



# Analisi di Sicurezza e Simulazione Multifisica

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Contributions from ENEA CR Brasimone, Bologna, Casaccia  
and  
UNIPI, UNIROMA1, POLIMI, POLITO

Convegno REATTORI DI IV GENERAZIONE E SICUREZZA NUCLEARE

*ENEA SEDE - ROMA*

*11 settembre 2015*

# INTRODUCTORY REMARKS

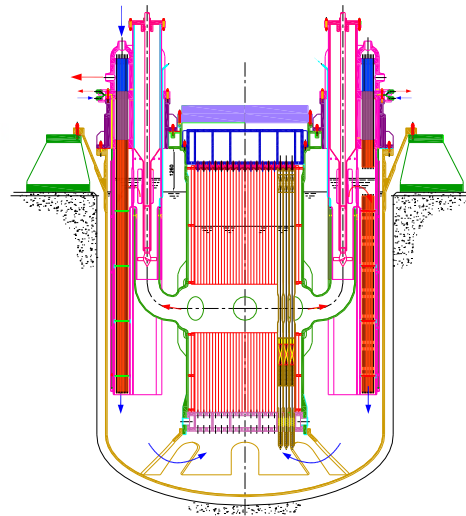
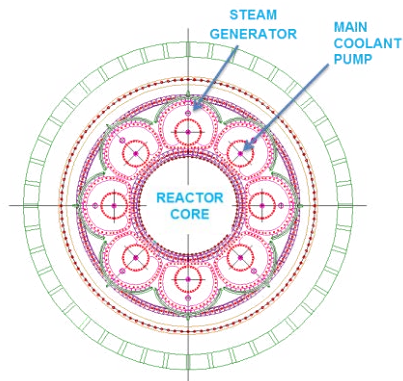
**Framework: DEMO LFR *ALFRED***



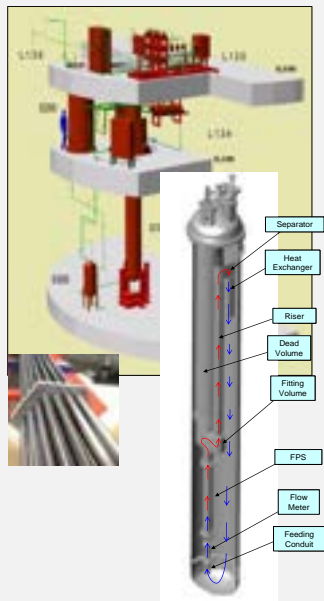
**Power: 300 MWth (125 MWe)**

**Primary cycle (molten lead): 400-480 °C**

**Secondary cycle (water/superheated steam): 335-450 °C**



# CODE VALIDATION ACTIVITIES



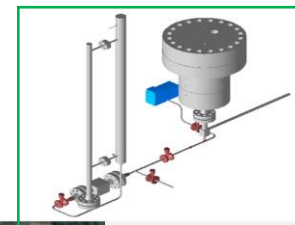
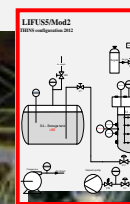
**CIRCE**



**NACIE-UP**



**HELENA**



**LIFUSS**

**CR Brasimone framework**

**National (ITA) Program (PAR)**

**EU Projects**

**IAEA**

**OECD**

**International Collaborations**



*CFD  
SYS-TH  
SIMMER-III /IV*



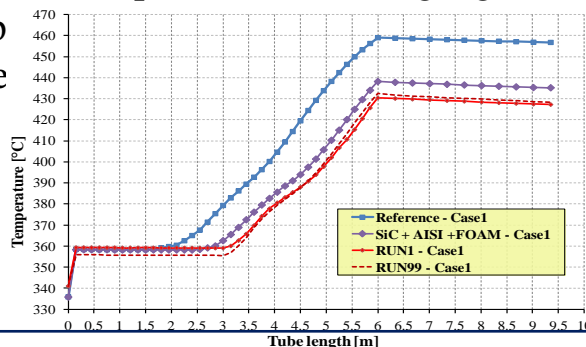
*Neutronic  
Fuel  
Coupling*

Besides, the instrumentation available in CIRCE facility, HERO has about 100 gauges

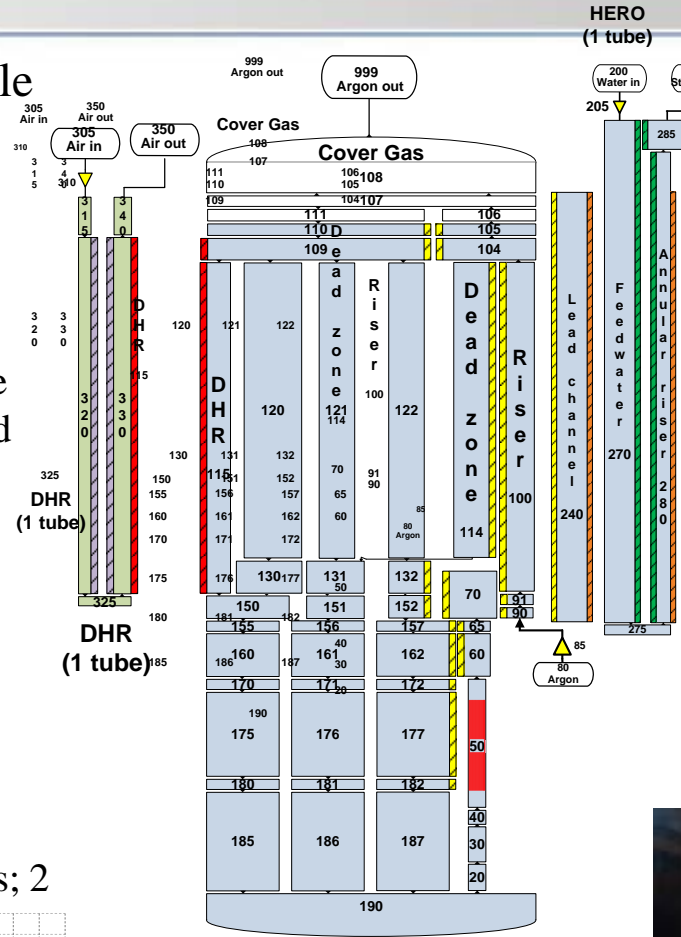
- To investigate the performance of the single tube and of the tube bundle
- To study the conductive HT across the inner wall with insulating material and external double wall
- To investigate instability
- To evaluate the convective HT
- To perform integral tests

Measurement points available in HERO

- 75 thermocouples (TC); 13 DP gauges; 2 abs. p gauge



Effect of the powders on the HEX performances



RELAP5 nodalization



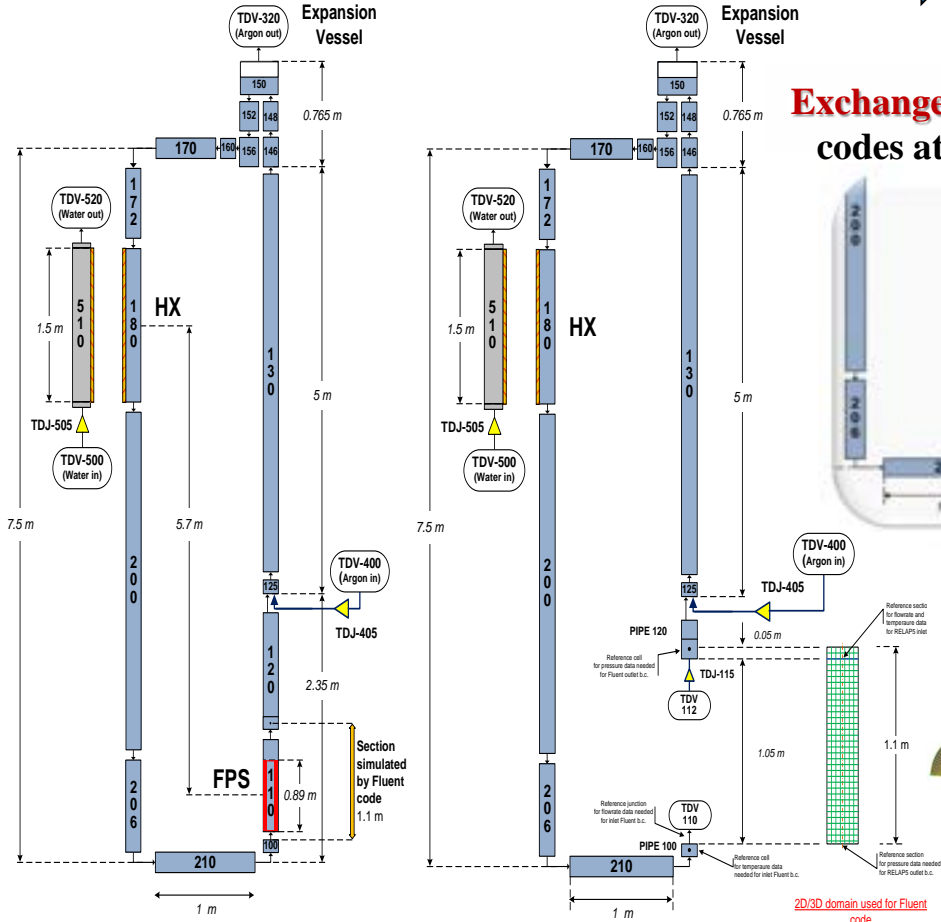
HERO test section



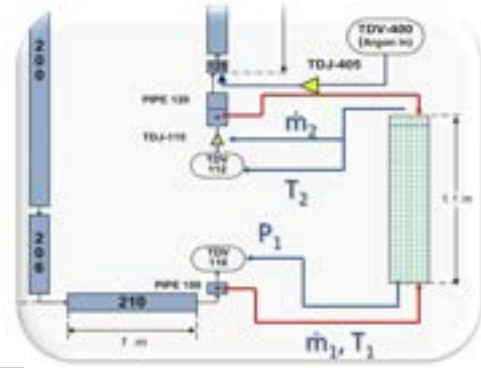
HERO upper part

- ✓ Italian National Program (PAR), a methodology was developed to couple *SYS-TH codes and CFD codes*
- ✓ Two methodologies: explicit coupling and implicit coupling → → [RELAP5+Fluent; RELAP5+CFX]
- ✓ Methodology applied to the NACIE tests

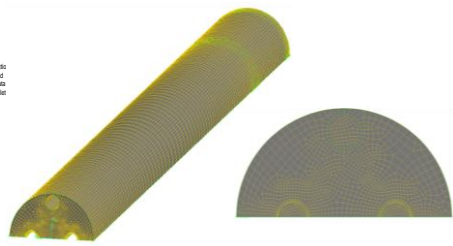
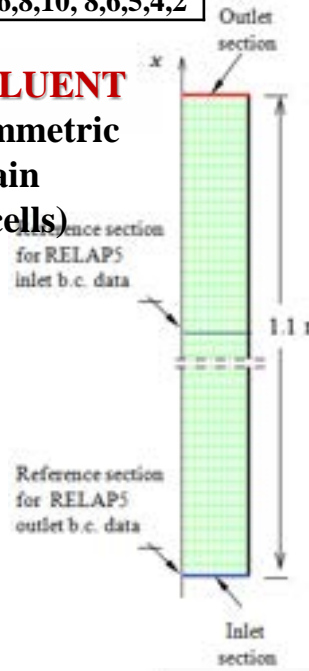
Name	$T_{av}$ [°C]	FPS Power %	G_lift [Nl/min]
Test 206	200-250	0	2,4,5,6,8,10, 8,6,5,4,2
Test 306	300-350	0	2,4,5,6,8,10, 8,6,5,4,2



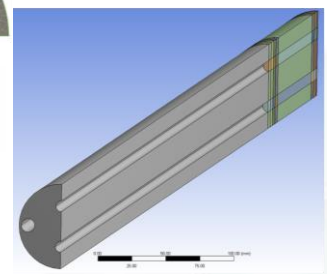
Exchange parameters among the codes at the interface domains



ANSYS FLUENT 2D axisymmetric domain (7200 cells)



ANSYS FLUENT 3D domain (141045 cells)



RELAP5 nodalization (stand alone)

RELAP5 nodalization (coupled)





# FUEL PIN PERFORMANCE MODELLING DEVELOPMENT AND VALIDATION



## Tool: TRANSURANUS fuel pin performance code

### Assessment of MOX fuel thermal properties and FGR

- ✓ Three experimental MOX fueled rods included in the International Fuel Pin performance Experimental database tested in PRIMO and IFA-597 experiments.
- ✓ Framework: ADP national programme in collaboration with UNIPI.

### Improving conductivity correlation of MOX fuel melting and modeling of Inception of FBR

- ✓ Based on 16 fresh MOX fueled rods tested in the EBR-II reactor in the experimental campaign HELD-P-19.
- ✓ Framework: ADP national programme in collaboration with UNIPI.

### Development of new models for FGR-swelling and He release

- ✓ Development and verification of a physically based single model to couple swelling and gas release. Development and verification of an He release model.
- ✓ Framework: ADP national programme in collaboration with POLIMI (and ITU).

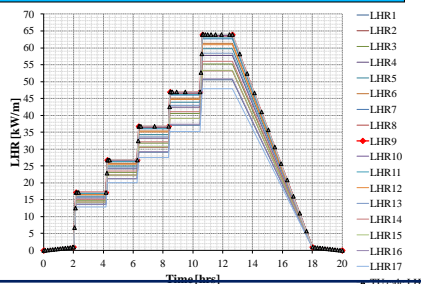
### Basis for modeling FGR in MA fuel

- ✓ Critical review of the existing models for FGR from MA MOX fuel and identification of the capabilities of TRANSURANUS code to cope this issue.
- ✓ Framework: PELGRIMM project

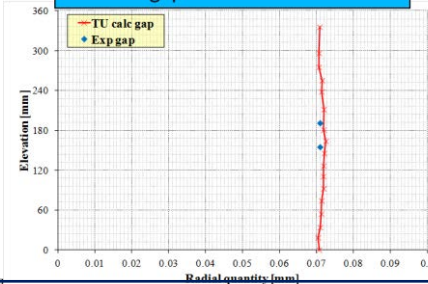
### Modeling MOX fuel behavior in LFR

- ✓ Identification of the main issues related to the lack of material properties and models to enhance the capability of TRANSURANUS code in simulating MOX fuel rods in lead fast reactor spectrum.
- ✓ Framework: ADP national programme in collaboration with POLIMI.

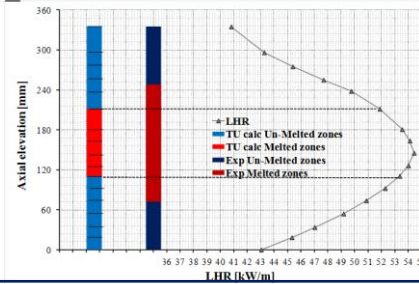
Linear power during the test at 17 axial elevations



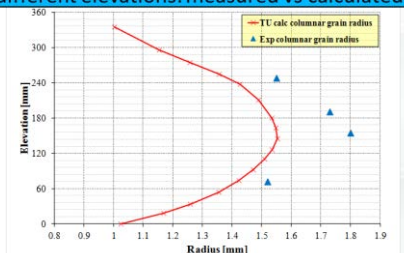
Residual gap at the end of the test



Calculated vs measured axial extension of melting



Radial extension of columnar grain at different elevations: measured vs calculated

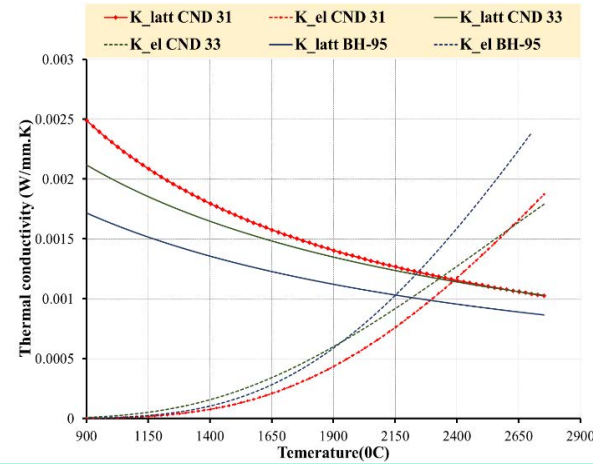
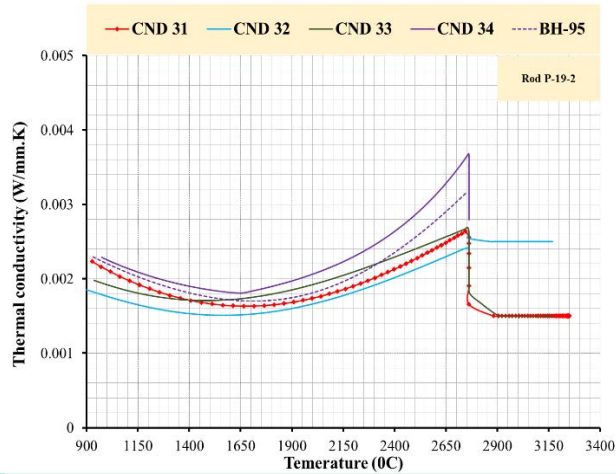




# FUEL PIN PERFORMANCE MODELLING DEVELOPMENT AND VALIDATION



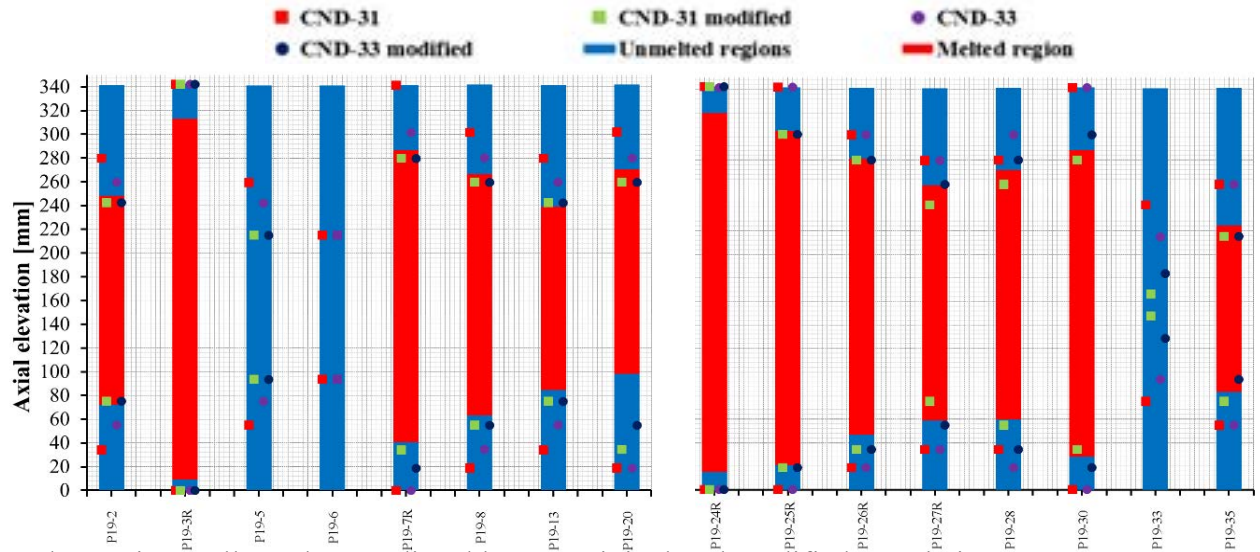
## Baron-Hervé vs TRANSURANUS correlation



Radial profile of thermal conductivity for rod P-19-2 as a function the radial temperature profile inside it

Lattice and electronic conductivities as a function of temperature at 92%TD, 25%Pu content for BH-95, and O/M ratio of 1.96.

Implementation of high temperature term according to Baron-Hervé



Axial elevation of melting as measured experimentally and as predicted by TU original and modified correlations.



# RELAP5/MOD3.3 ANALYSIS



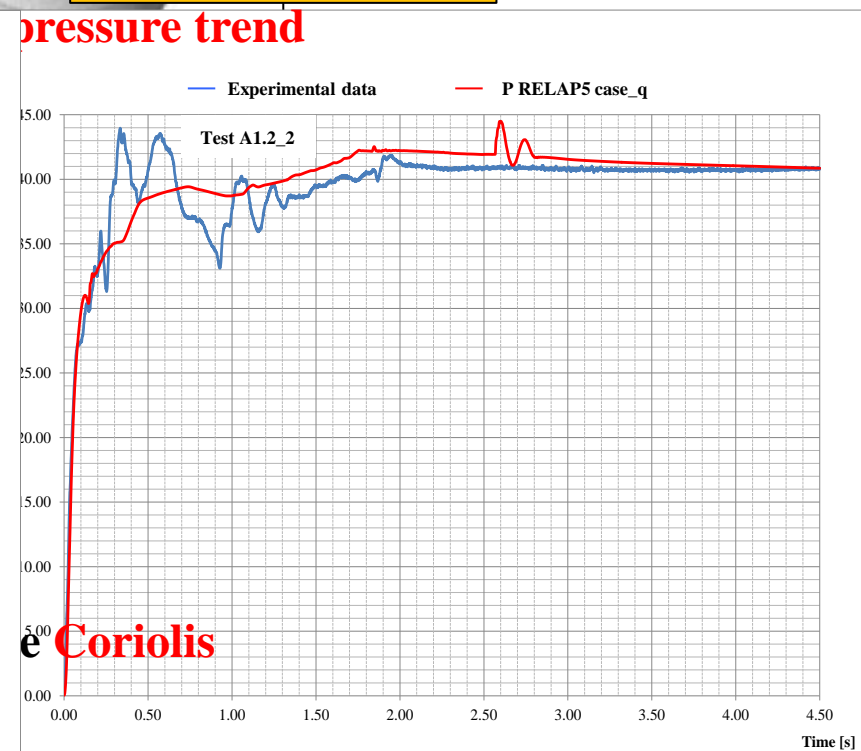
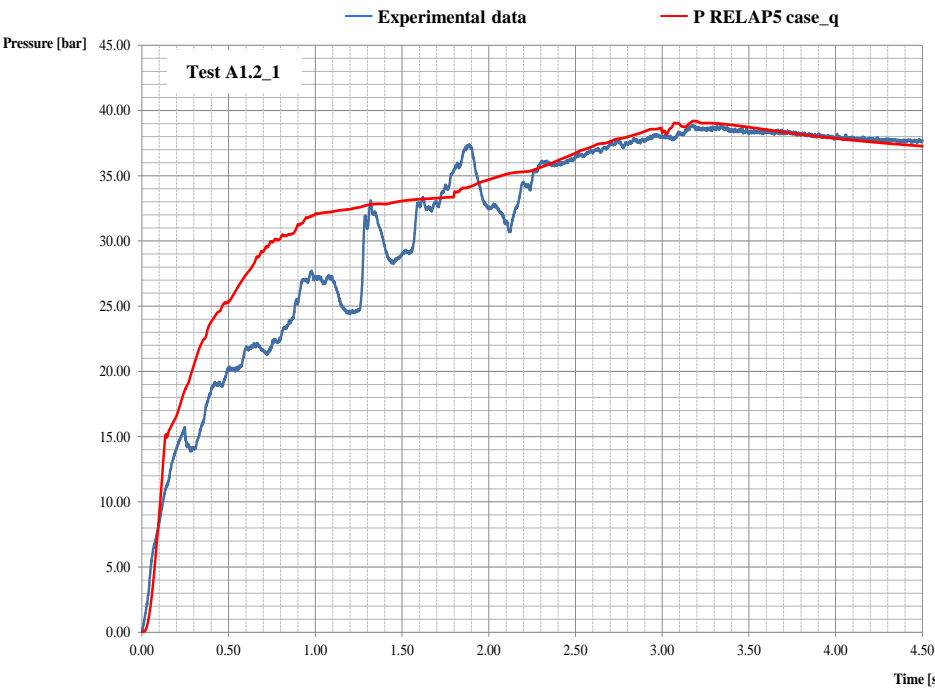
WATER

DALIZATION

#	T vlv opening [s]	K [V4],[V14]	K [Coriolis]	A Coriolis [m <sup>2</sup> ]
a	0.25	7	0.5	4.53e-05

15 simulations for two different tests

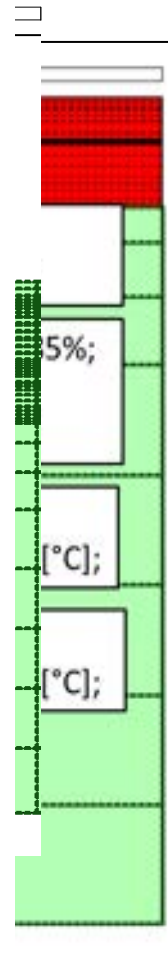
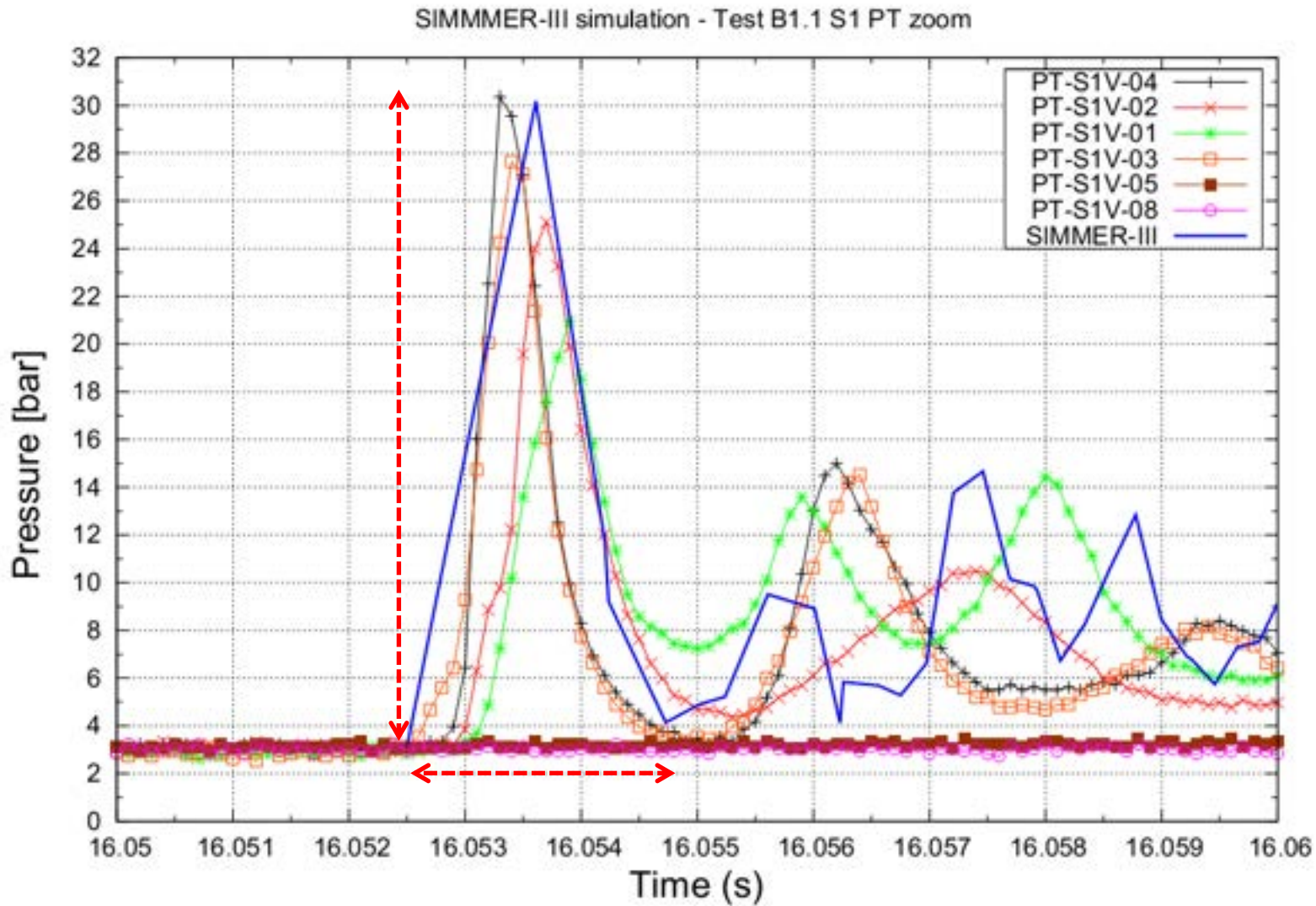
RI	q	0.25	10	2.5	4.53e-05	III
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e Coriolis



## RESULTS MORPHING

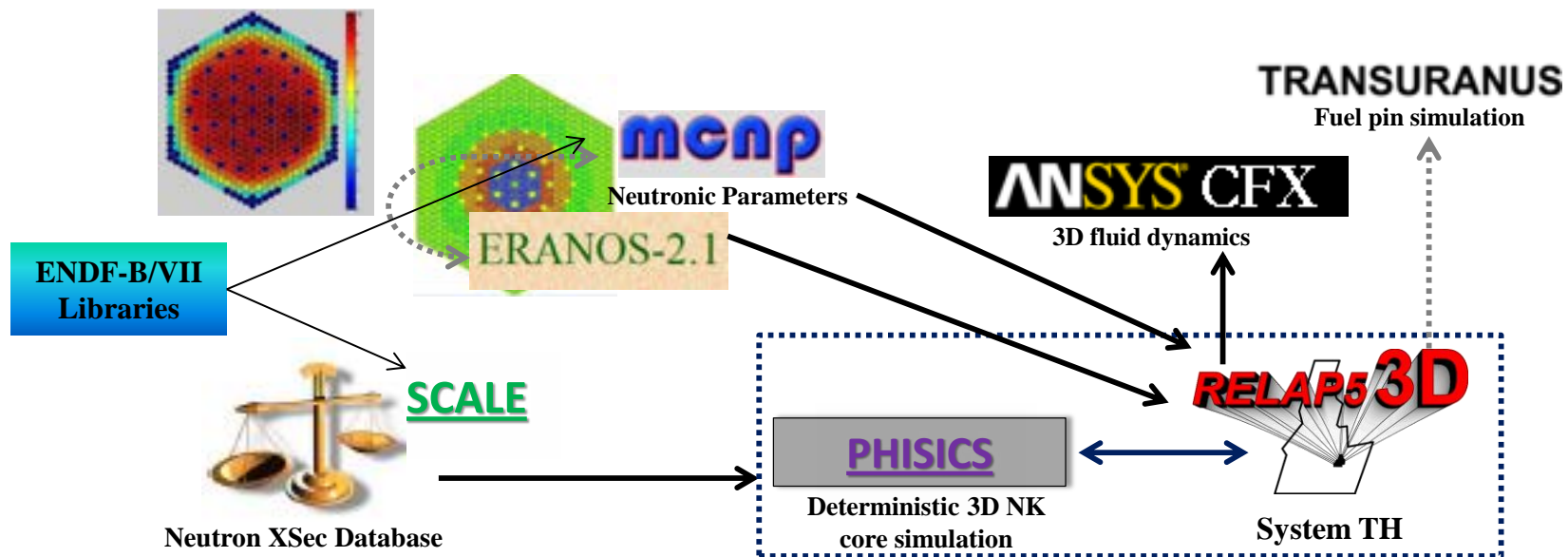


# STRATEGY FOR SAFETY ANALYSIS

ACTIVITY PERFORMED IN THE FRAMEWORK OF EBR-II BENCHMARK:

- ❖ **Analyses of SHRT-17 completed.** TH nodalization of EBR-II (*configuration SHRT-17*) completed. Steady state achieved. Blind calculation and post-test analysis of SHRT-17 carried out and submitted.
- ❖ CFX modeling of XX09 fuel assembly available and analysis of SHRT-17 test carried out
- ❖ Neutronics activities: development of a EBR-II MCNP6 neutronic model; development 33-group MG cross sections by SCALE6/NEWT code; and RELAP5-3D©/PHISICS simulation

- ❑ RELIABLE APPROACHES FOR SAFETY ANALYSIS CONSISTS IN SETTING UP AND QUALIFYING A CHAIN OF CODES AND THEIR INTERFACES



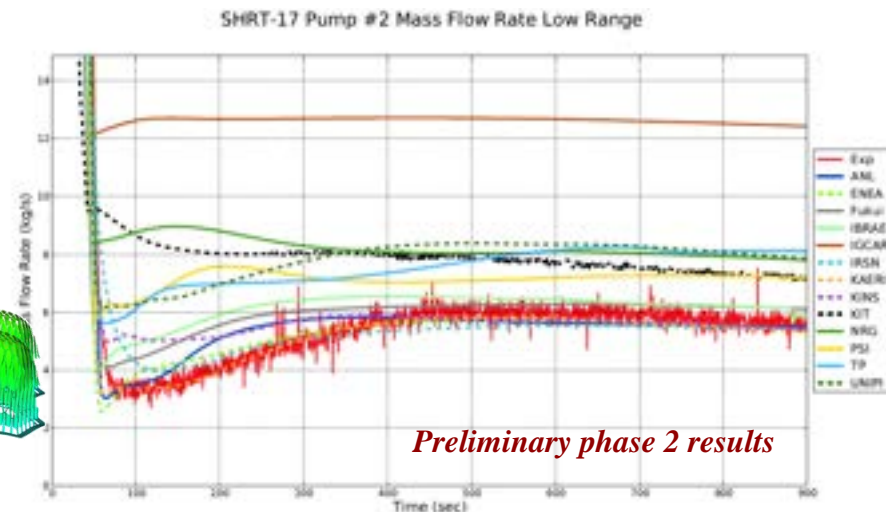
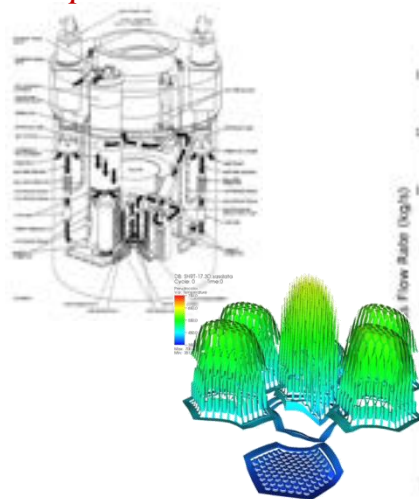
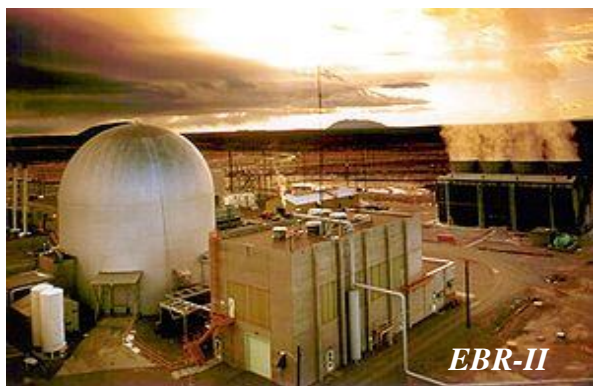
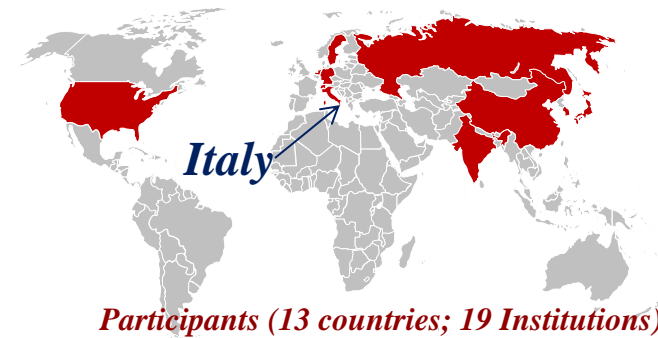
# OBJECTIVES / FRAMEWORK

## OBJECTIVES:

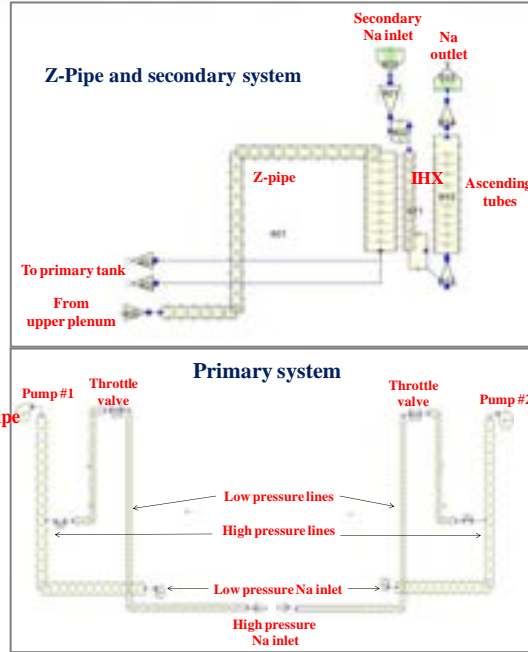
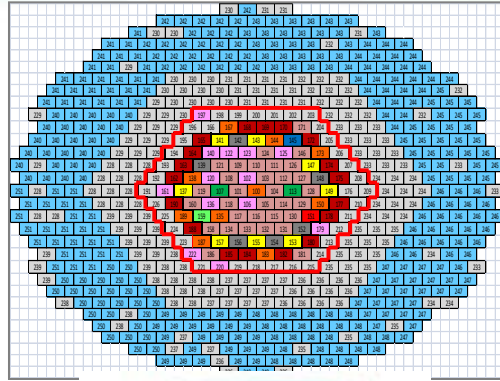
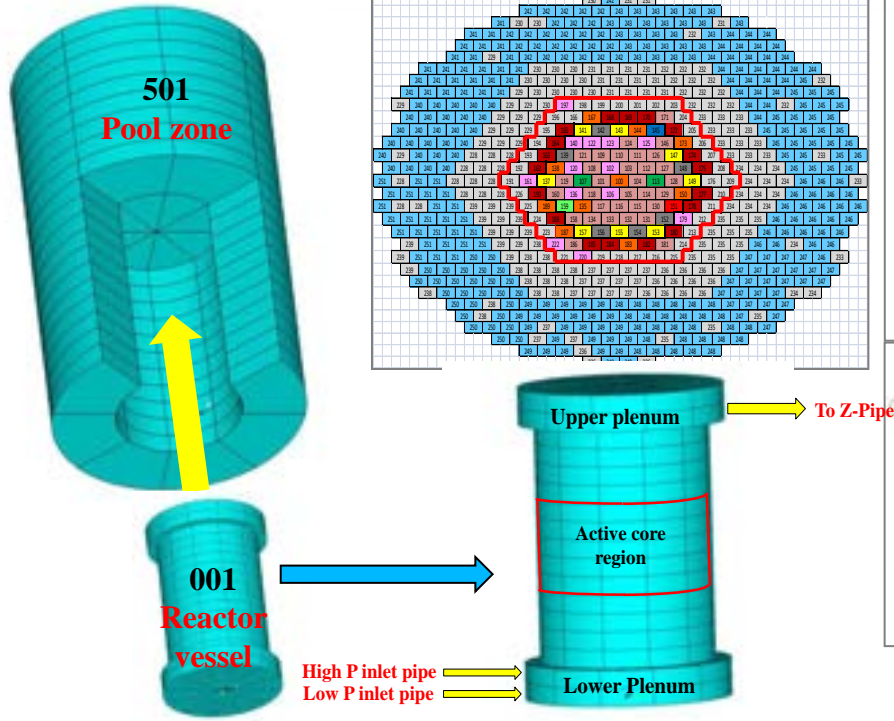
- to develop reliable **approaches for safety analysis** of new generation *FR systems* (i.e. **LFR**), i.e. *TH-SYS codes, CFD and NK including coupling*
- to improve the understanding of FR neutronics, TH and SYS analysis → TH processes and phenomena, neutronics features and interconnections

## ACTIVITIES BENEFIT FROM UNIQUE AND VALUABLE EXP DATA:

- IAEA CRP Benchmark on EBR-II (Int. framework)
- EBR-II SHRT-17 and SHRT-45R provided by ANL
  - *Protected and Unprotected Loss of Flow*
  - *Multi-physics activity based on experimental data*

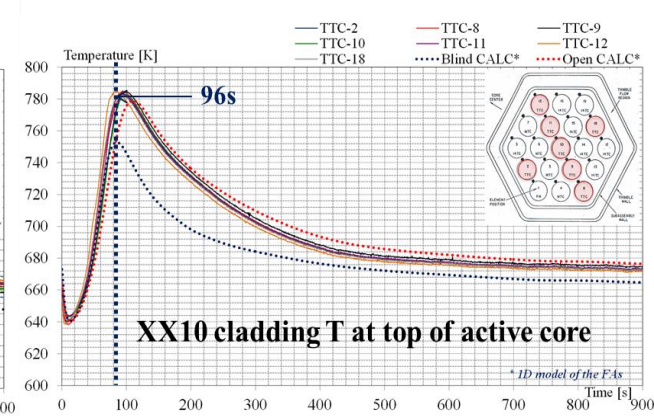
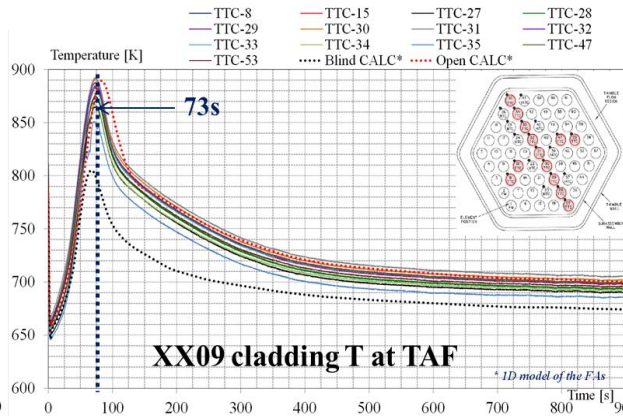
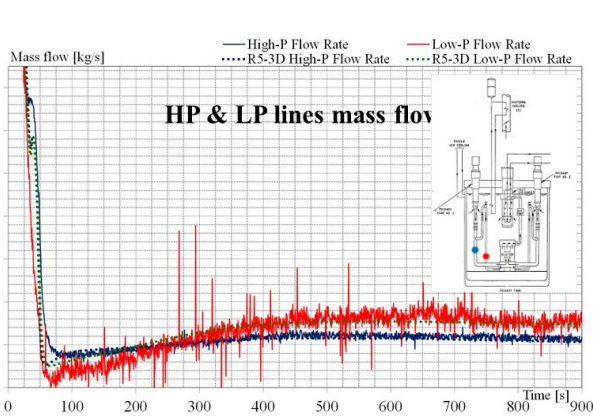






- Driver FA modeled one by one with pipe components according with the geometrical description reported in the specifications
- Blanket region modeled with equivalent PIPE components according with the azimuthal configuration, grouping reflector and blanket FAs, separately

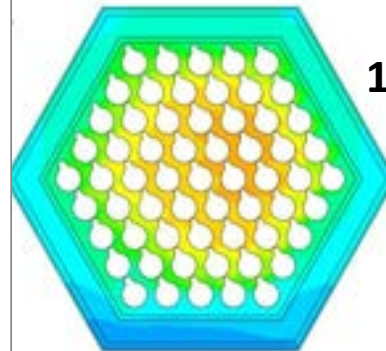
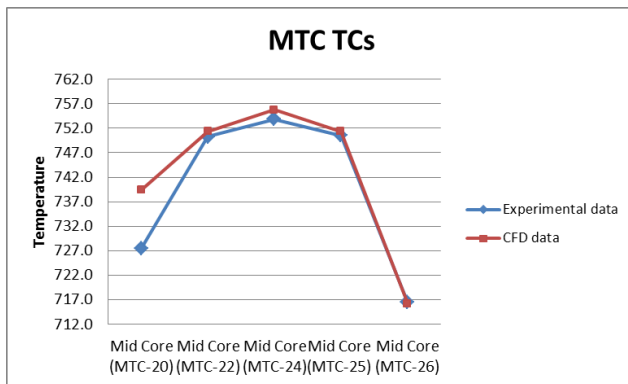
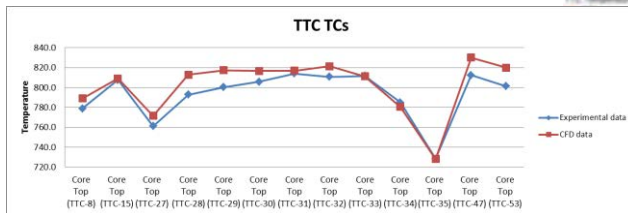
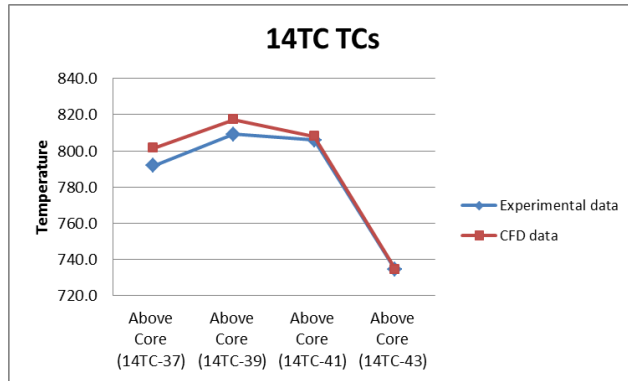
#	QUANTITY	Value
1	Tot. No. of HYDR vol.	3985
2	Tot. No. of HYDR junct.	6428
3	Tot. No. of HYDR vol. in the core	2460
4	Tot. No. of heat structures	5248
5	Tot. No. of mesh points in the heat structures	31236
6	Tot. No. of core active structures (radial x axial)	8 x 5



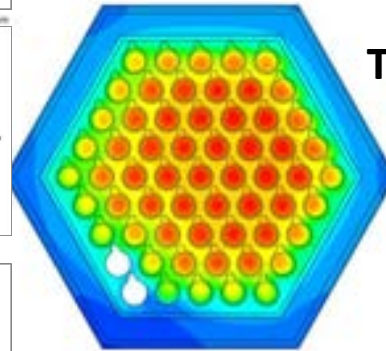


# CFD MODELING

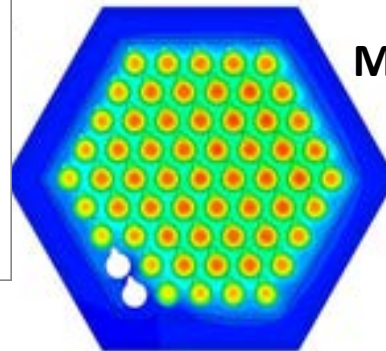
First test case (XX09) stationary:  $m_{FA}=2.44$  kg/s,  $m_{THIMBLE}=0.25$ kg/s,  $W_{tot}=464.6$  kW,  $T_{inlet}=626.4$  K



14TC



TTC



MTC

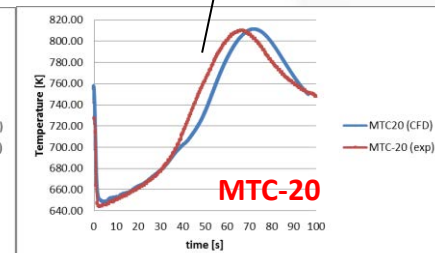
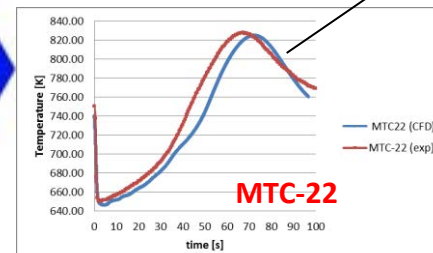
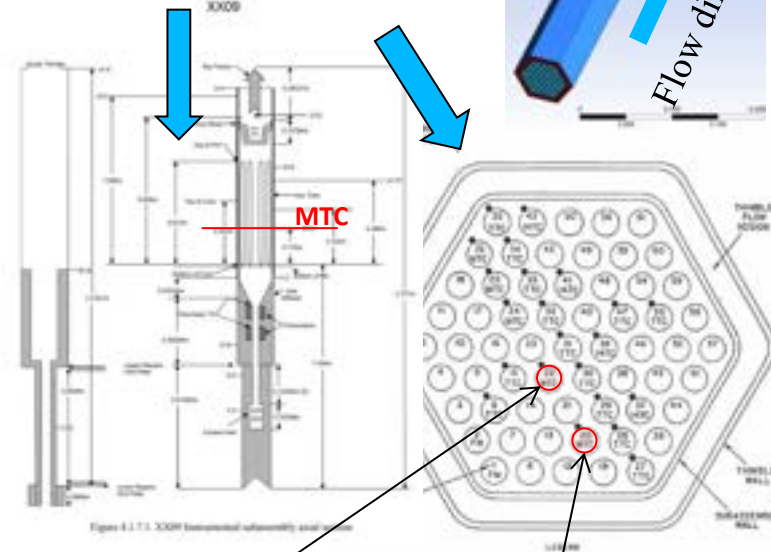
Three measuring sections in XX09

MTC h=172 mm

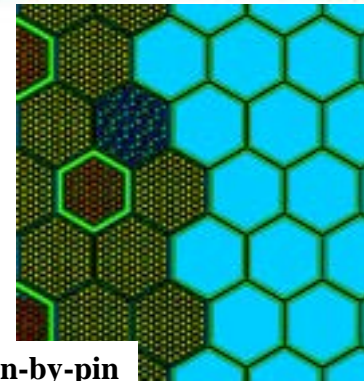
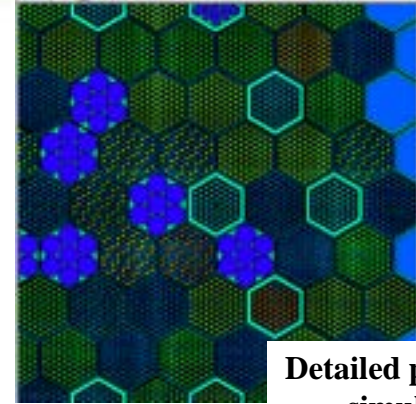
TTC h= 322 mm

14TC h=480 mm

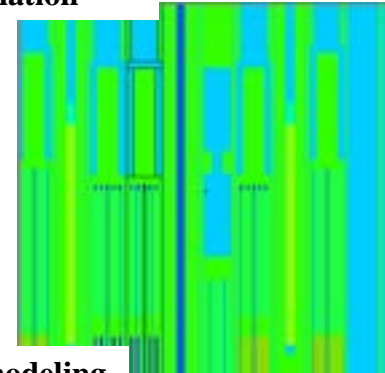
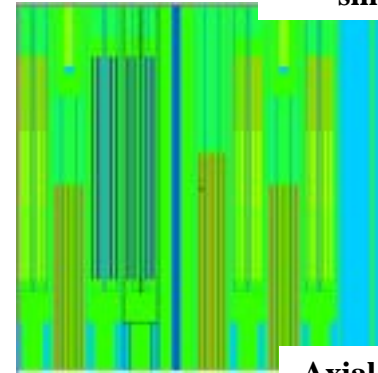
Active region h= 343 mm



- ❑ **MCNP6** code modeling
- ❑ Detailed pin-by-pin modeling
  - Core modelling, including radial blanket
  - Modelling of Top and Bottom core structures
  - Use up to **45 different fuel materials**
    - No axial homogenization



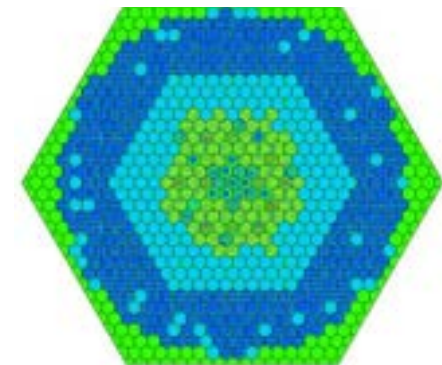
Detailed pin-by-pin simulation



Axial modeling

MCNP6 RUN	K-eff
15 materials / 1.0E-7	1.04819 ± 33 pcm
45 materials / 1.0E-7	1.02755 ± 24 pcm
45 materials / 1.0E-9	<b>1.02802 ± 24 pcm</b>

- ❑ **Preliminary** results obtained
- ❑ Assessing the effect of fuel composition homogenization (15 or 45 materials) / isotopes threshold selection (1.0E-7 / 1.0E-9)
- ❑ Further tests to be performed increasing material compositions

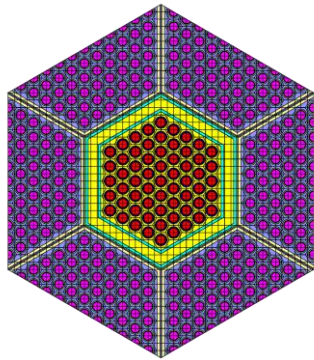


Core x-y view

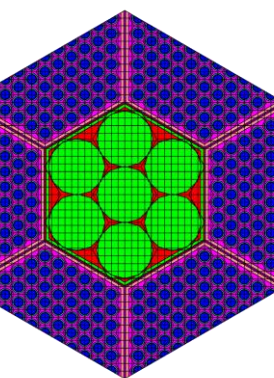
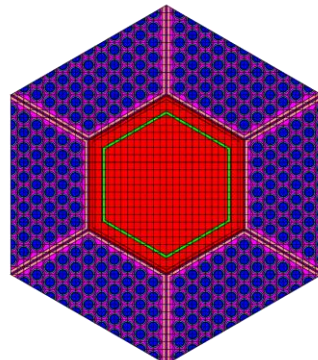


## SCALE6.1/NEWT code for the EBR II XSec database Generation

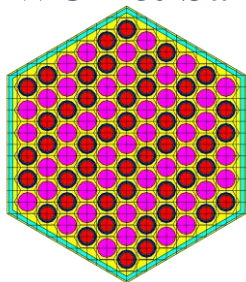
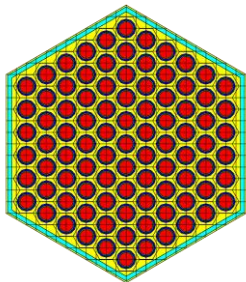
- **BONAMI/CENTRM** for Self-Shielding calculations
- **NEWT** code for 2D neutron transport calculations



HWCR & Safety CR



Dummy S/A

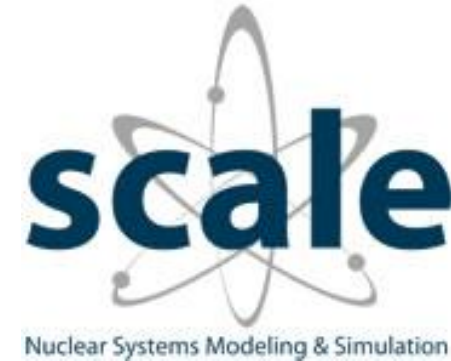


Fuel S/A

Bot. & Top Reflector



Radial  
Reflector



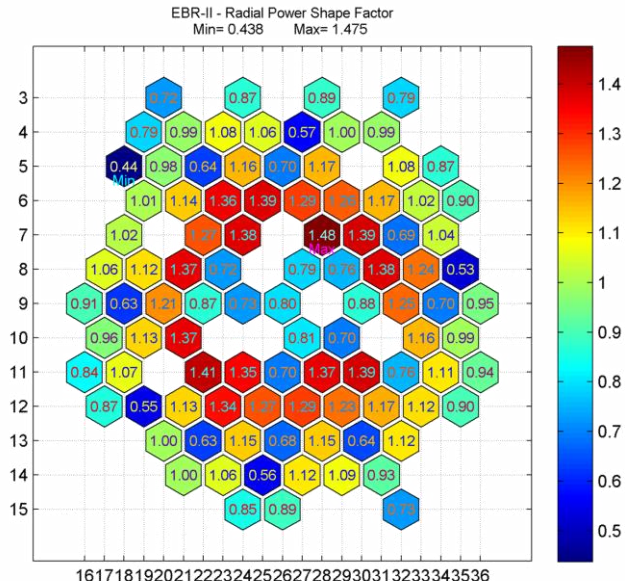
Nuclear Systems Modeling & Simulation

238-group  
ENDF/B-VII.0

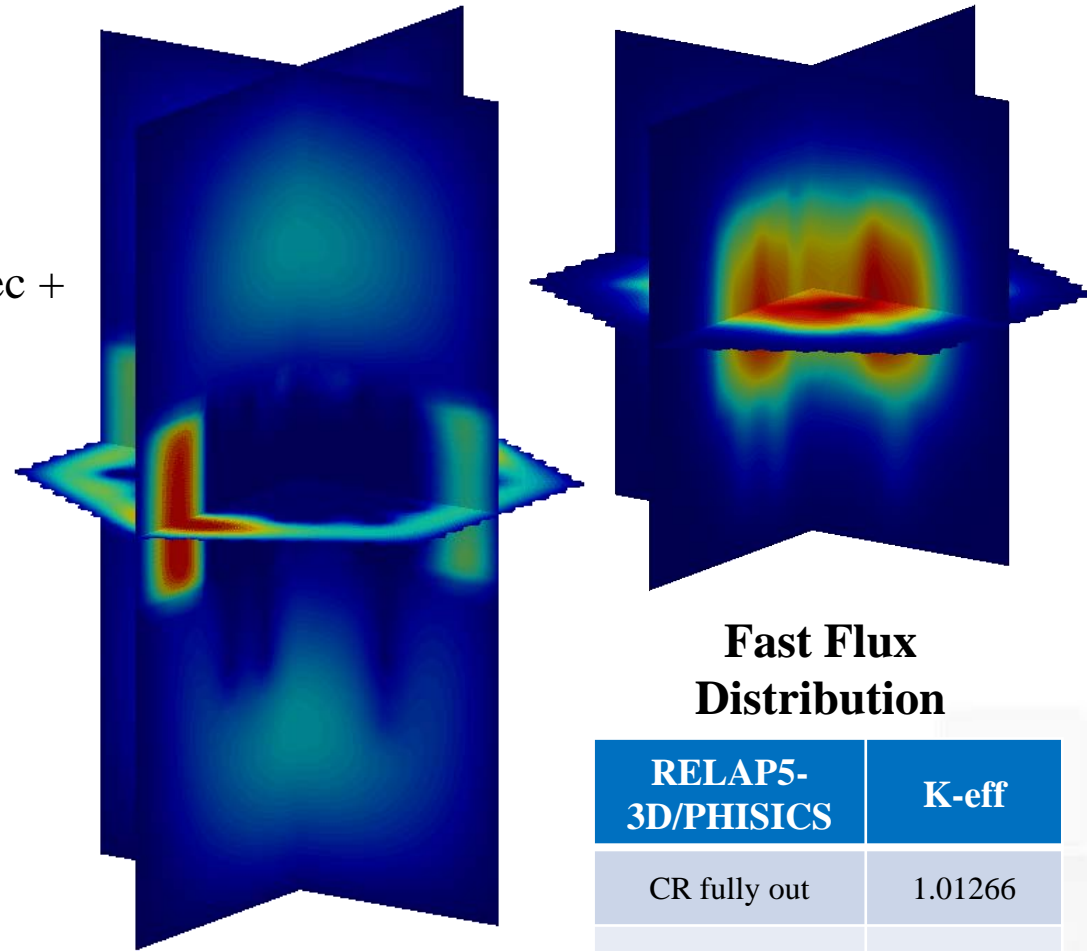


33-group  
XSEC Libraries

- ❑ Initial 3D NK TH Calculations performed with simplified RELAP5-3D TH nodalization  
→ XSec library validation ongoing
- ❑ PHISICS model:
  - full core + stainless steel reflector
  - 1 node/assembly, 6 axial
- ❑ Sample calculation with 33 MG Xsec + Nodal Diffusion (P1 approx.)



**Power Distribution**



**Fast Flux Distribution**

RELAP5-3D/PHISICS	K-eff
CR fully out	1.01266
CR in (reference insertion depth)	0.98072

**Thermal Flux Distribution**



# CONCLUSIVE REMARKS



## ACTIVITIES SUPPORTED AND CARRIED OUT IN THE FRAMEWORK OF PAR PROJECTS

- ❑ ARE PERFORMED IN SYNERGY WITH INTERNATIONAL FUNDED AND COLLABORATIVE PROJECTS
- ❑ BENEFITS FROM THE UNIQUE AND VALUABLE EXPERIMENTAL ACTIVITIES SET-UP IN THE ENEA INFRASTRUCTURES
- ❑ ARE AIMED AT DEVELOPING AND IMPROVING CURRENT NUMERICAL TOOLS SETTING UP AND IMPLEMENTING CODE MODELS FOR GEN. IV HLM FR
- ❑ ALLOW THE ENHANCEMENT OF KNOWLEDGE IN THE FIELD OF GEN. IV HLM FR
  - SETTING-UP AND TESTING STRATEGIES OF CODES' USE AND THEIR COUPLING TO ADDRESS MULTI-PHYSICS PROCESSES → THUS, SUPPORTING THE DESIGN ACTIVITIES
- ❑ CONSIST OF LARGE EFFORTS FOR MAINTAINING COMPETENCES AND FOR IMPROVING PROFESSIONAL SKILLS IN THE FIELDS OF SAFETY ANALYSIS
- ❑ ARE A VALUABLE SUPPORT FOR KEEPING STATE OF THE ART COMPETENCES IN GEN. IV HLM FR TECHNOLOGY
  - ALSO RELEVANT BEYOND NUCLEAR FISSION