FISA 2013

European Commission

EU2013.LT

EDUCATION SCIENCE RESEARCH

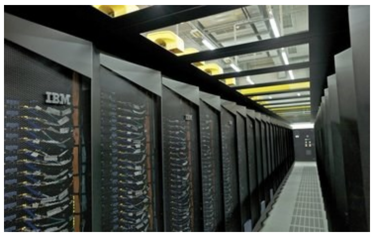
# Advanced Numerical Simulation for Reactor Safety

- Numerical simulation tools used for the design and safety evaluation of NPP are under continuous **development**, **improvement** and **validation**.

SNETP
Sustainable Nuclear Energy Technology Platform

- Goals of the SNETP for 2020:
  - maintain safety and competitiveness in fission technology
  - provide long-term waste management solutions
- A key challenge:
  - Development and consolidation of integrated simulation platforms for current and future fission reactor designs.
- Some EU initiatives for R&D in reactor safety:
  - SNETP, Horizon 2020 and NUGENIA

- Supercomputer century, new tools available (TOP 500)





- In FP7, ambitious projects were launched to develop powerful simulation platforms for reactor multi-physics analyses

- **NURESIM platform**
  - NURISP and NURESAFE projects

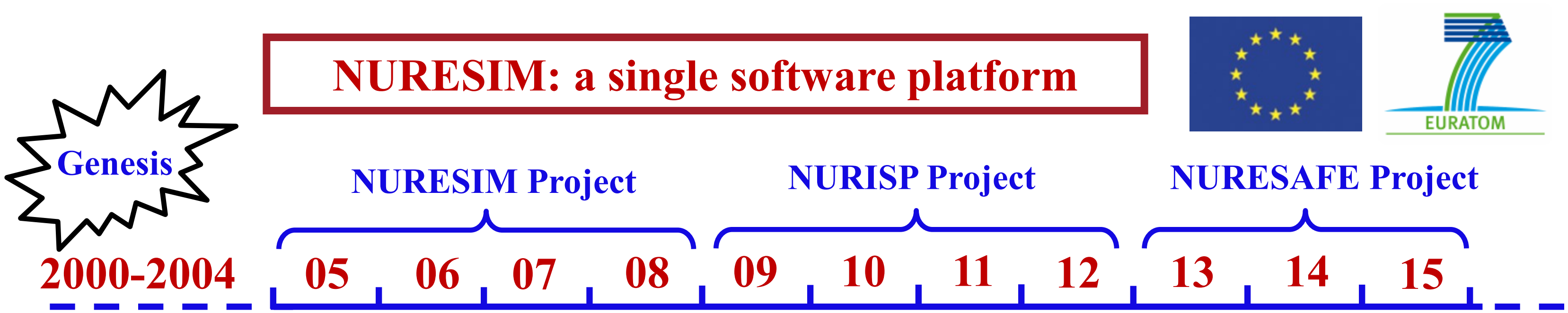
- **HPMC project**

- **THINS project**

- NURESIM project established the basic architecture of the NURESIM platform and resulted in a first prototype of a truly integrated multi-physics simulation environment.

- The NURISP project was conceived as a consolidation of the platform plus an extension towards higher-resolution both in space and time.

- The NURESAFE project will show the extended capabilities of the platform and demonstrate the readiness of the tool for Industrial safety applications.



# NURESAFE objectives:

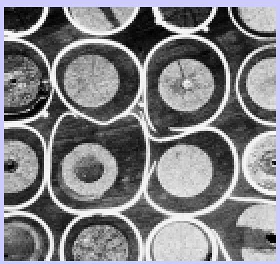
- To develop the NURESIM Software Integrated Platform
  - Includes core-physics, thermal-hydraulics, fuel thermo-mechanics
- For simulation of LWR
  - PWR incl. VVER, BWR
  - Normal operation and design basis accidents
- A reference platform
  - Includes state-of-the art codes, well validated
- A Common European development
  - 23 partners contributing (Research centers, Universities, industry)

# The NURISP-NURESAFE process

| Breakthroughs in reactor modeling | Integration into the NURESIM platform | Simulation of challenge situation targets |
|---|---|---|
| CFD modeling: coupling ITM and phase averaged models, heat tranfer modeling…. | generic environment for code coupling, data processing ➔ cost effective | Safety relevant |
| Neutron transport: two level PIJ-MOC scheme | SALOME open-source platform | Multiphysics |
| Dynamic local fuel thermomechanics behaviour | Easy coupling with uncertainty quantification (Uranie) | Multiscale |
| Core physics: explicit pin-by-pin, at least at the hotspot | | Higher fidelity simulation of MSLB, BWR ATWS, LOCA, PTS, RIA,………………….. |

# Selected results from NURISP: Thermomechanics

**LOCA simulation**: Development of a complete set of models for the numerical simulation of dispersed flow film boiling regime at a CFD scale



PHEBUS LOCA TEST
View of ballooned zones

During LOCA reflooding phase :

Specific thermohydraulic effects in the ballooned core area

➔ Flow deviation around the balloons

➔ Modification of heat transfers

Core Coolability = SAFETY CHALLENGE

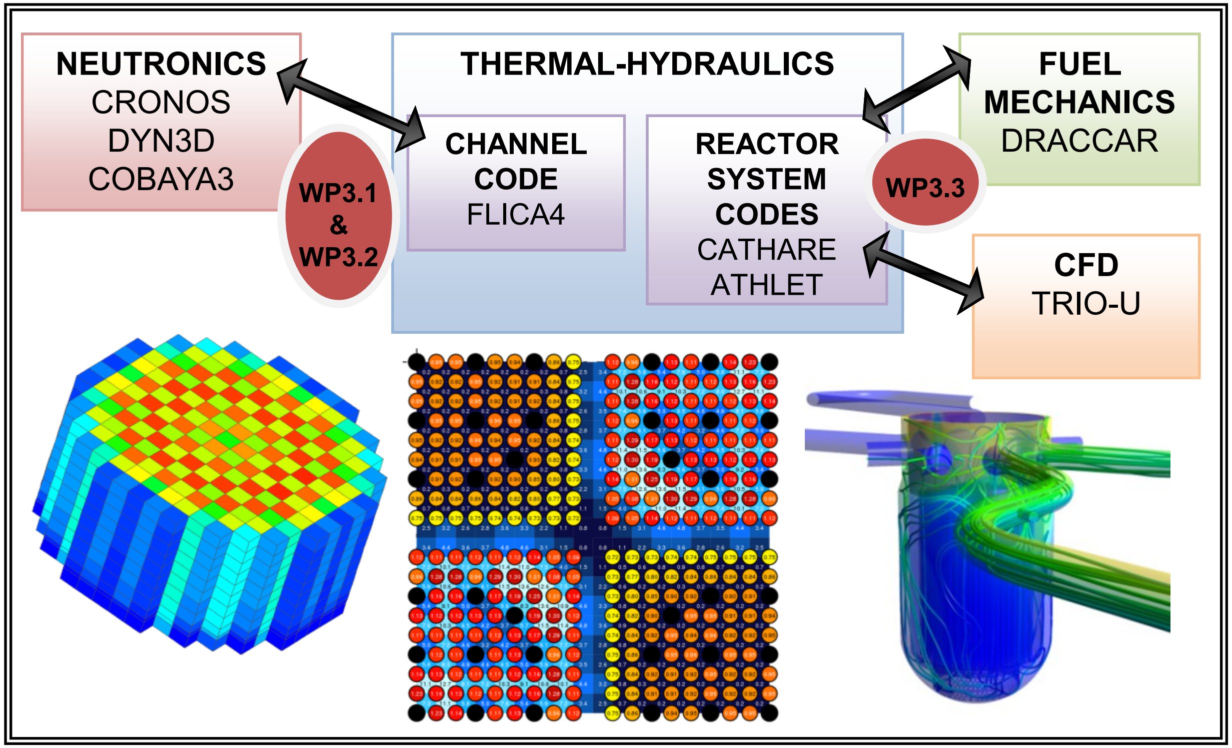

➔ Development of a **coupling** between **thermomechanics** and **thermal-hydraulics** codes

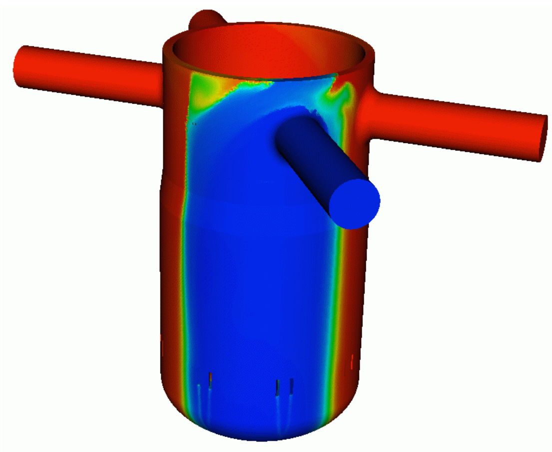
➔ Improved modeling of **dispersed flow film boiling** at CFD scale including:

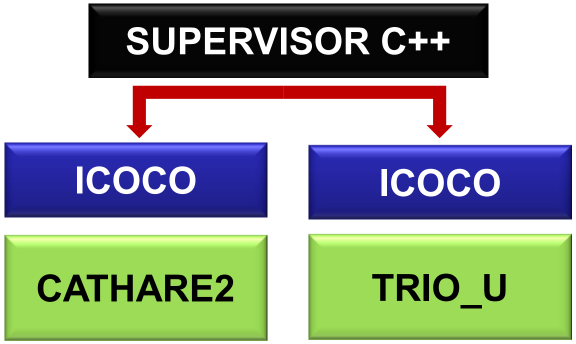
Radiative heat transfer
Droplet size evolution and dynamics
Heat transfer at drop impact

# Selected results from NURISP: Multi-Physics

**Multi-physics and multi-scale coupling**: Development of a coupling standard involving: Interpolation procedures, data communication, temporal schemes, ...

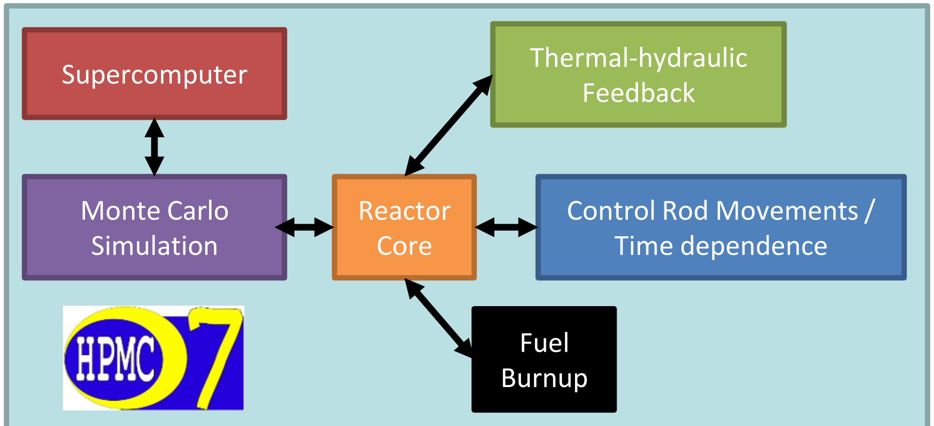




# HPMC (High Performance Monte Carlo Reactor Core Analysis) 1.10.2011- 30.9.2014

- **Main goals:**
  - Improved coupling with thermal-hydraulics
  - Optimized depletion calculations
  - Time dependent Monte Carlo
  - Use of High Performance Computing techniques
- **HPMC will deliver:**
  - Reference solutions for fuel assembly and cores simulations of any kind of reactor types
  - High-fidelity whole core solutions for safety demonstration



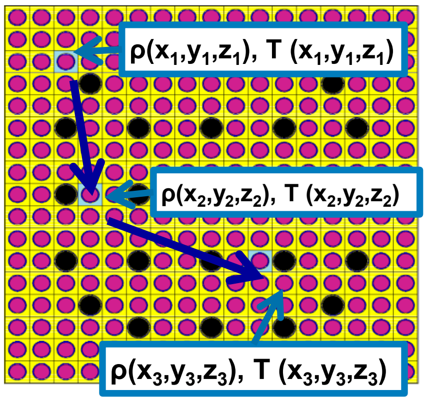

**HPMC: Elements of advanced Monte Carlo Thermal hydraulic Core Simulations**

## HPMC Main Simulation Tools:

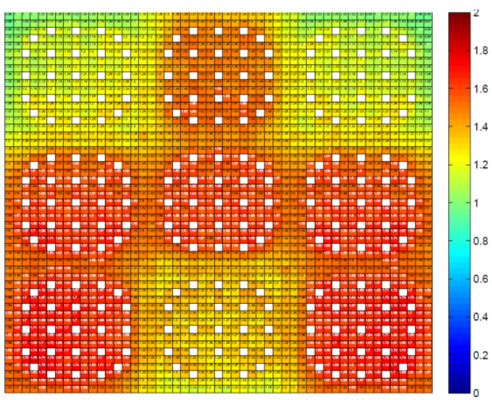
- Monte Carlo Codes: SERPENT, MCNP
- TH Codes: SUBCHANFLOW, FLICA4
- Coupled MC/TH Code Versions:
  - Internal coupling:
    - KIT: MCNP/SUBCHANFLOW
  - External coupling:
    - DNC: MCNP/SUBCHANFLOW
    - KIT: PIRS System (Python based Coupling of MCNP/SERPENT and SUBCHANFLOW)

# Selected results from HPMC:

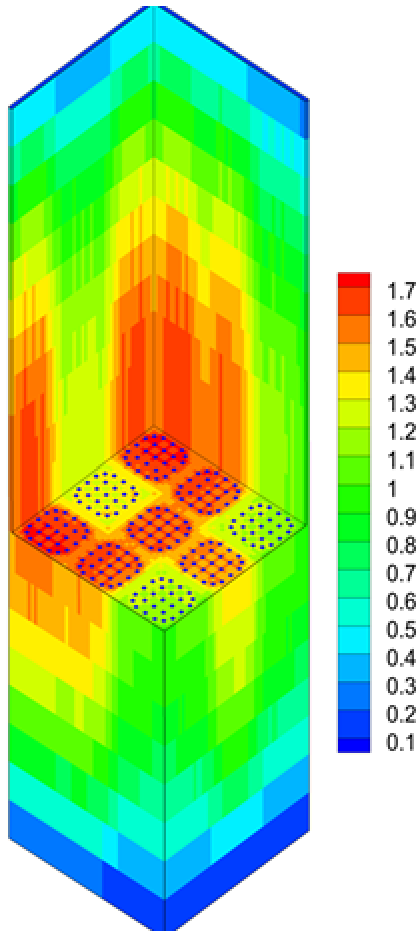
## *High Fidelity MC/TH Coupling: PWR 3x3 FA Cluster*




**3D Online TH feedback during neutron history simulation**



**Weight window mesh and 2D power**




**3D Power distribution**

### MCNP/SUBCHANFLOW Simulations:

- **Internal coupling**
- Uniform convergence due to WW
- Stochastic implicit Euler method for convergence acceleration
- **On-the-fly** T-interpolation of XS
- **Variance reduction** with an iterative flux-based **Weight Window (WW) technique**
- Accelerated tallying with custom written Collision Density and Track – Length estimators
- Parallelization of MCNP and SCF with hybrid **MPI/OpenMP**
- Utilization of HPC - Blue Gene/Q

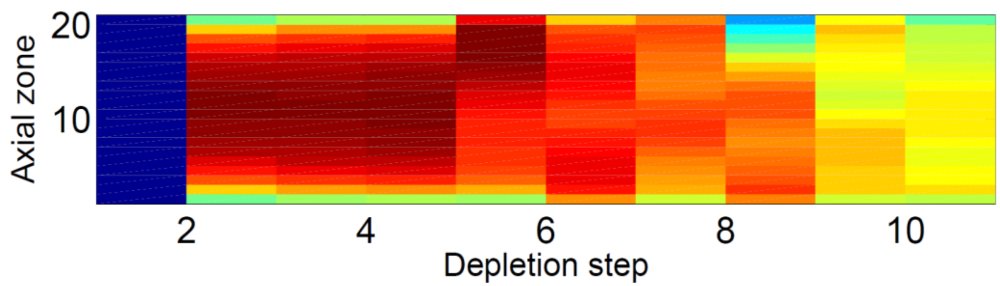
# Selected results from HPMC:

## Optimal Monte Carlo Depletion Integration

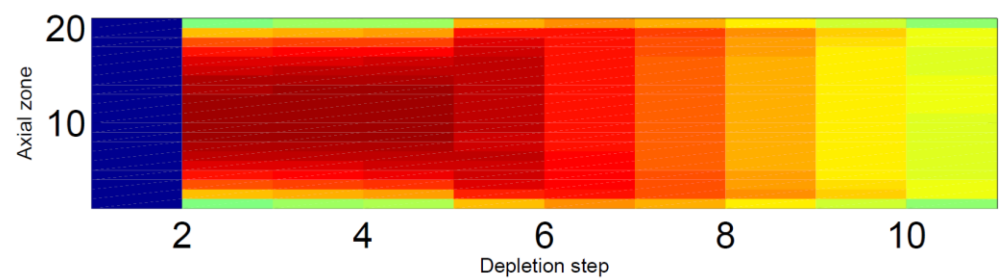
- Current MC-depletion methods e.g. predictor-corrector are numerical unstable.

- **New Stochastic Implicit Euler** (SIE) method proposed to overcame it.

- The SIE-based scheme was implemented in Serpent: PWR FA burn-up calculation demonstrated that MC depletion with SIE is **stable for any time step length.**



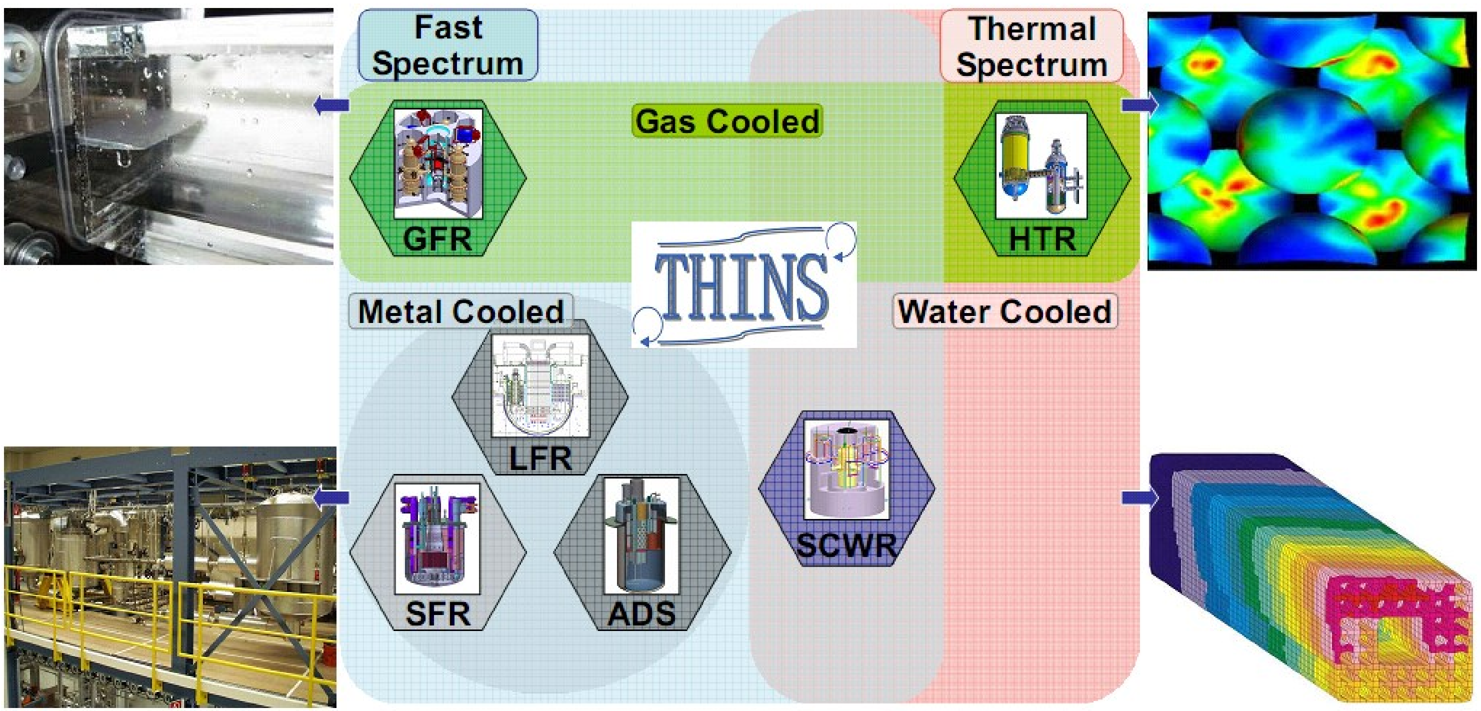

Spatial distribution of Xe-135 in a **conventional predictor-corrector based MC-burnup** calculation of a PWR-FA with 10.0 MWd/kgU step.




Spatial distribution of Xe-135 in a **SIE-based MC-burnup** calculation of a PWR-FA with 10.0 MWd/kgU step (same statistics in all calculations).

# THINS (Thermal-Hydraulics of Innovative Nuclear Systems)

## 01.02.2010 - 31.01.2014




- ✓ **Systems: GEN-IV + ADS**
- ✓ **Phenomena: Cross-cutting TH**

- **THINS main objectives:**
  - Generation of **data base** for development and validation of new models and codes;
  - Development of new physical **models** and modeling approaches for accurate description of crosscutting thermal-hydraulic phenomena;
  - Improvement of numerical engineering **tools** for the design analysis of INS;
  - Optimum usage of available European resources in experimental facilities, numerical tools and expertise

# THINS Methodology

**Cross-cutting phenomena**

↓ Task definition ↓ ↑ Application

**Experimental studies**

13 experiments

↓

**Data base**

↑

**DNS**

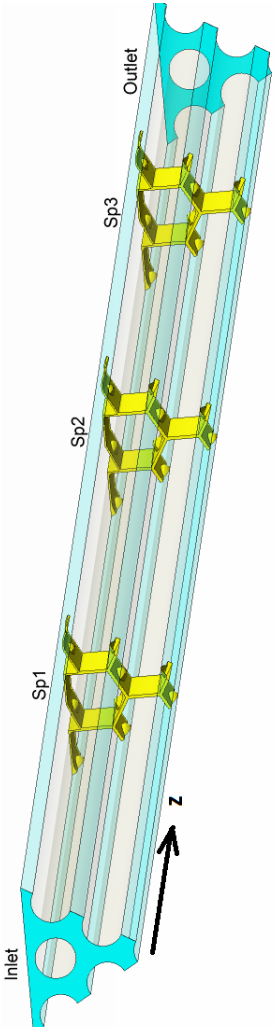
**Support to experiments** ←

→ **Data for model development & code validation**

**Num. simulation**

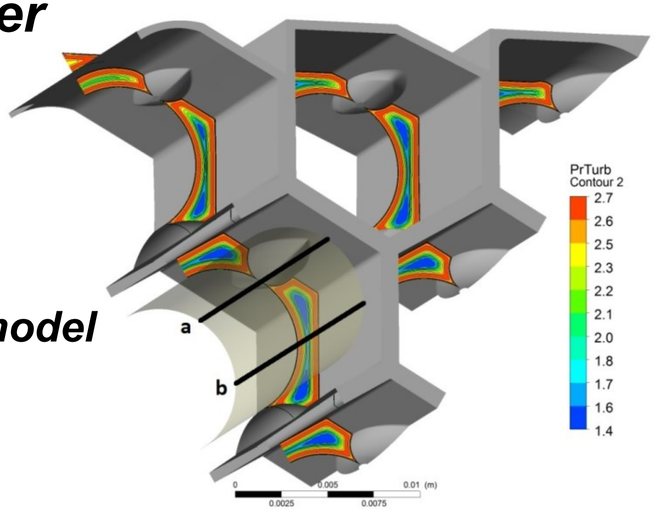
- System codes
- CFD
- Sub-channel & others
- Individual models

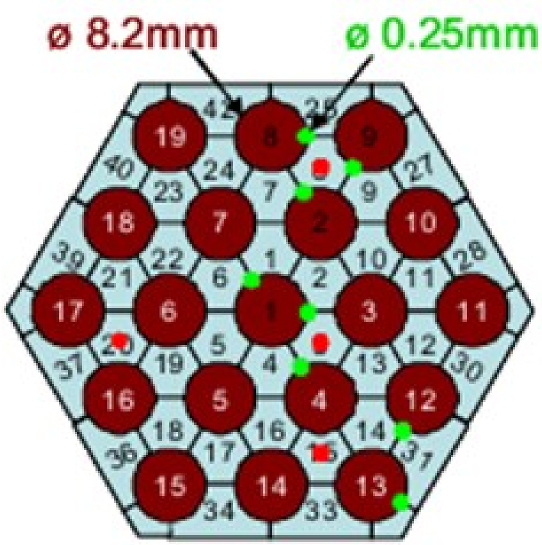
# Selected results from THINS:
## *Simulation of LBE cooled rod bundle heat transfer*



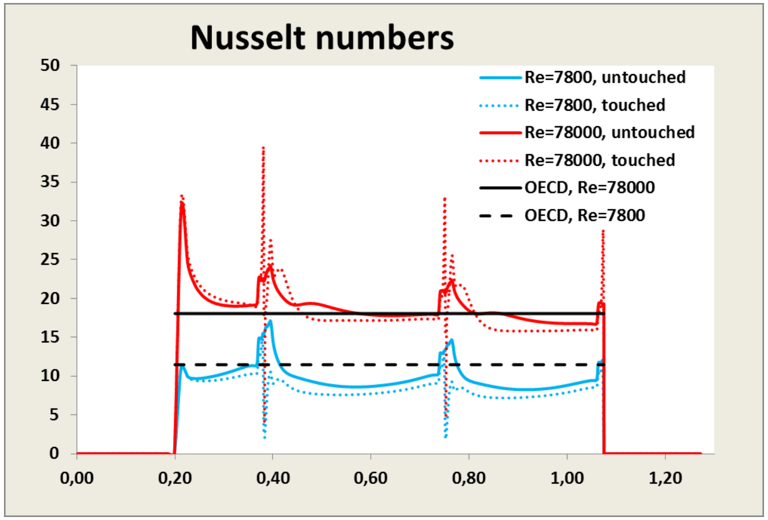

### *KALLA experimental facility (KIT)*

***Numerical simulation:***
***ANSYS CFX, Mesh number: 22 millions***
***Turbulence model: Omega Reynolds stress model***




***19 rod bundle:***
***D=8.2 mm, P=11.5 mm***
***L=1.3 m, 3 spacers***

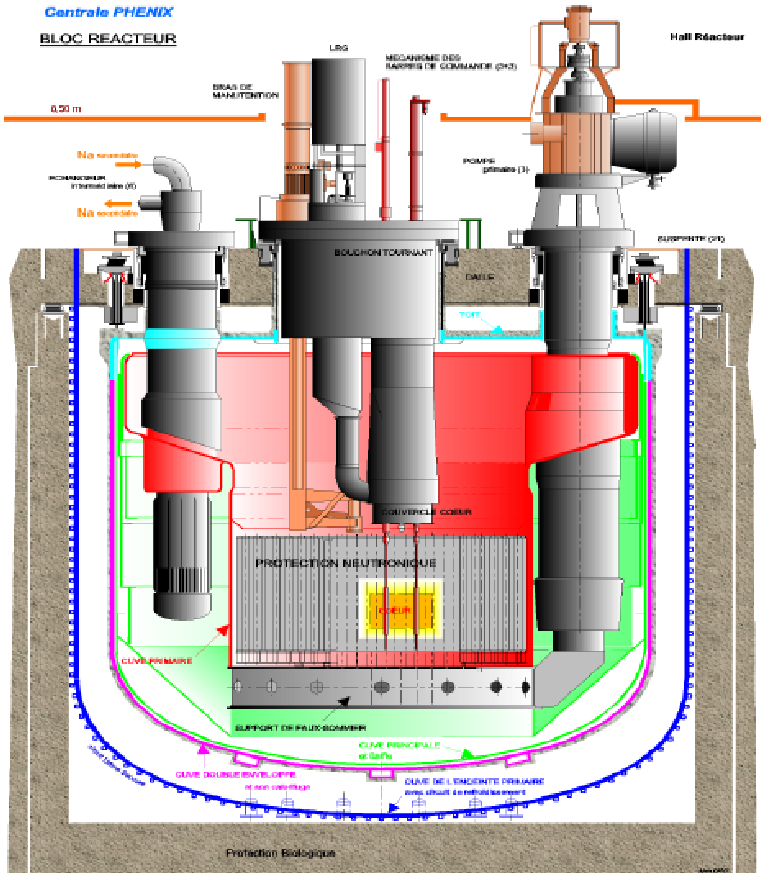



**CFD results: Local Nusselt numbers**

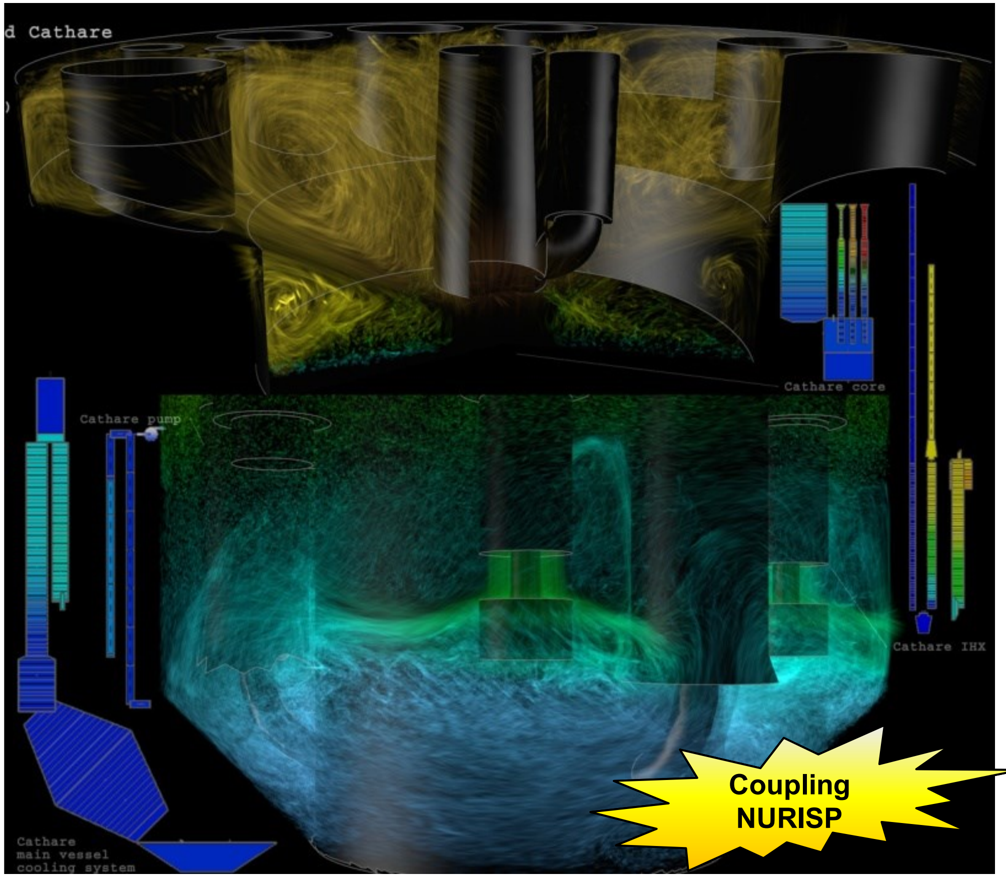
# Selected results from THINS:

## *Simulation of PHENIX natural convection test*

**Comparison of measured data with numerical results**




**Scheme of PHENIX primary system**




**Numerical simulation CATHARE coupled with TRIO-U**

*Advance simulation of passive cooling mechanism*

- Conclusions
  - The philosophy of the European Simulation platform has been demonstrated trough the **novel and flexible coupling** of Multi-physics and Multi-scale domains.
  - The **advancement of numerical simulation for nuclear fission reactors** is a great challenge that is preferably tackled on EU level.
  - The European scientific community is **working together** towards the development of Advanced Numerical Simulation tools needed to assess the safety of **current and future reactor designs**.

- Outlook
  - Extend the NURESIM platform capabilities to GEN-IV reactors.
  - Demonstrate the reference capabilities of the coupled Monte Carlo/TH codes against experiments.
  - Application of the lessons learnt within THINS project. Thermal-hydraulics is recognized as a key scientific subject in the development of innovative reactor systems.
  - Synergy effects between NURESAFE, HPMC and THINS to be concreted in follow up projects

NURISP

NURESAFE

# THANKS FOR YOUR ATTENTION

HPMC 7

THINS