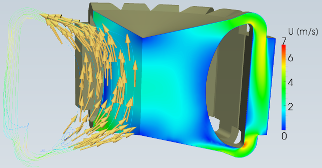
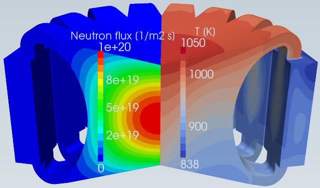
Atelier Sûreté-MSFR
Grenoble, France,
24 – 25 Nov. 2014

# A simplified benchmark for MSFR modelling tools

# Simulation tools for the MSFR




- Legacy reactor physics codes are not suitable for MSFR steady-state and transient analysis
- (Unfortunately) the development of new tools is required
- These new tools should be tested/verified/compared

# Code development in the EVOL project

Several multiphysics tools have been developed, adopting a variety of approaches:

- Neutronics
  - Deterministic (mainly few-group diffusion)
  - Monte Carlo
  - Hybrid (e.g., fission matrix)
- Spatial-discretization
  - Finite-volume
  - Finite-element
  - ...
- Time-integration/coupling
  - Explicit
  - Implicit (Euler, BDF, RK, ...)

# Code development in the EVOL project

- Code availability
  - Open source-based (e.g., OpenFOAM, SERPENT, ...)
  - In-house (TUDelft, KIT Karlsruhe, ...)
  - Commercial (COMSOL, FLUENT, ...)

  - 2D $(r, z,)$ codes
  - Fully 3D codes
  - Parallel computing capabilities ?

**How should we test/verify/compare the different tools?**

Results of the EVOL CFD benchmark and comparisons among the partners highlighted differences for steady-state and transient simulations.

Several suspects have been identified:

- Nuclear data libraries
- Delayed neutrons data
- Turbulence models
- Geometrical domain approximations
- Coarse mesh discretization
- ...

Impossible to verify the consistency of the results of the different tools!

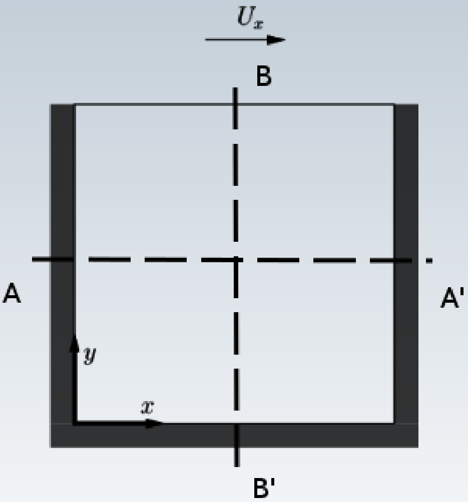
# How should we test/verify/compare the different tools?

## A possible solution

**Definition of a simplified benchmark for the MSFR simulation tools.**

Let's get rid of any OTHER source of discrepancies:

- Prescribed nuclear data library (e.g., JEFF-3.1.1)
- Few-group cross-sections provided
- Simple 2D geometry
- No turbulence
- Cartesian discretization




Dimensions: 2m x 2m.

# Simplified benchmark for the MSFR simulation tools

Material composition:

- Flibe (LiF + $BeF_2$ at 2:1). Natural Li enrichment
- $^{235}U$ as fissile

High neutronics similarity with the MSFR in terms of:

- Reaction rates ratios (similar neutron spectrum)
- $k_{inf}$, dominance ratio

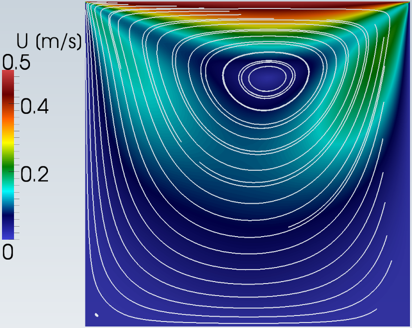
## Phase-0 Single-physics verification

- Step-0.1 Velocity field
- Step-0.2 Neutronics
- Step-0.3 Temperature field

## Phase-1 Steady-state coupling

- Step-1.1 Circulating fuel
- Step-1.3 Power coupling
- Step-1.5 Buoyancy
- Step-1.7 Full coupling

## Phase-2 Transient simulations




Velocity $U_x$ imposed at the top boundary of the square 2D cavity.
Viscosity increased to have stable laminar solution.

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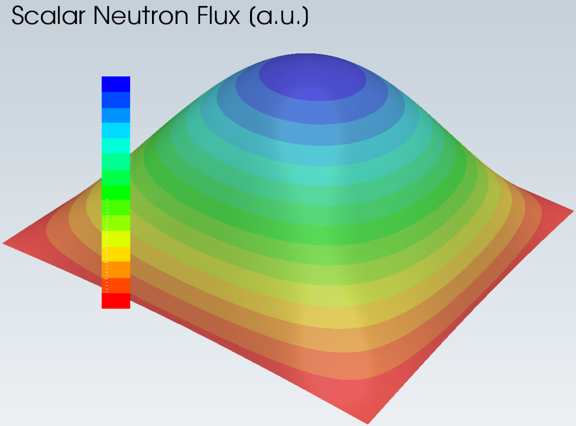
# Step-0.2 Scalar neutron flux distribution




Vacuum boundary conditions.
Very small spectrum change from the center to the boundaries.

## Phase-0 Single-physics verification

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- Step-0.3 Temperature field

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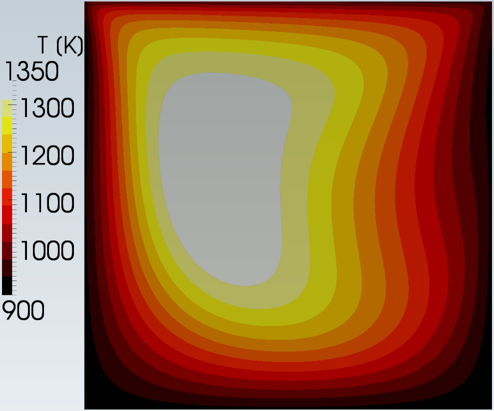
## Phase-2 Transient simulations

# Step-0.3 Temperature field




Heat source distribution from Step-0.1.
Velocity field from Step-0.2.
$q'' = h \cdot (T - T_{cold})$ $T_{cold} = 900K$.
Thermal conductivity 1 $W/m \cdot K$.

**Phase-0** Single-physics verification

- Step-0.1 Velocity field
- Step-0.2 Neutronics
- Step-0.3 Temperature field

**Phase-1** Steady-state coupling

- Step-1.1 Circulating fuel
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- Step-1.5 Buoyancy
- Step-1.7 Full coupling

**Phase-2** Transient simulations

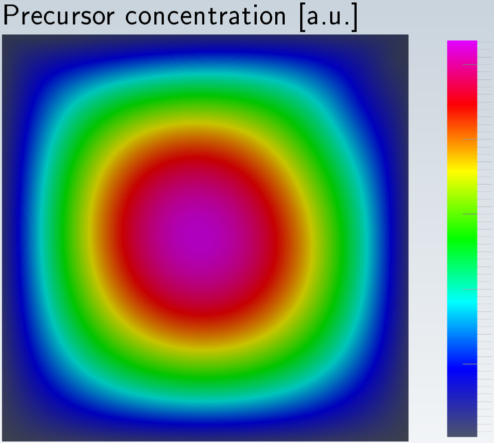
**Is the effect of delayed neutron precursors motion correctly taken into account?**

**Main "observable": DNP distributions & $\beta_{\text{eff}}$ decrease**

Fixed velocity field (Step-0.1)
Uniform fuel temperature ($900K$)

# Delayed neutron precursors distribution of the Step-1.1

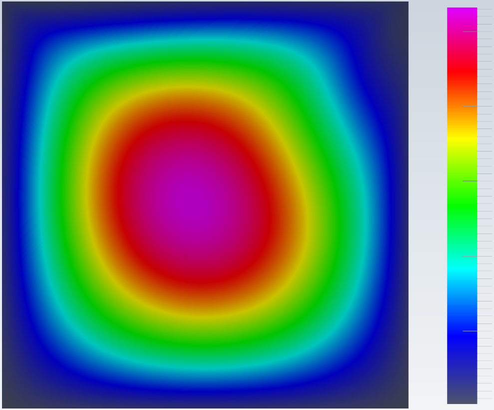
## $8^{th}$ DNP family, $\lambda \sim 3.55 s^{-1}$



# Delayed neutron precursors distribution of the Step-1.1

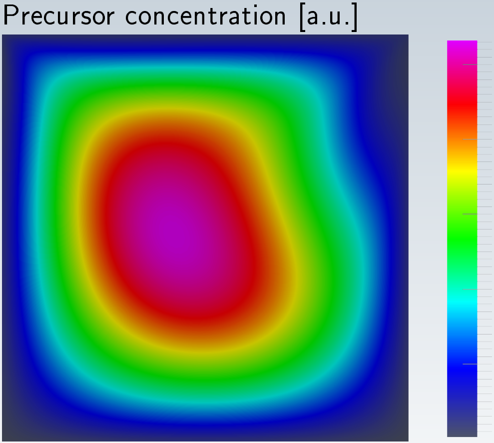
$7^{th}$ DNP family, $\lambda \sim 1.63 s^{-1}$

Precursor concentration [a.u.]



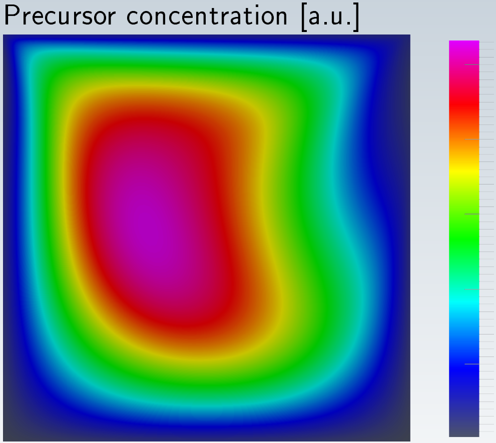
# Delayed neutron precursors distribution of the Step-1.1

## $6^{th}$ DNP family, $\lambda \sim 0.67 s^{-1}$



# Delayed neutron precursors distribution of the Step-1.1

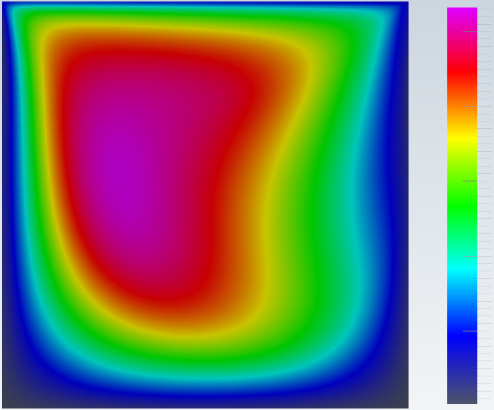
$5^{th}$ DNP family, $\lambda \sim 0.29 s^{-1}$



# Delayed neutron precursors distribution of the Step-1.1

$4^{th}$ DNP family, $\lambda \sim 0.13s^{-1}$

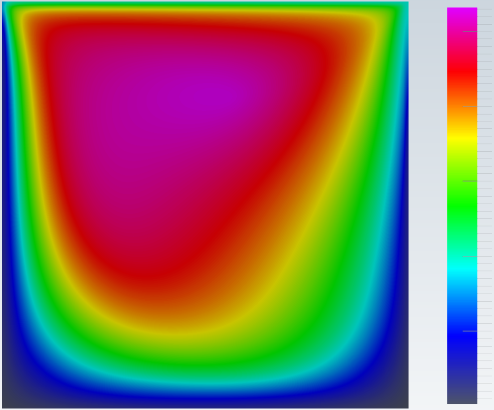
Precursor concentration [a.u.]



# Delayed neutron precursors distribution of the Step-1.1

## $3^{rd}$ DNP family, $\lambda \sim 0.042 s^{-1}$

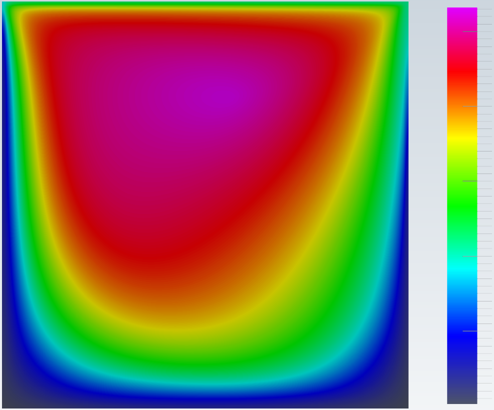
Precursor concentration [a.u.]



# Delayed neutron precursors distribution of the Step-1.1

$2^{nd}$ DNP family, $\lambda \sim 0.028s^{-1}$

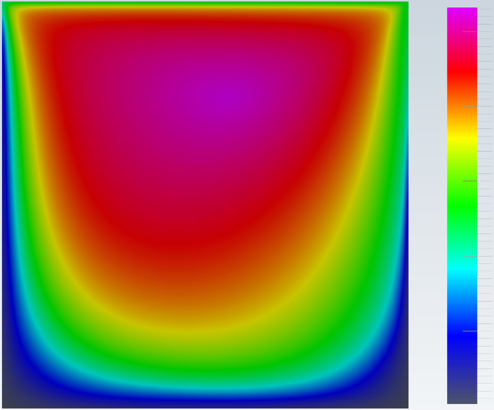
Precursor concentration [a.u.]



# Delayed neutron precursors distribution of the Step-1.1

$1^{st}$ DNP family, $\lambda \sim 0.012 s^{-1}$

Precursor concentration [a.u.]



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## Phase-2 Transient simulations

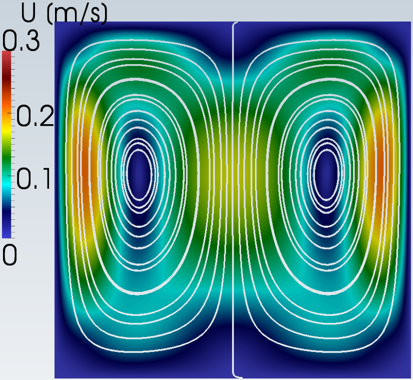
# Step-1.1 "Buoyancy" (two-way coupling)

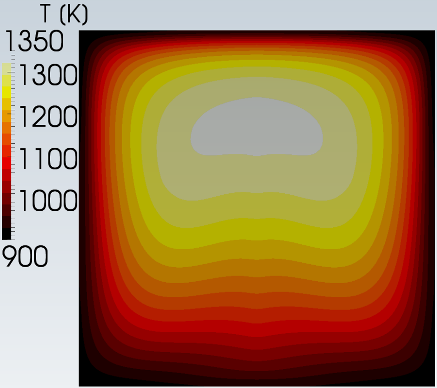
**Is the system behaviour under natural circulation correctly predicted?**

Main "observable": velocity field & reactivity decrease

# Step-1.1 "Buoyancy" (two-way coupling)

## Temperature and velocity fields




Constant fuel volumetric expansion coefficient ($2 \cdot 10^{-4} K^{-1}$).

## Phase-0 Single-physics verification

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## Phase-2 Transient simulations

- Step-2.X Work in progress...

**Suggestions?**

# Summary

A simplified benchmark for MSFR modelling tools is under development

Main goal: test the capabilities related to the MSFR peculiarities (fuel motion and strong multiphysics couplig)

“NON-goal”: provide yet another benchmark for stand alone, “single-physics” CFD or neutronics codes

# THANK YOU FOR THE ATTENTION

Vue sur l'agglomération Grenobloise depuis le sommet du Moucherotte (Bertrand93)

# QUESTIONS? SUGGESTIONS? NEW IDEAS?