Coupling of SERPENT and OpenFOAM for MSR analysis

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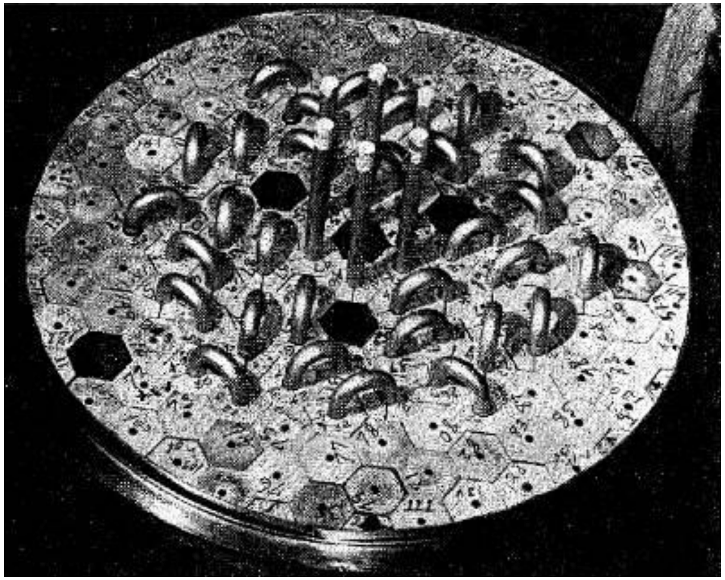
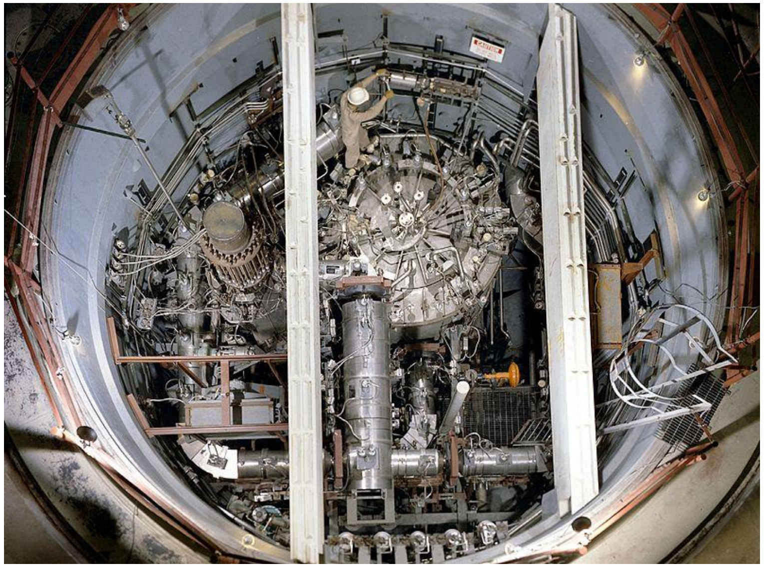
Industrial supervisor – Steve Curr, Rolls-Royce

Background

- Developed in the USA as a compact, low operating pressure system for aircraft propulsion
- Aircraft Reactor Experiment (ARE), 1954
- Molten Salt Reactor Experiment (MSRE), 1966-1969





[1] https://whatisnuclear.com/reactors/msr.html
[2] http://www.daretothink.org/europe-evols-molten-salt-fast-reactor/

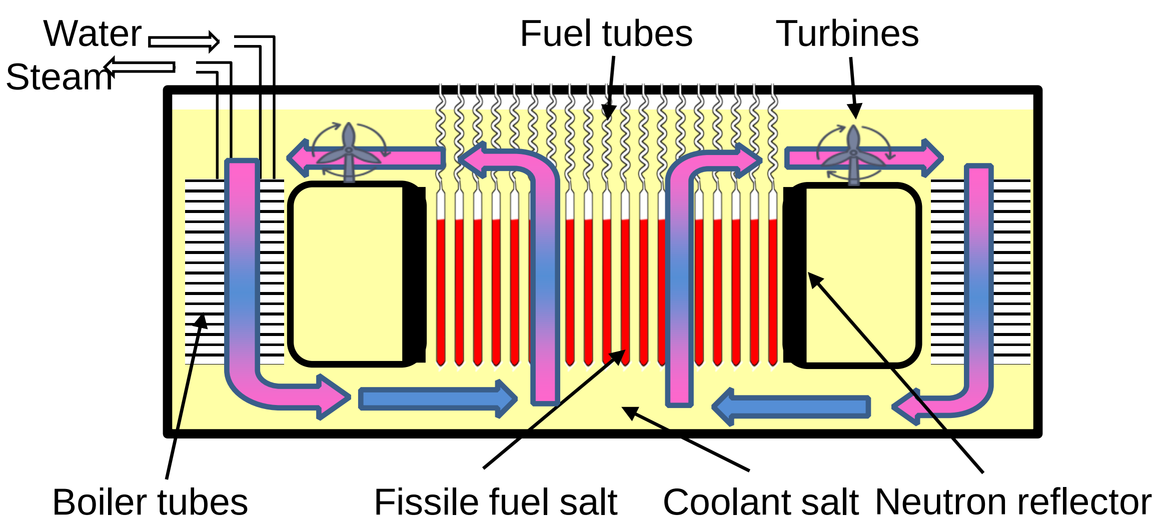
MSRs

- Operate at close to atmospheric pressure
- Molten salt provides an effective coolant
- Continuous removal of poisonous fission products
- Additional fissile material could be introduced

Two designs are considered during this project:

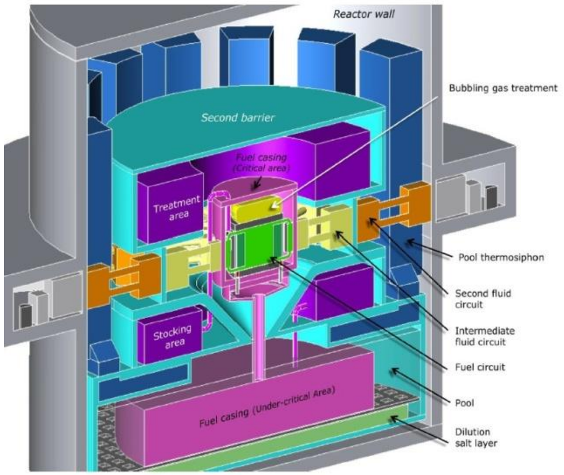
SSR

(Stable Salt Reactor, 3.5 m core radius)



MSFR

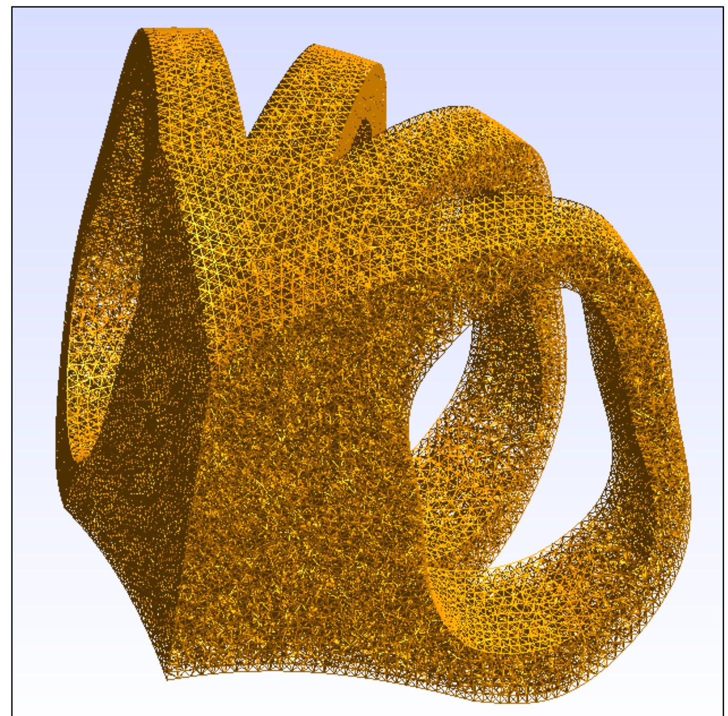
(Molten Salt Fast Reactor, 1.25 m core radius)



MSFR

- MSFR is a concept design designed at EVOL*
- Breeder reactor
- Drain tanks are used as a safety mechanism
- Continuous online refuelling
- No internal mechanisms

Fuel salt is LiF–ThF4–UF4
Fuel salt density is 4.3 g/cm3
Core radius 1.25 m
Core height 2.5 m



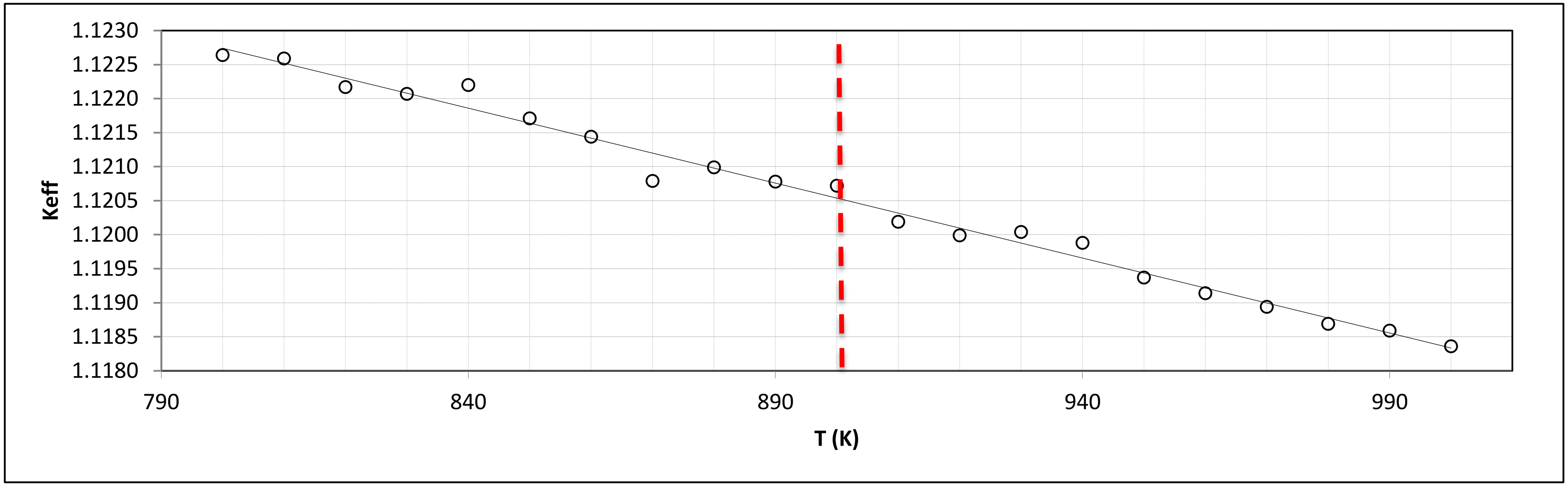
One quarter of MSFR model

*Evaluation and viability of liquid fuel fast reactor system

MSFR

MSR modelling issues

- Liquid fuel salt changes its physical properties with temperature (density, thermal conductivity, etc.);
- This in turn influences the rate of heat production;
- Hence a need for coupled neutronics and thermal-hydraulics analysis.



Average operating temperature = 900K

Software

Salome

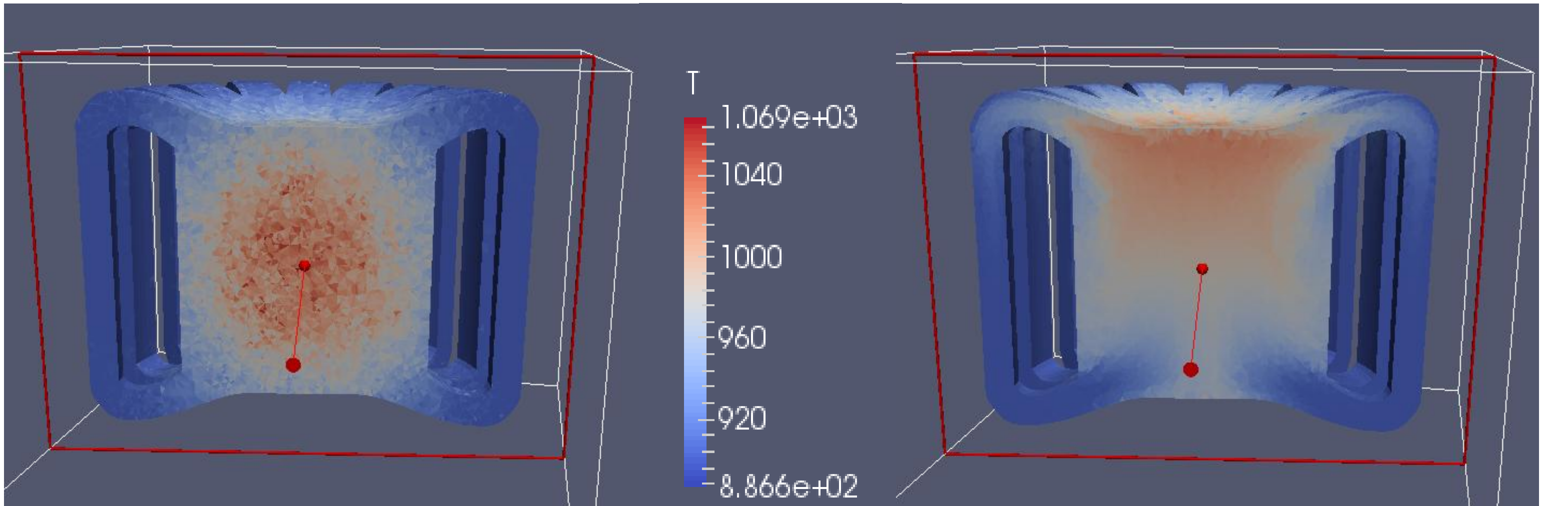
- an open-source software which provides a generic platform for Pre- and Post-Processing for numerical simulation;
- Enables to accurately represent complex geometries;
- Provides the potential for future alteration and optimisation of core shape.

OpenFOAM

- an open source CFD software package and has been previously coupled with SERPENT code for similar analysis.

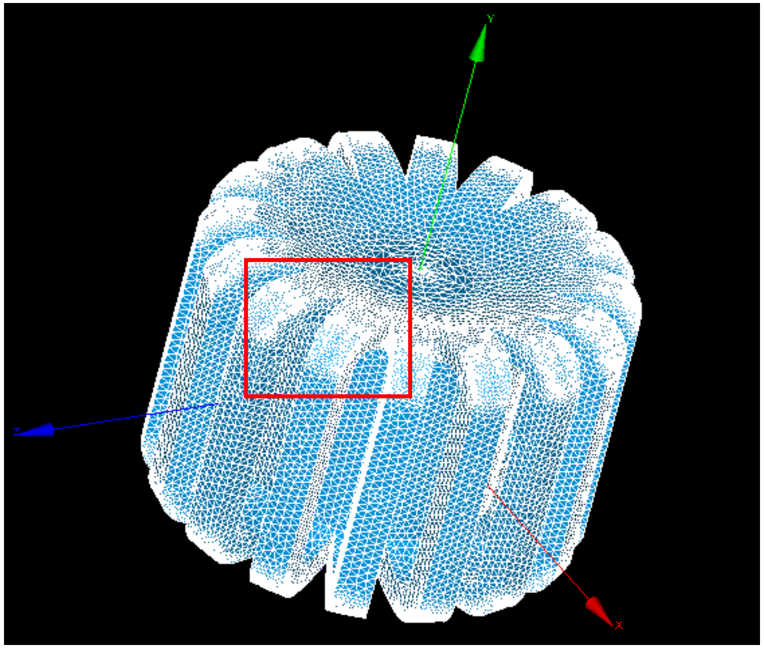
SERPENT

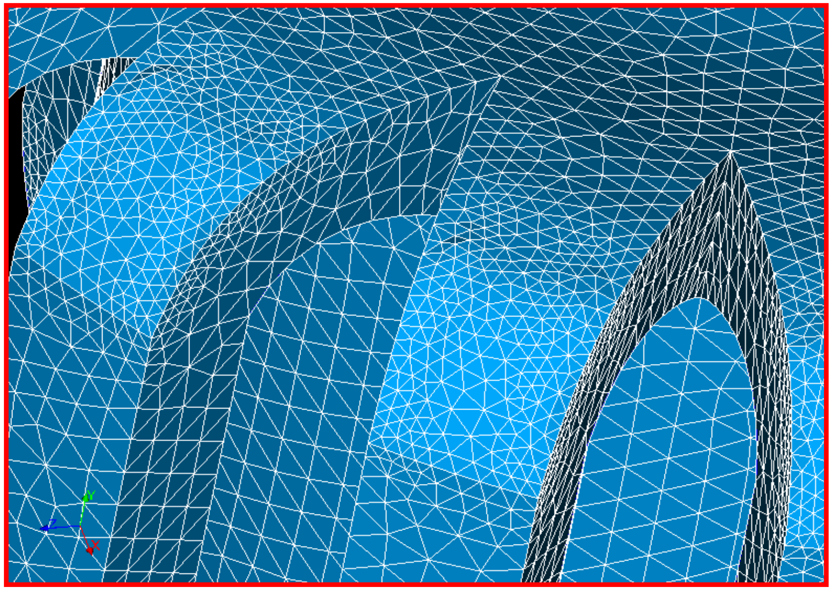
- an open-source three-dimensional continuous-energy Monte Carlo reactor physics burnup calculation code.



MSFR. Model

- The tetrahedral mesh was used as the one that allows to be incorporated in OpenFOAM solver and SERPENT neutronics code.
- Average Δx=0.011m.

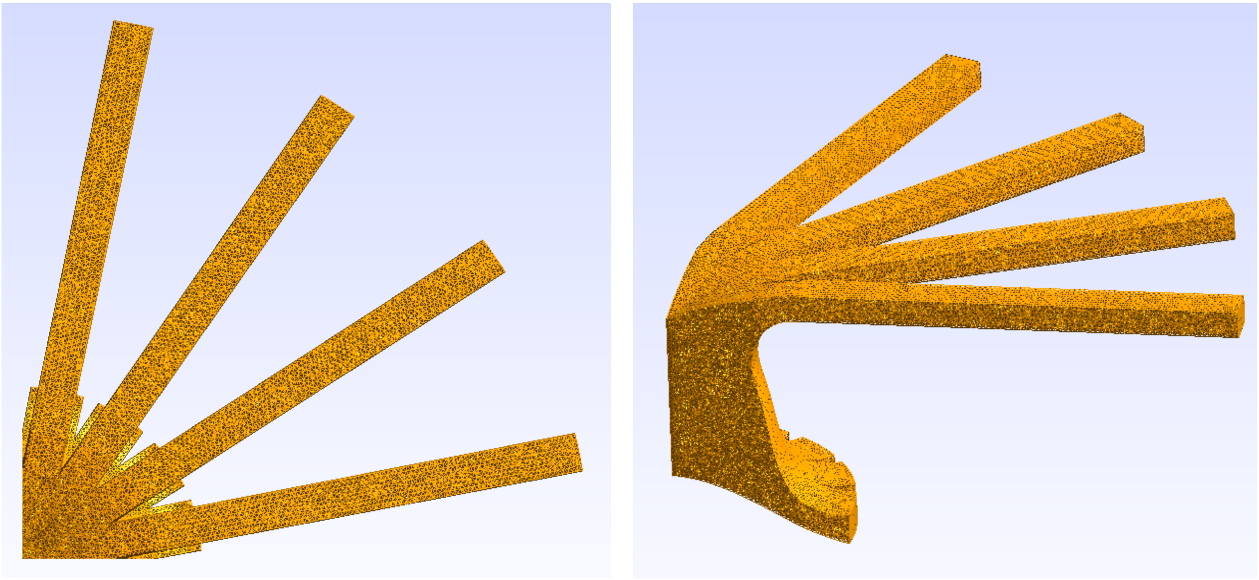




MSFR model in Salome

MSFR. Model

- In further analysis ¼ of MSFR core is modelled.
- The heat exchangers are represented as channels pointing outwards and act as a black box (the inlet temperature is always at 900K).



MSFR mesh models

MSFR. Model

- GMSH demonstration

MSFR. CFD

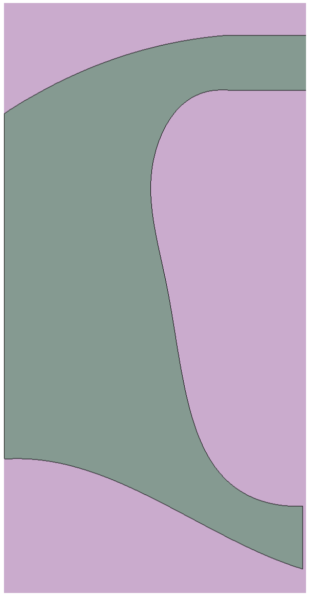
- Based on the physical proprieties of the fuel salt and short time-scales a standard OpenFOAM salver called buoyantBoussinesqPimpleFoam was chosen.

- **buoyantBoussinesqPimpleFoam** is a transient solver for buoyant, turbulent flow of incompressible fluids.

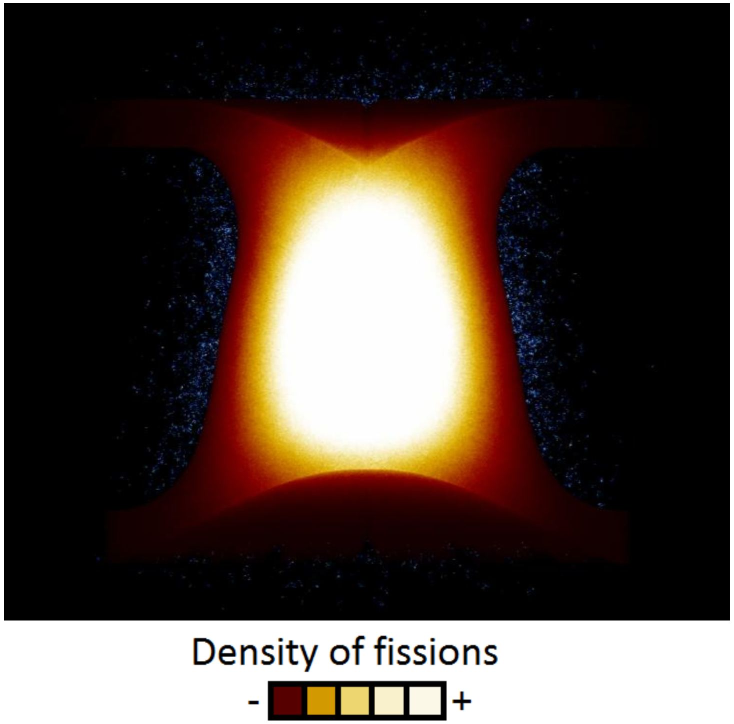
- According to the description of the fuel salt physical and dynamical properties, Re number was obtained (Re=**747,245.9**) and the flow was estimated to be turbulent.

MSFR. Neutronics

SERPENT geometry is created with the aid of multi-physics interface, and uses the same mesh as OpenFOAM.
The mesh has 234,795 tetrahedrons.



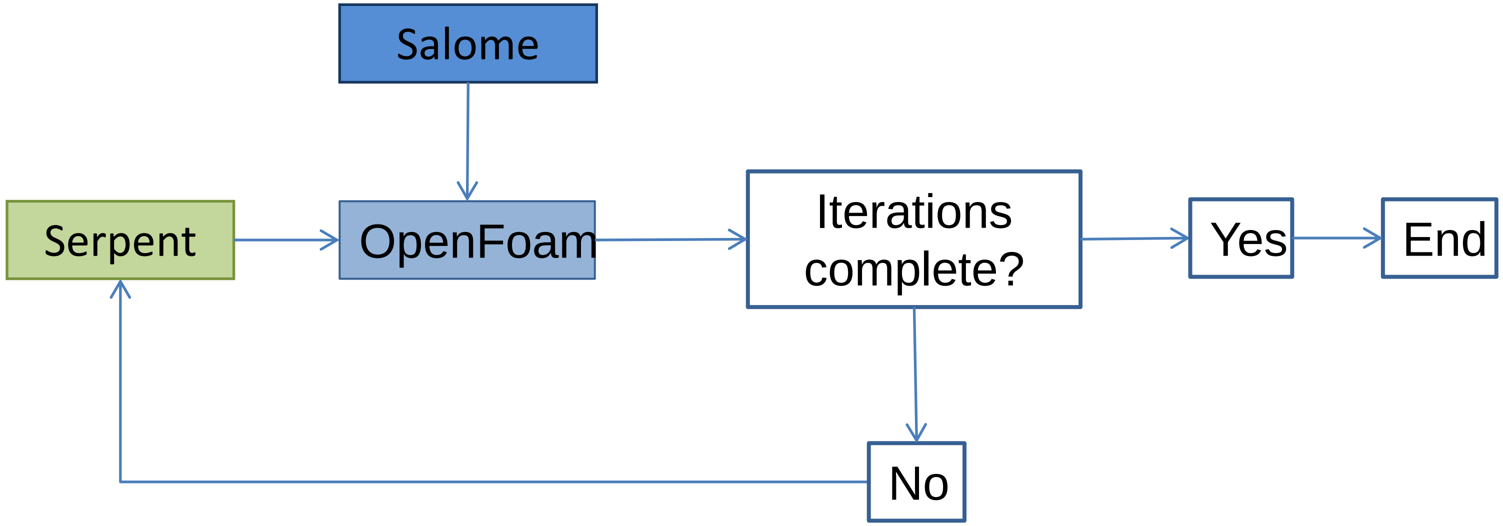
MSFR Serpent model



Fission distribution in MSFR core

MSFR. Coupling

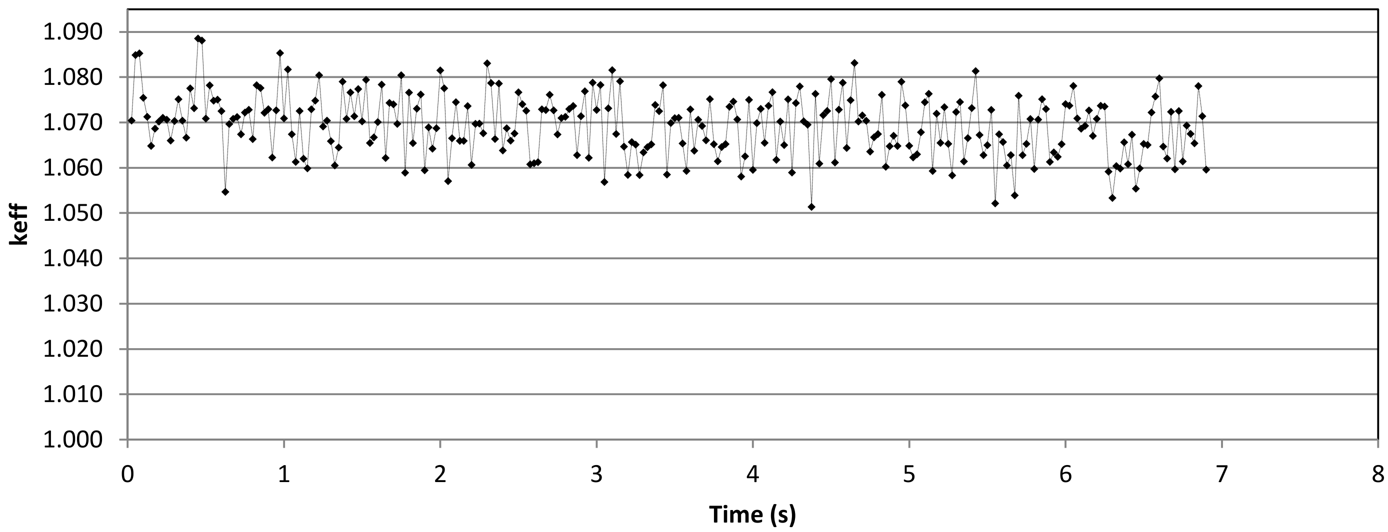
- Coupling Serpent with OpenFoam would enable thermal feedback on neutronics calculations;
- Fuel burnup is taken into account;
- Script is under development.



MSFR. Coupling

The method allows to obtain the following outputs:

- power distribution across the mesh;
- temperature, density and pressure values as well as velocity vectors for each cell, etc.;
- k_{eff} variation with time.

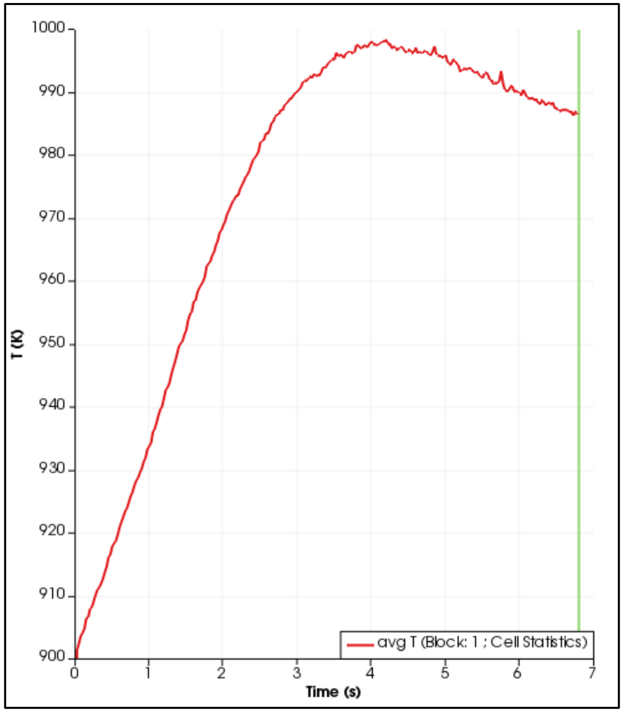


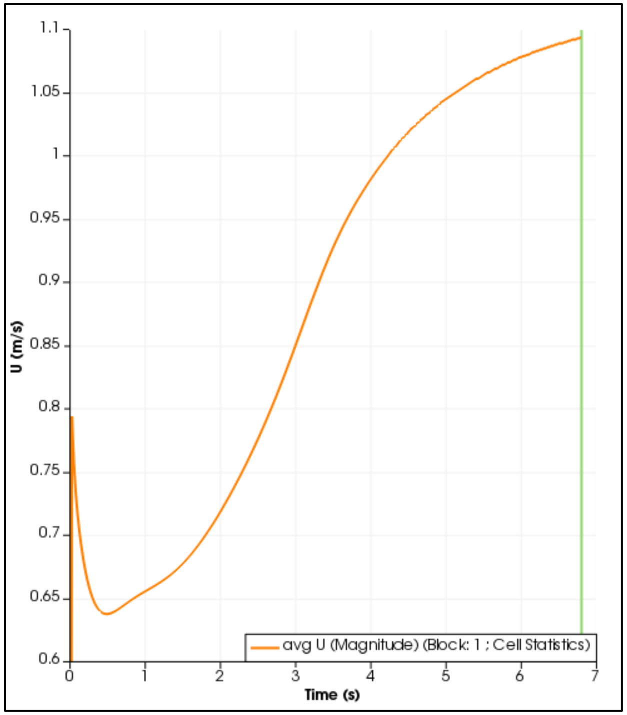
k_{eff} variation vs operating time

MSFR. Coupling

Video demonstration

- Temperature
- Velocity





Further work

- Code optimisation to make it more applicable for other reactor models;
- Optimisation of the iteration loop;

- Estimate steady-state temperature allocation and optimise core geometry if necessary;
- Perform burnup analysis with the new temperature allocation and compare it to neutronics only analysis;
- Accident scenario simulations.

Thank you for your attention!

- Thanks to Rolls-Royce

- Special thanks to

  Prof. Tim Abram

  Seddon Atkinson (Sheffield)