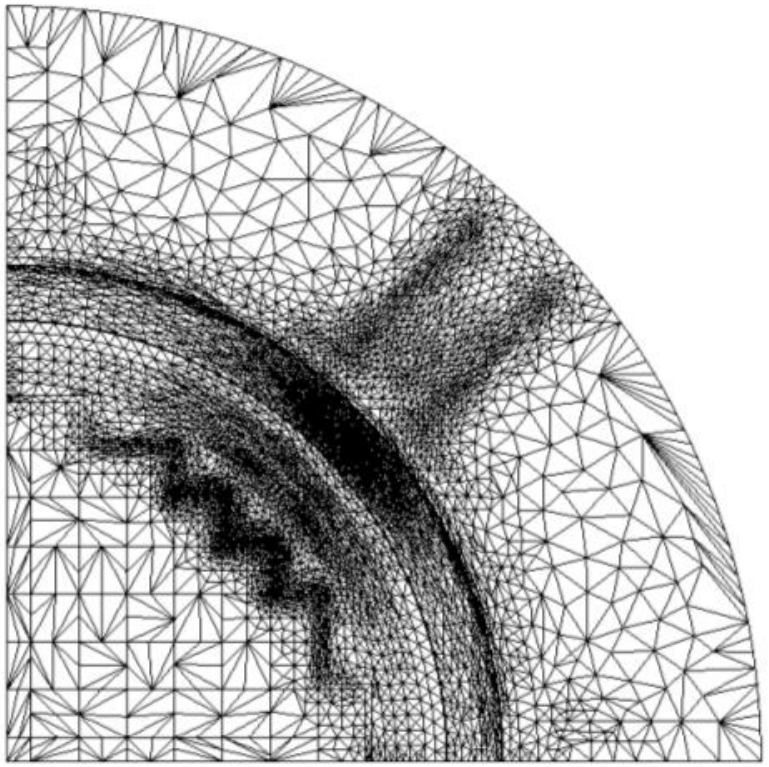
Sensitivity Map

Adjoint methods for Large Scale Problems



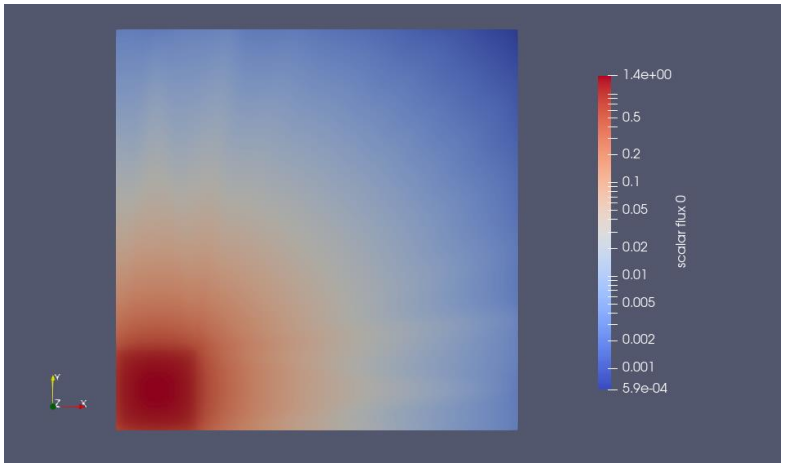


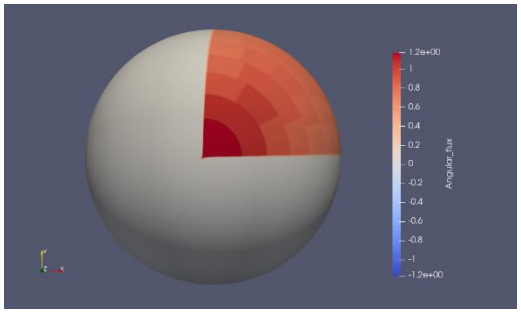


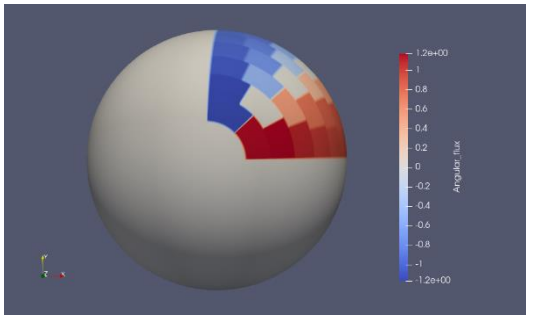


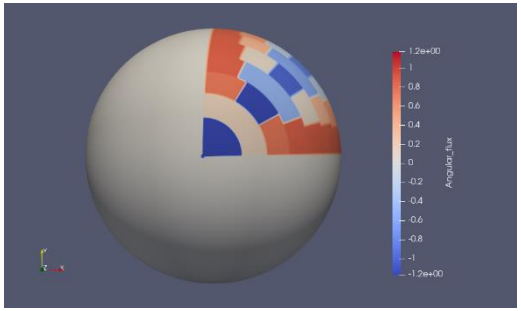
Reduced Order Models

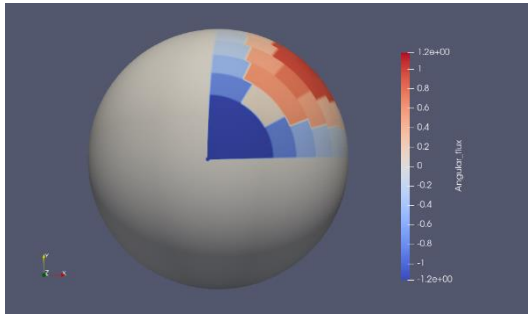
- BTE computationally expensive to solve
- Discretisations DOF: Angles = 1000s Space = 1000000s
- ROMs – form optimised basis functions – reduce DOF by orders of magnitude
- First Angular ROMs of NT







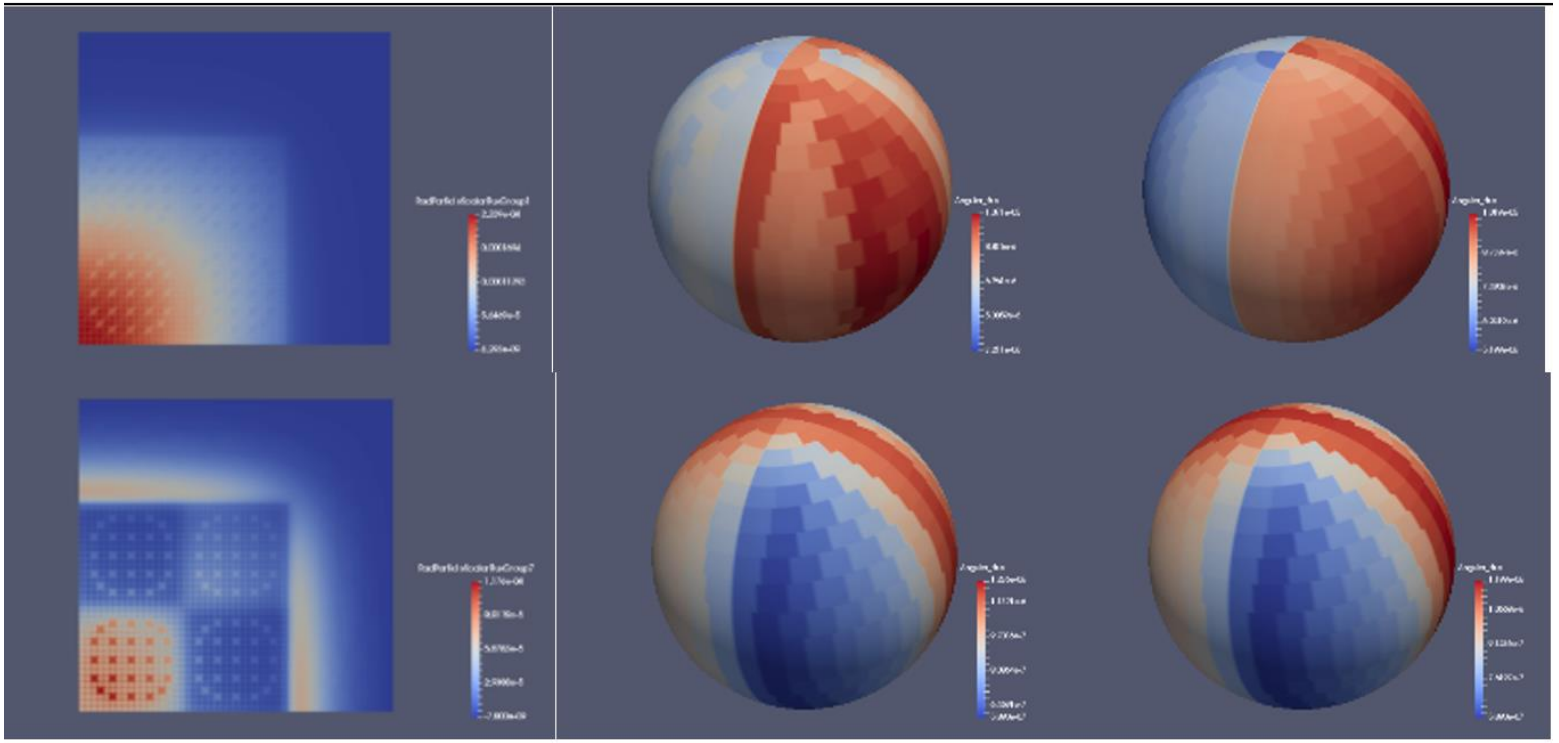




Reduced Order Models

Fast/thermal flux

Angular fluxes



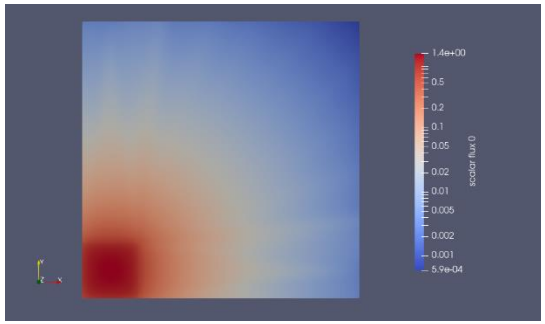
SN (< 200s)

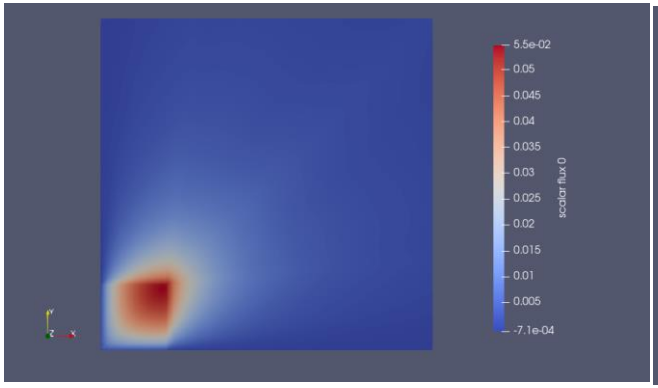
ROM (6)

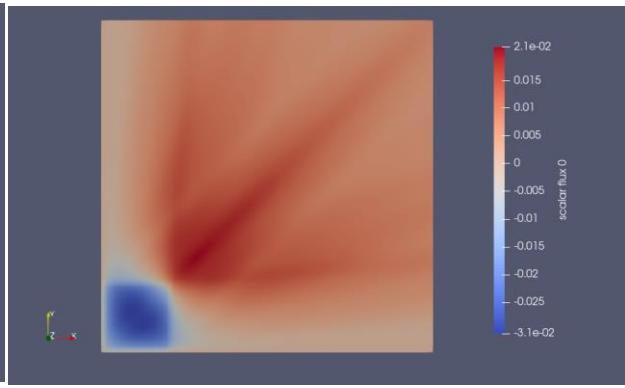
Typically 2 orders of size reduction

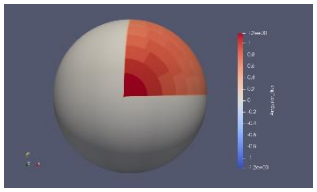
Space-Angle Reduced Order Models

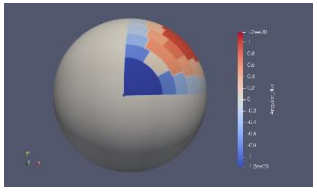
1. Spatial ROMs resolve spatial dependence of Angular ROMS
2. Further reductions in size – 6 Orders of magnitude

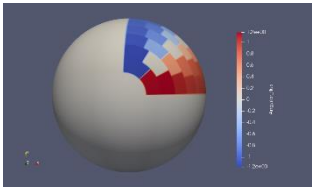


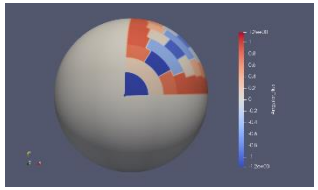


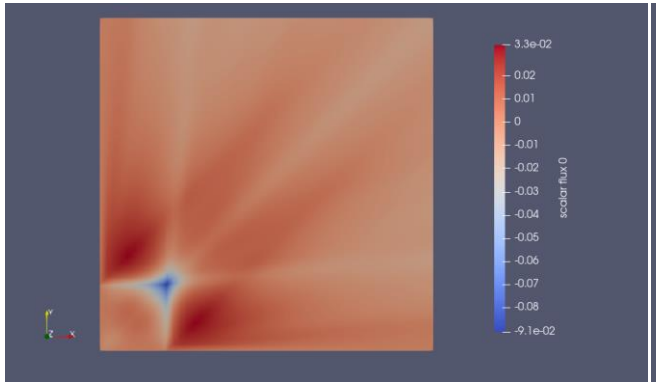


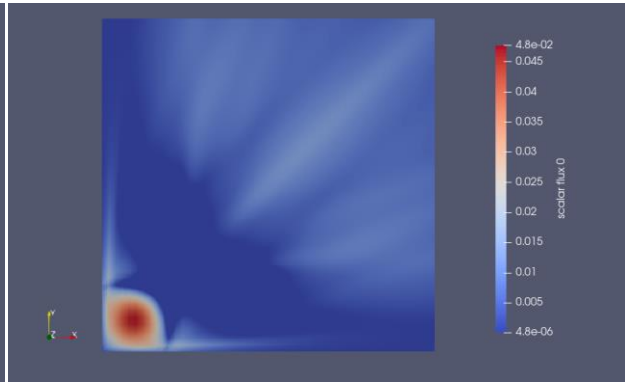




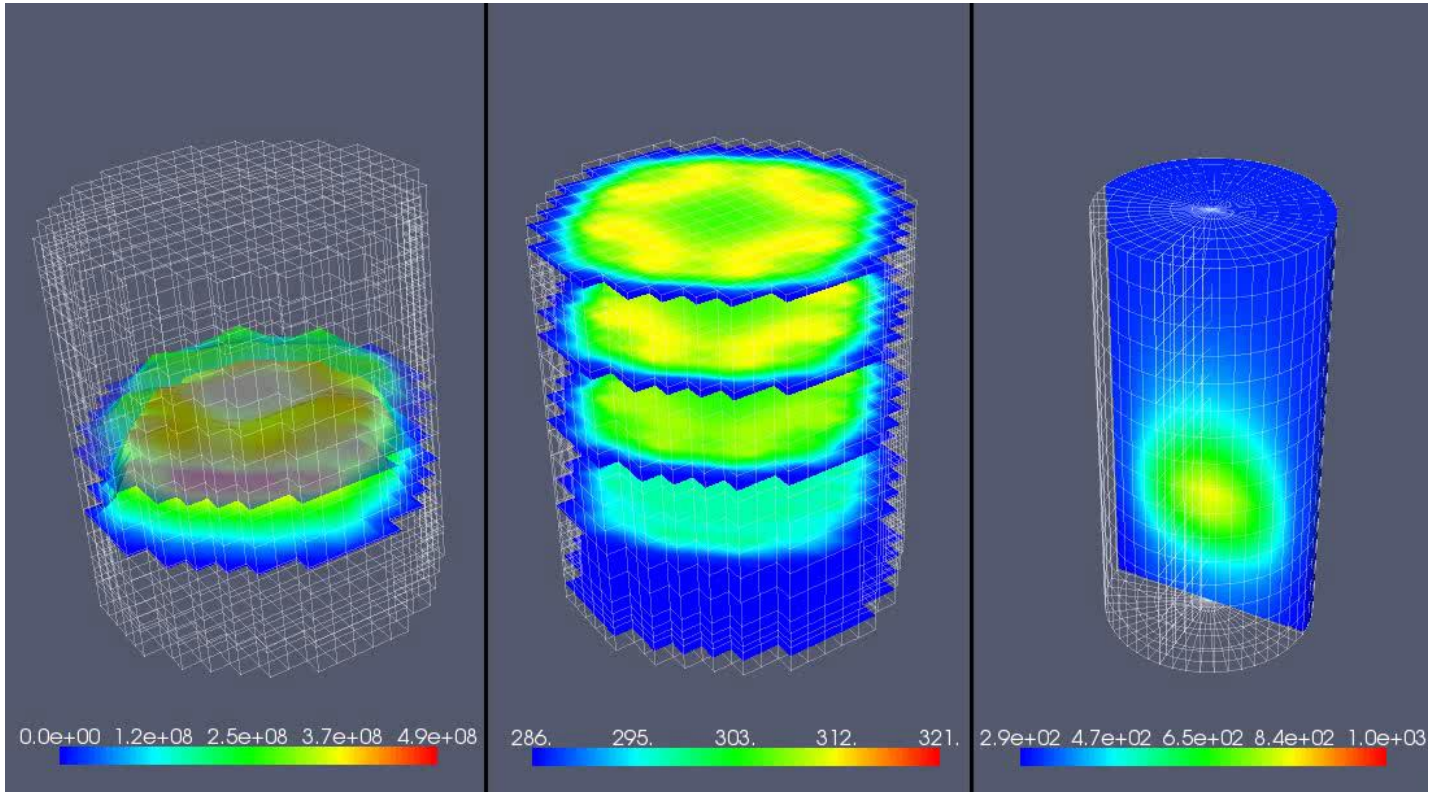




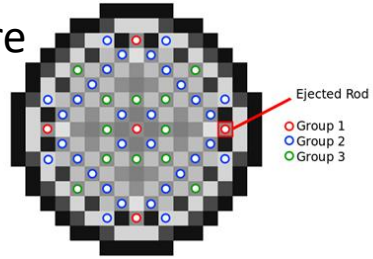




Simulated Control Rod Ejection

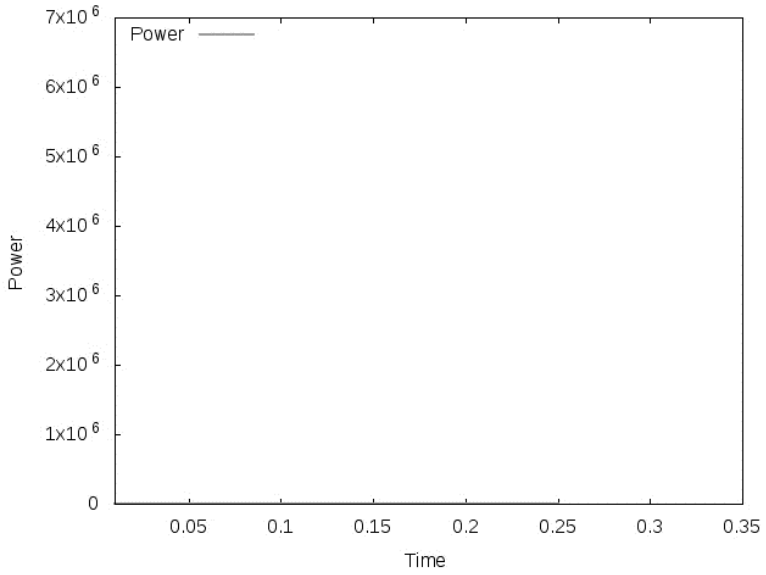


Power coolant temperature fuel pin temperature

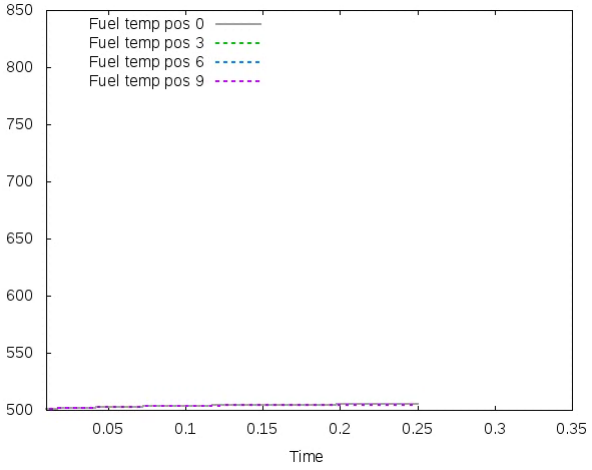


ROMs for Transients: Cold Slug Injection

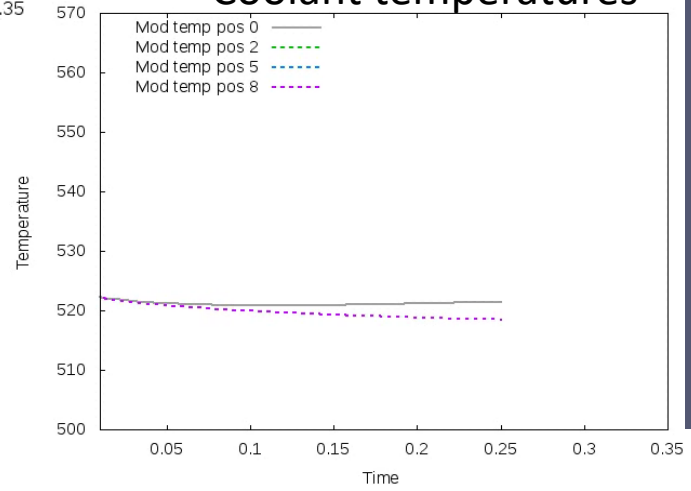
Power



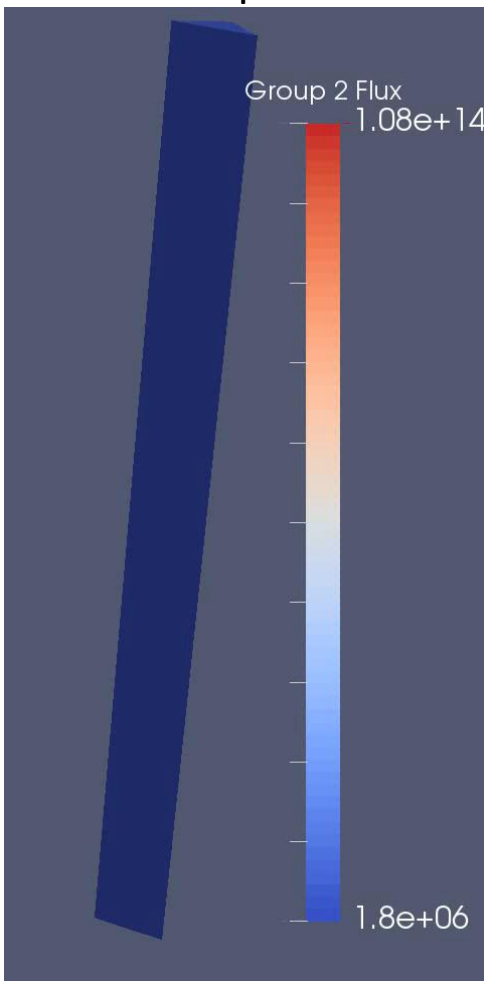
Fuel temperatures



Coolant temperatures

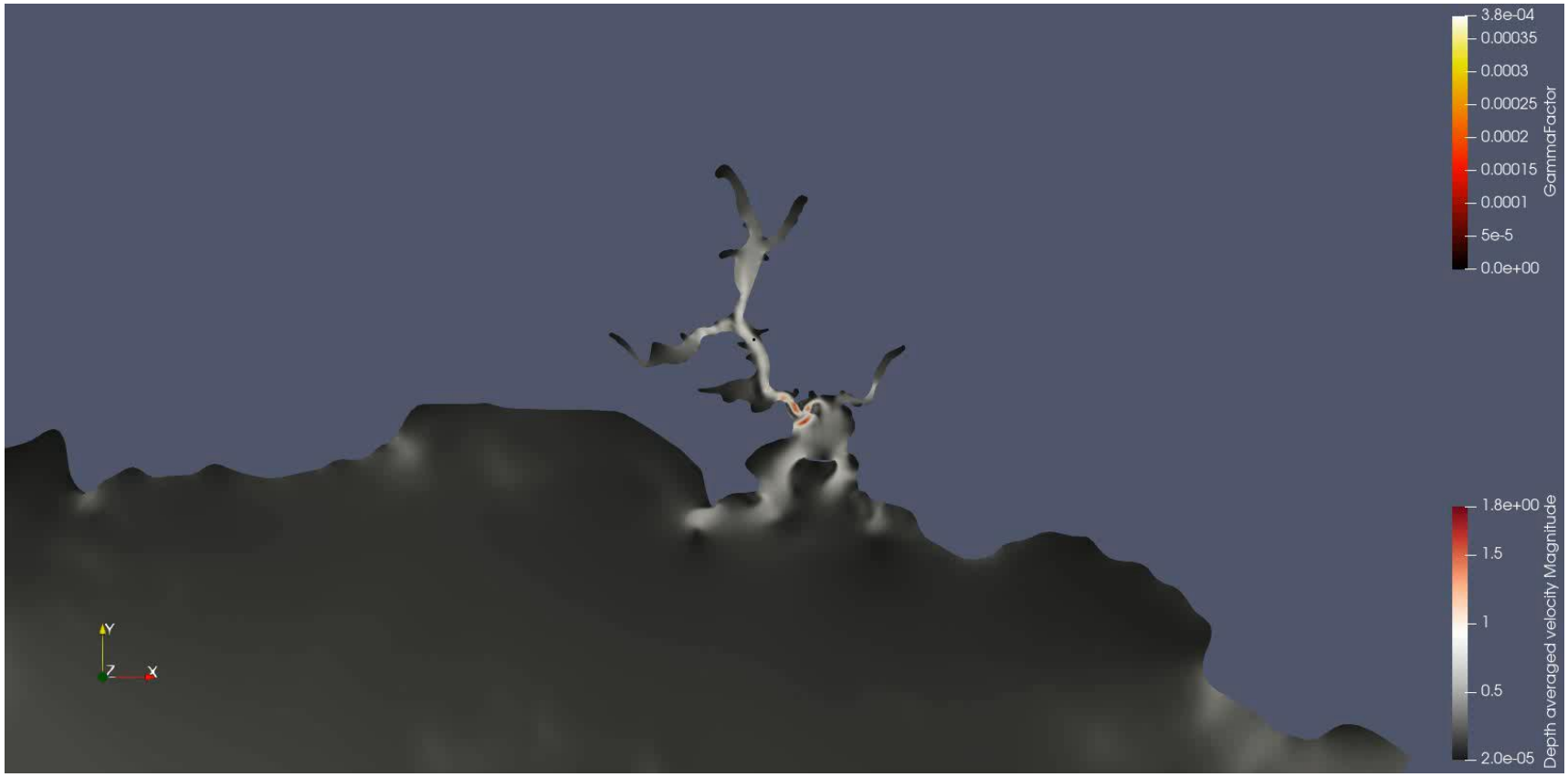


Group 2 Flux



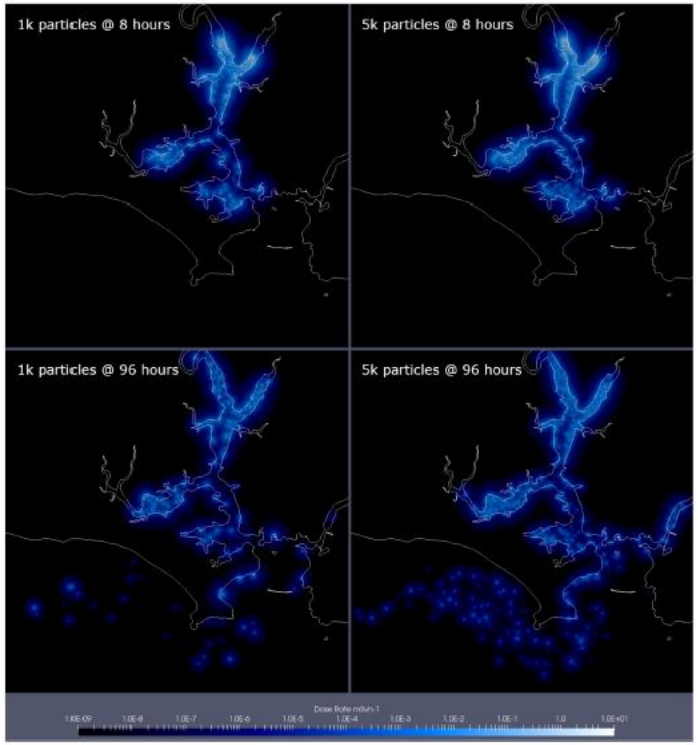
Transient simulation:
fixed control rods
Inlet coolant reduced by 15C at 200 seconds
This ROM simulations was computed in seconds!

Coastal modelling radionuclide release monitoring



A Little (HMS Sultan,ICL) coastal modelling of radioactive release
Firedrake – unstructured FEM, parallel solvers, adjoint sensitivity, particle modelling.

Gamma Shine dose calculatons



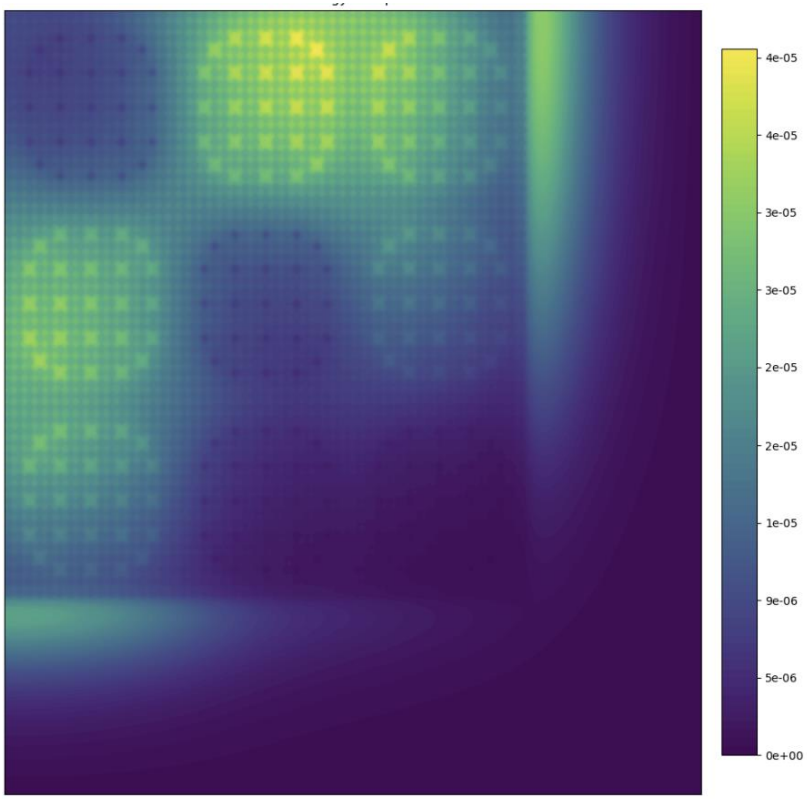
Track release dispersion – estimate gamma dose

Emergency response and managed release

Forming EPSRC proposal (managed release and accident predictions)

Looking for industrial partners (working with Sellafield, EDF, Fukushima university)

Future Directions



AI-Based Reactor Physics Modelling

QMUL-Imperial-Sheffield

- Multi-physics reactor modelling using AI tools throughout
- Optimised for all computing architectures
- AI-differentiation tools for sensitivity analysis
- Data-Assimilation, Uncertainty Quantification, Digital-Twin.