R&D And Experimental Activities at ENEA Connected with the Use Of RELAP5-3D Code

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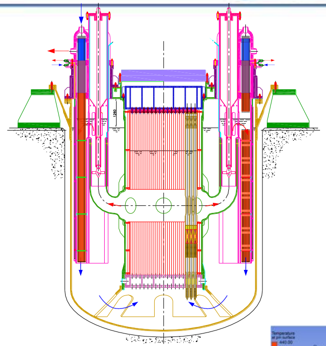
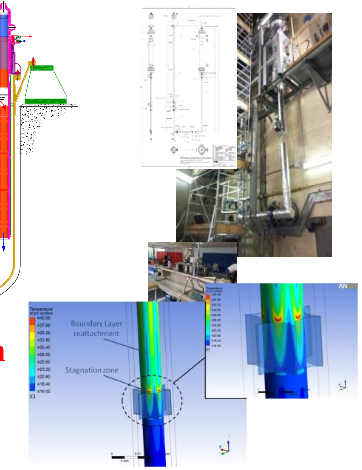
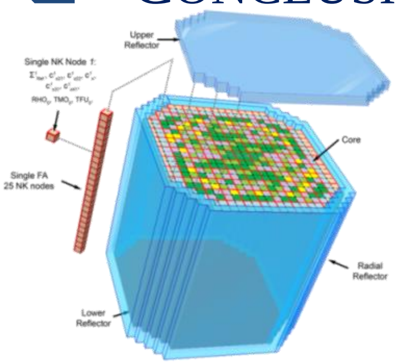
- NUCLEAR FUSION
  - LEADING TH FUSION FACILITIES @ ENEA CR BRASIMONE
  - DESIGN, MODELING & SIMULATION ACTIVITIES
- CONCLUSIVE REMARKS



LFR design

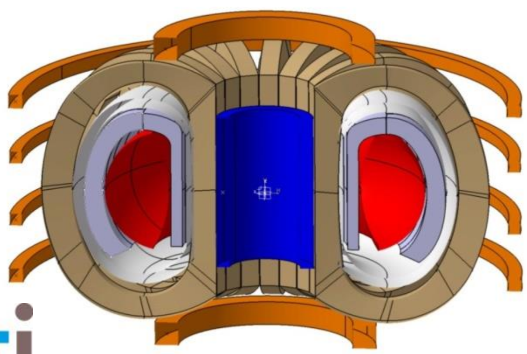


NACIE facility: NC experiments and coupling

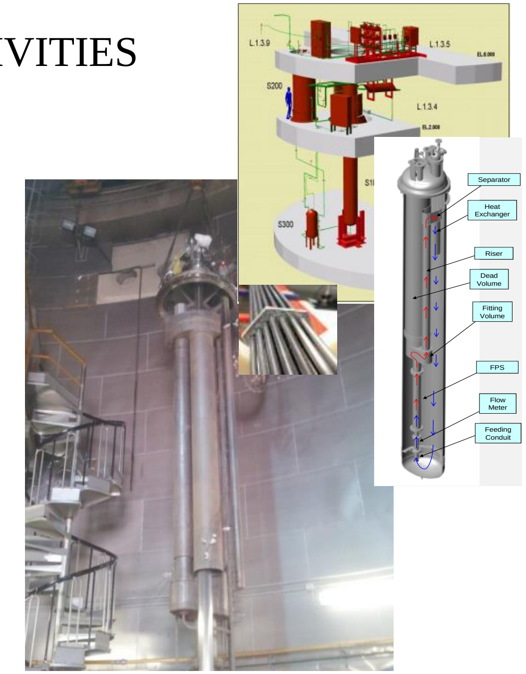


Oskarshamn-2 NPP Core 3D NK Modelling

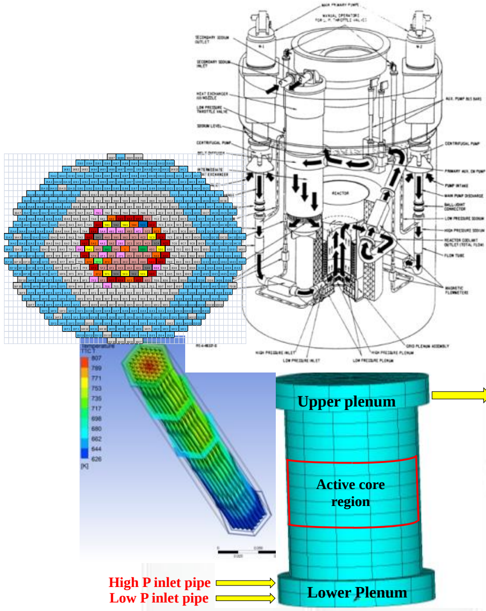
TH Training Course



DEMO and ITER R&D and designs



Integral Test Experiments and component testing: CIRCE/HERO facility



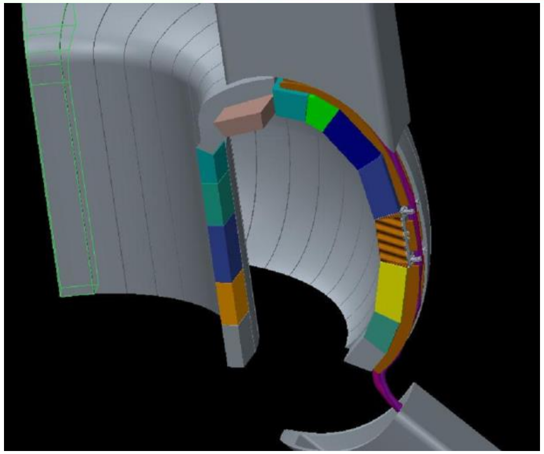
IAEA EBR-II benchmark: RELAP5-3D, coupling, chain of codes

INTRODUCTORY REMARKS

- Use of computer codes
  - for supporting the design and the execution of the experiments
  - for improving code modelling and computer codes capabilities
  - for supporting design of Gen. 4 and fusion reactors
  - for validation activities in the framework of national, EU and Int. Projects
  - …
- SYS-TH, CFD, neutron physics, structural mechanics, fuel pin mechanics, CAD, codes (e.g. **RELAP5**, CATHARE, ERANOS, MCNP6, PHISICS, CFX, ABAQUS, ANSYS, TRANSURANUS)
- **RELAP5/M3.3**: 1) LBE, Lead, He fluid proprieties implemented; 2) Liquid metals Seban-Shimazaki, Ushakov, Mikityuk correlations implemented, 3) Used for validation of correlations, training, coupling, etc.
- **RELAP5-3D** : 1) Mainly used for International benchmark activities, 2) code to code bechmarking, 3) DEMO WCLL design support, etc…

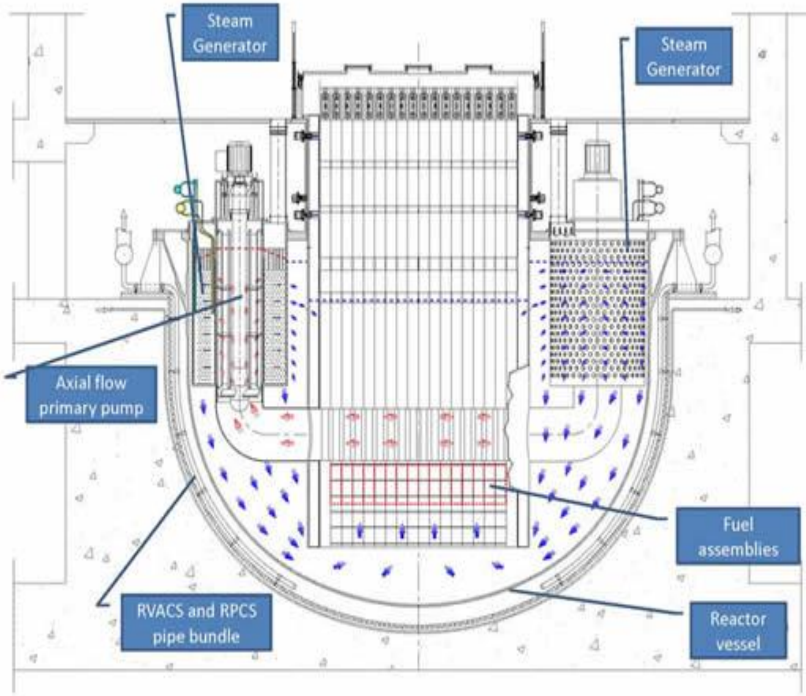
INTRODUCTORY REMARKS

- TH-SYS codes are used for LWR
  - Capability to simulate a wide range of working fluids ☺
- Extensively used and validated for TH analysis of LWR
  - Limited validation for other working fluids ☹



DEMO CAD of poloidal segmentation

- Gen. IV LFR and ADS: LBE &Lead for PS and water for SS
- DEMO WCLL breeding blanket: PbLi and water working fluids
  - EC framework programme and National projects support their development
  - TH-SYS codes applied for preliminary design, preliminary accident analysis and scoping calculations
  - TH-SYS codes used to support exp. activities (planned and ongoing) and vice-versa
  - Development, verification, validation independent assessment needed



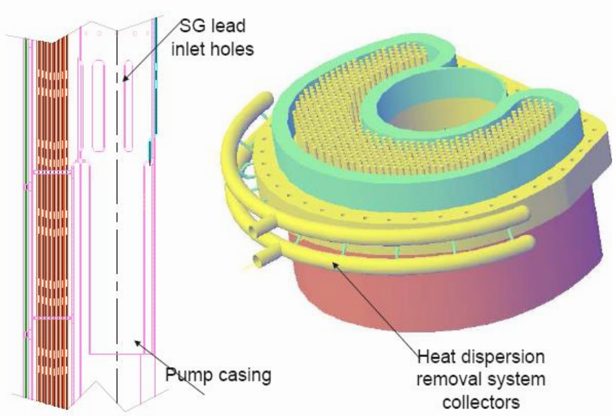
Schematic view of ELSY design

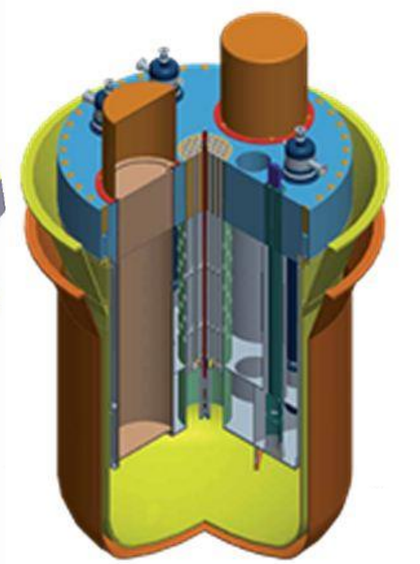
OBJECTIVE AND GENERAL FRAMEWORK

Objective: to illustrate ***R&D And Experimental Activities at ENEA Connected With The Use Of RELAP5-3D Code***

Framework: **National and International collaborations and projects in a wide spectrum of R&D fields**

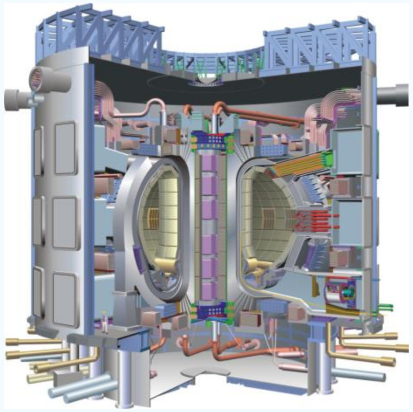
DEMO **LFR** ***ALFRED*** ⇨ ***W: 300 MWth***
Prim. fluid: molten lead
Sec. fluid: water/ steam

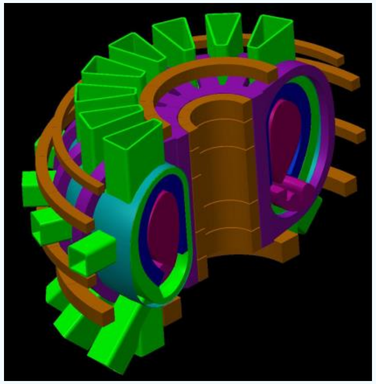




National (ITA) Program (PAR)
EU Projects
IAEA
OECD
International Collaborations

ITER AND DEMO ⇨ ***Design activities***
R&D activities





National (ITA) Program (PAR)
EU Projects
ITER Project
F4E
EFDA

Objective: to illustrate ***R&D And Experimental Activities at ENEA Connected With The Use Of RELAP5-3D Code***

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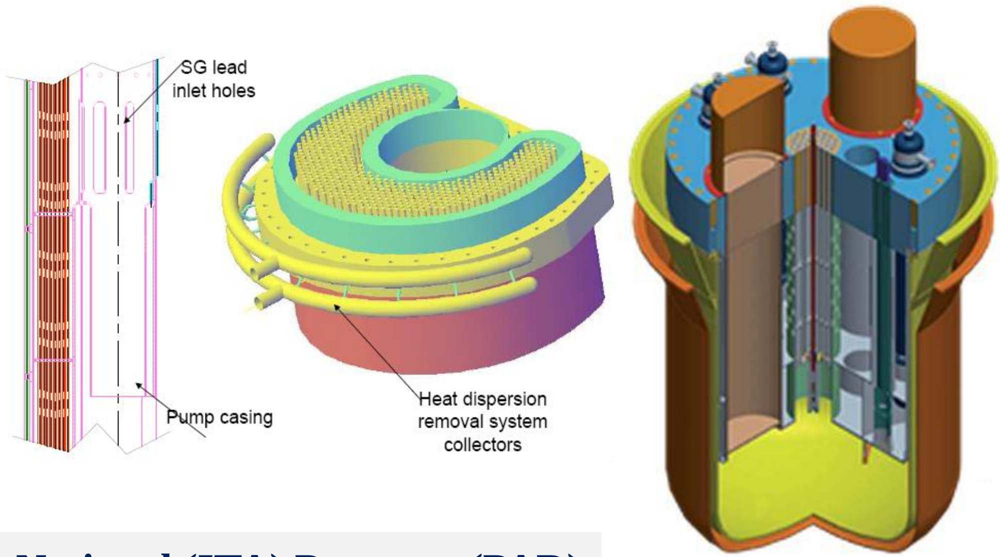


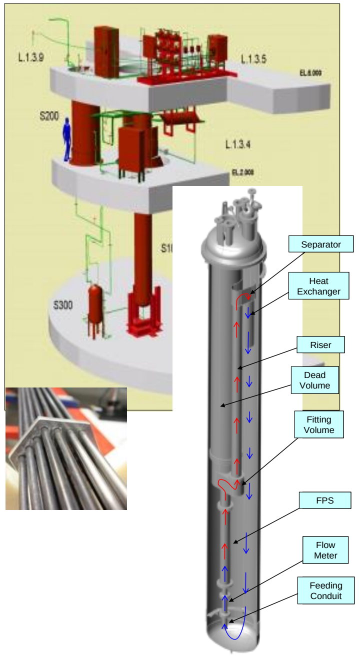
National (ITA) Program (PAR)

EU Projects

IAEA

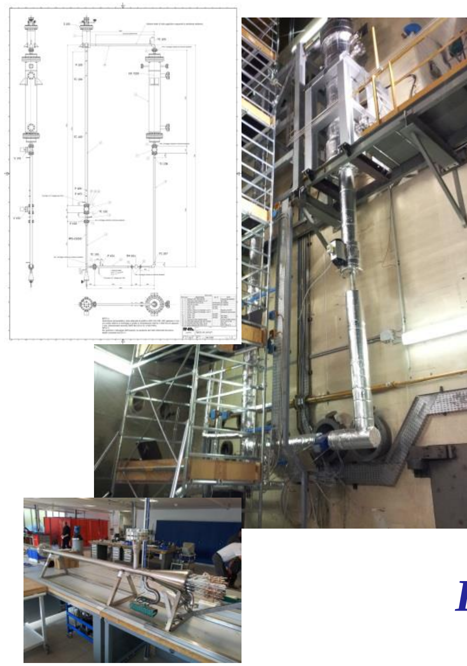
OECD

International Collaborations



CIRCE

90 LBE tons pool with instrumented bundle and 1to1 scale HX.
FPS power 900 kW

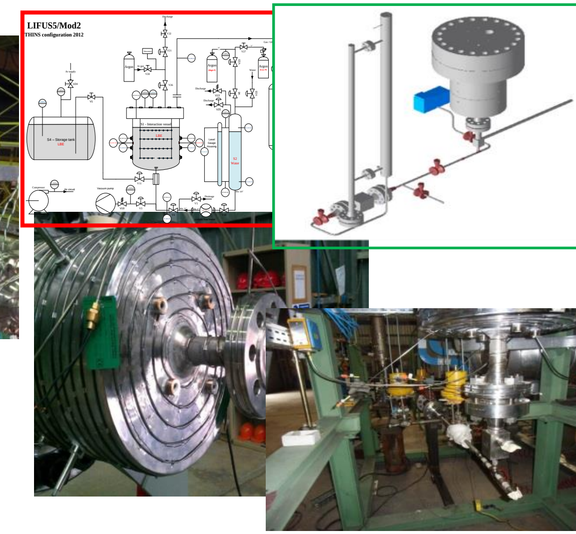


NACIE-UP

Natural/gas-lift circulation LBE loop with 19-pin instrumented **pin bundle.**

HELENA

Forced circulation Lead loop with mechanical pump, corrosion test section and valve test section



LIFUS5

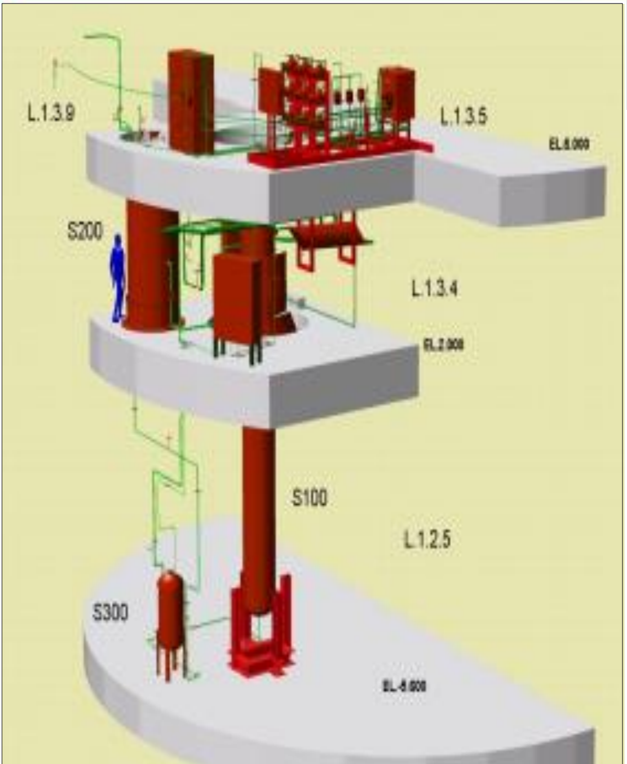
Facility with several test sections to investigate ***water/LBE interaction*** and SGTR phenomena

CFD
SYS-TH
SIMMER-III and IV

Neutronic
Fuel
Coupling

Other large and small scale exp facilities

CIRCE FACILITY

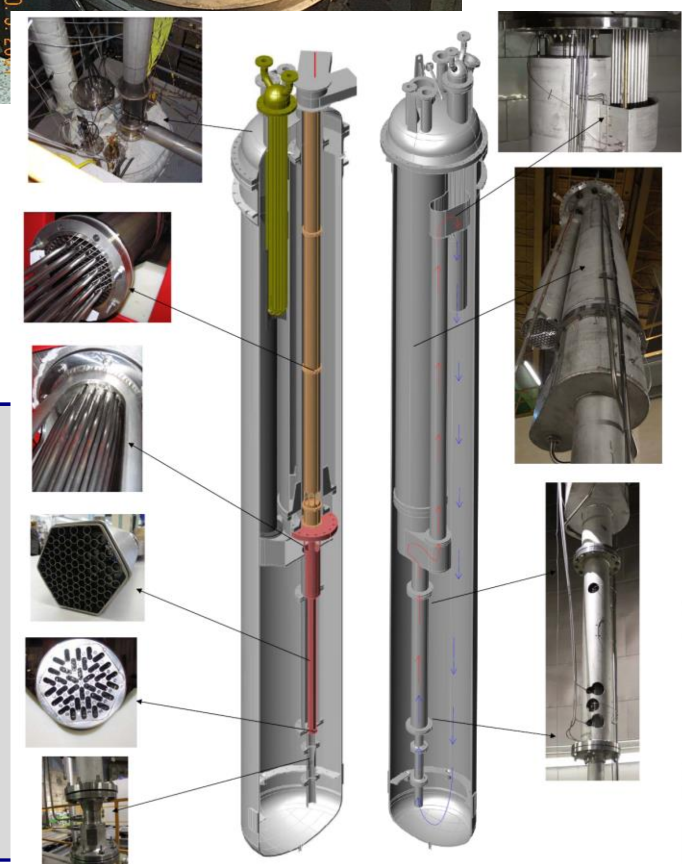


CIRCE facility

LBE primary coolant; water/superheated steam heat exchanger; air non-condensable DHR

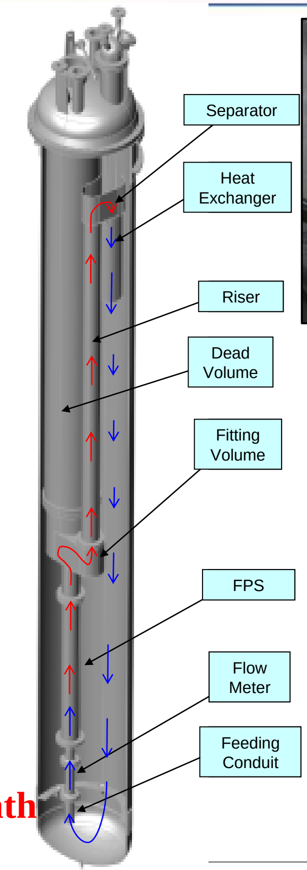
PARAMETERS	VALUE
Outside Diameter	1200 mm
Wall Thickness	15 mm
Material	AISI 316L
Max LBE Inventory	90000 kg
Electrical Heating	1 MW
Cooling Air Flow Rate	3 Nm^3/s
Temperature Range	200 to 550 °C
Operating Pressure	15 kPa (gauge)
Design Pressure	450 kPa (gauge)
Argon Flow Rate	15 Nl/s
Argon Injection Pressure	600 kPa (gauge)

- TH experiments (i.e. pool TH; assessing and improving empirical HT correlations; supporting SYS-TH, CFD and coupling validation; etc.)
- ITF experiments in different system configurations (i.e. transient and accident scenarios; phenomena; codes performance, etc.)
- Components development and testing
- Liquid metal chemistry in a pool configuration

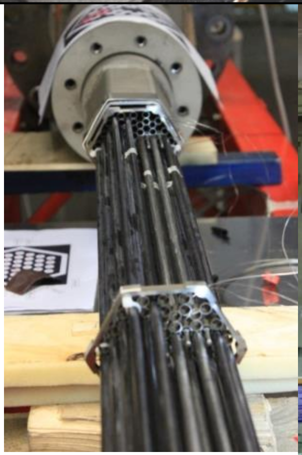

Details of CIRCE

RELAP5 APPLICATION TO CIRCE-ICE EXPERIMENTS

- RELAP5 simulations of 4 CIRCE-ICE tests:
  - Test A: Isothermal Characterization Test
  - Test B: Full Power NC experiment
  - Test C: Unprotected Loss of Heat Sink
  - Test D: Unprotected Loss of Flow

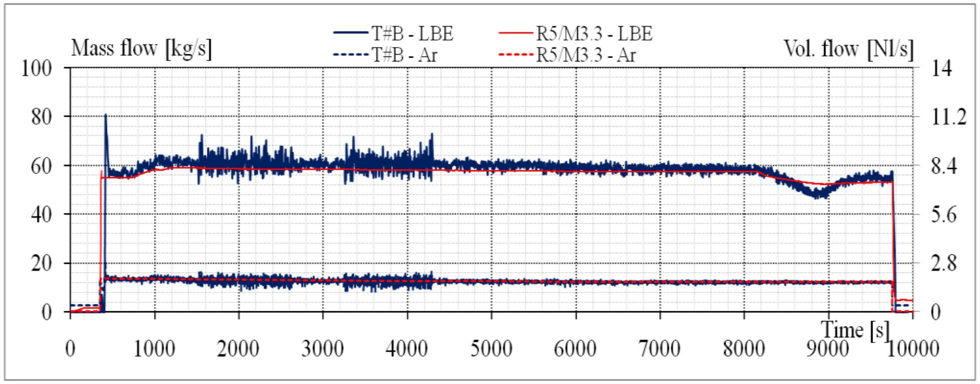


CIRCE flow path

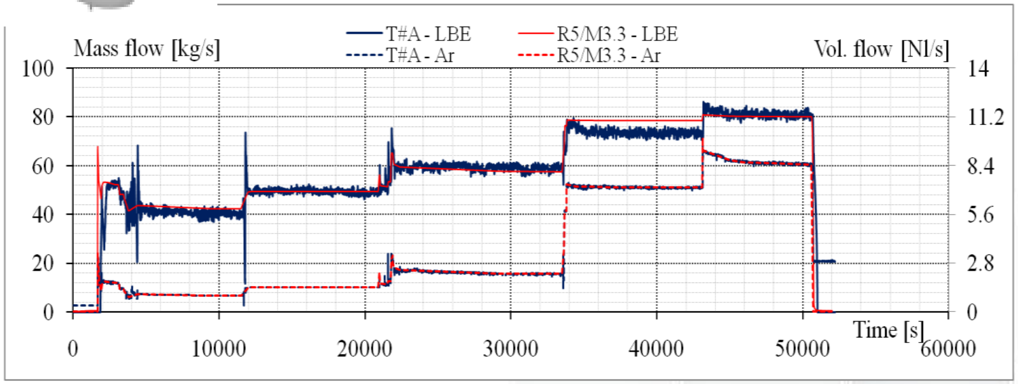


Fuel bundle

Test section



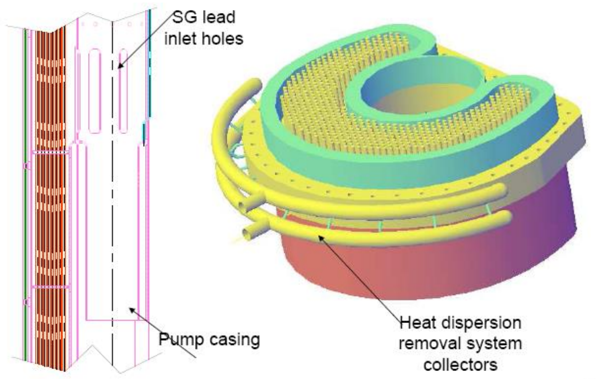
Characterization test



NC test: mass flow rate

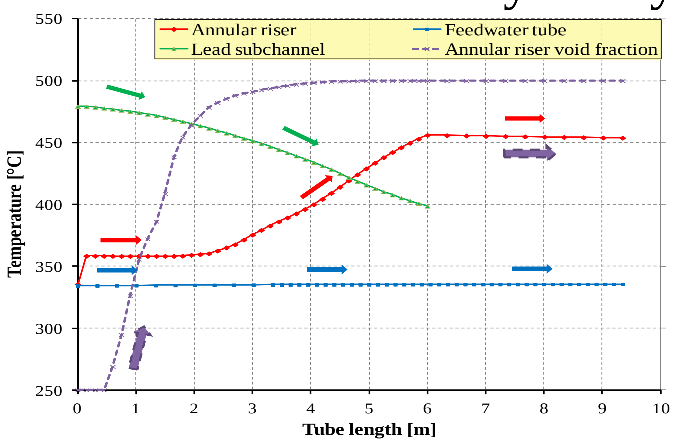
HERO experimental campaign in CIRCE facility

- ALFRED is the design of the LFR technology demonstrator
- HERO - **Heavy liquid mEtal pRessurized water cOoled** tubes is a test section will be installed in CIRCE facility.

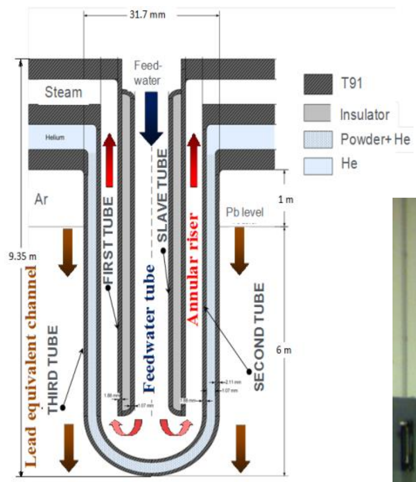


ALFRED design of SG casing

  - Reference SG tube: byonet type

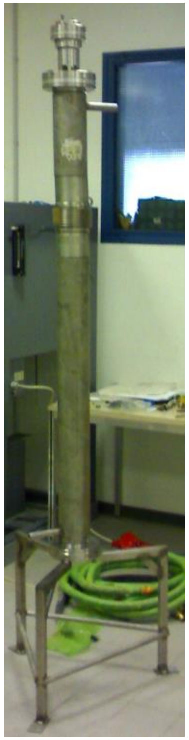


Pre-test RELAP5/Mod3 (ENEA version)

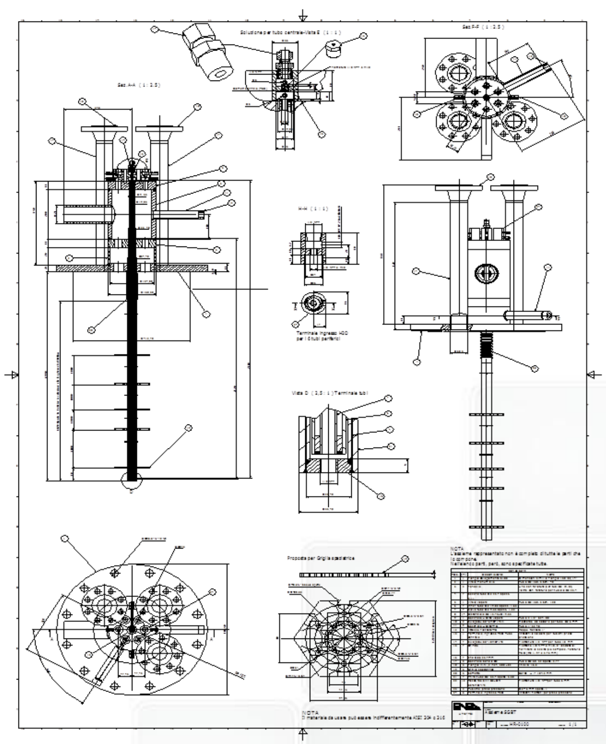


Byonet tube scheme

  - HERO: 7 byonet tubes of LFR SG scaled 1:1
  - Supported by TxP (Tubes for Powders) facility to:
    - Determine the thermal conductivity of powders into a representative annular gap
    - Determine the influence of the powder compaction grade on the conductivity.
    - Investigate the influence of the filling gas (Helium) pressure



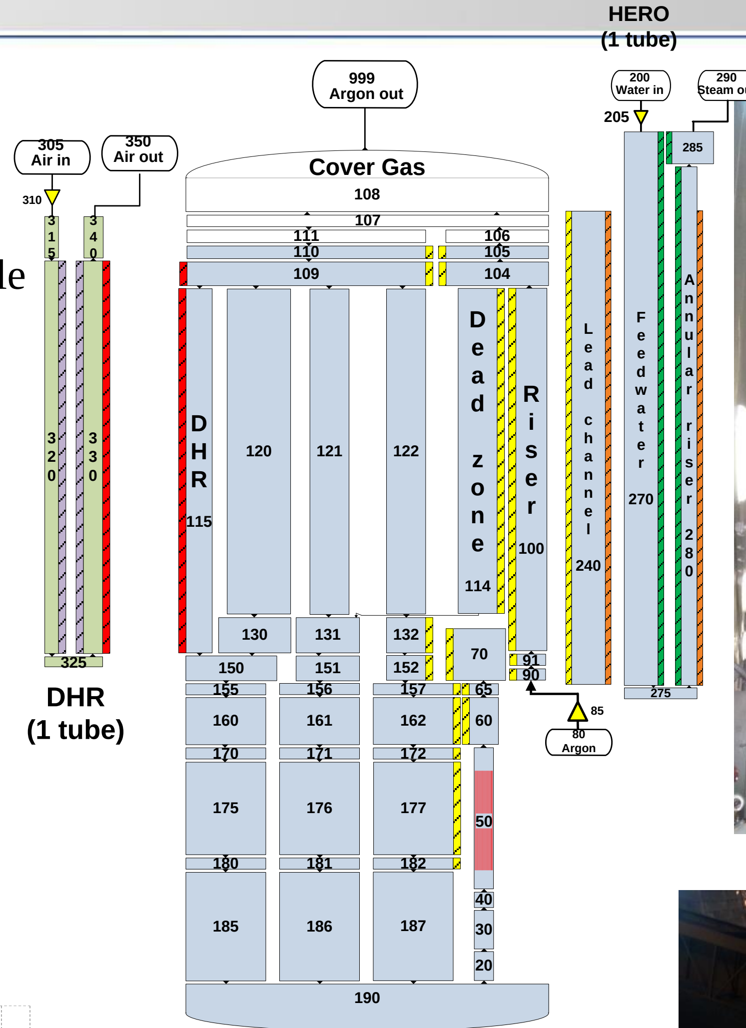
TxP



Test section design

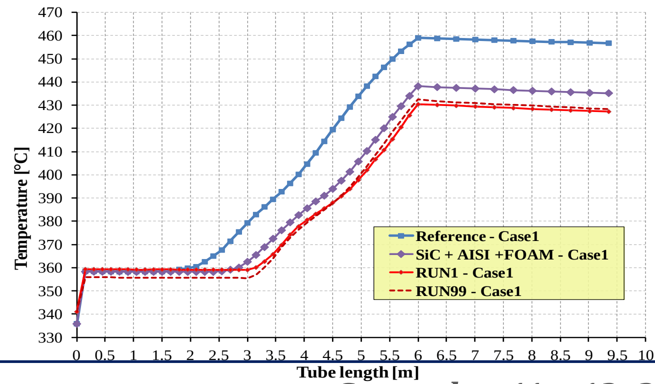
RELAP5 APPLICATION TO HERO EXPERIMENTS

- 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. pressure transducer; 8 mass flow rate gauges

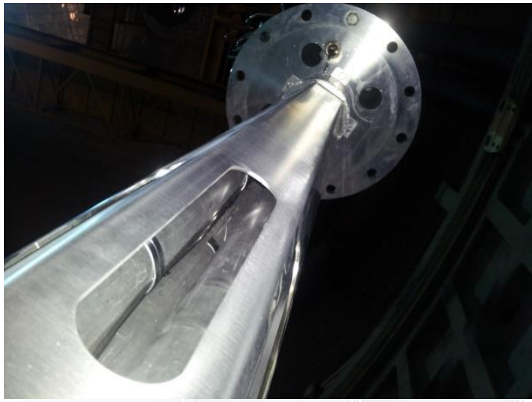


RELAP5 nodalization

HERO test section



Effect of the powders on the HEX performances

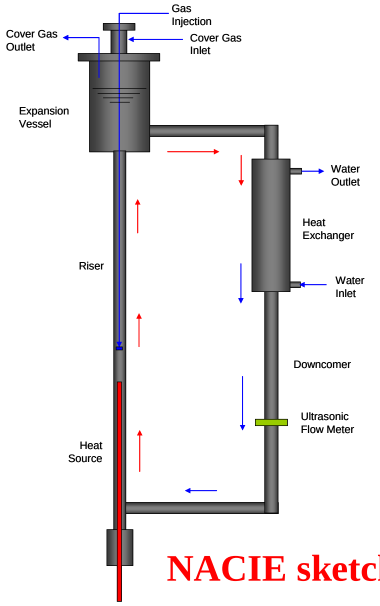


HERO upper part

NACIE FACILITY

- Vertical Parts Length: 8 m
- Horizontal Parts Length: 1 m
- Pipe Diameter: 2,5”
- Pipe Material: AISI 304
- Working Fluid: LBE
- HLM Inventory:1000 kg
- Average Temperature: 350°C
- Pin Assembly Power: 30-50 kW
- LBE Inventory: 1000 kg
- Design Pressure: 10 bar
- Design Temperature: 550°C

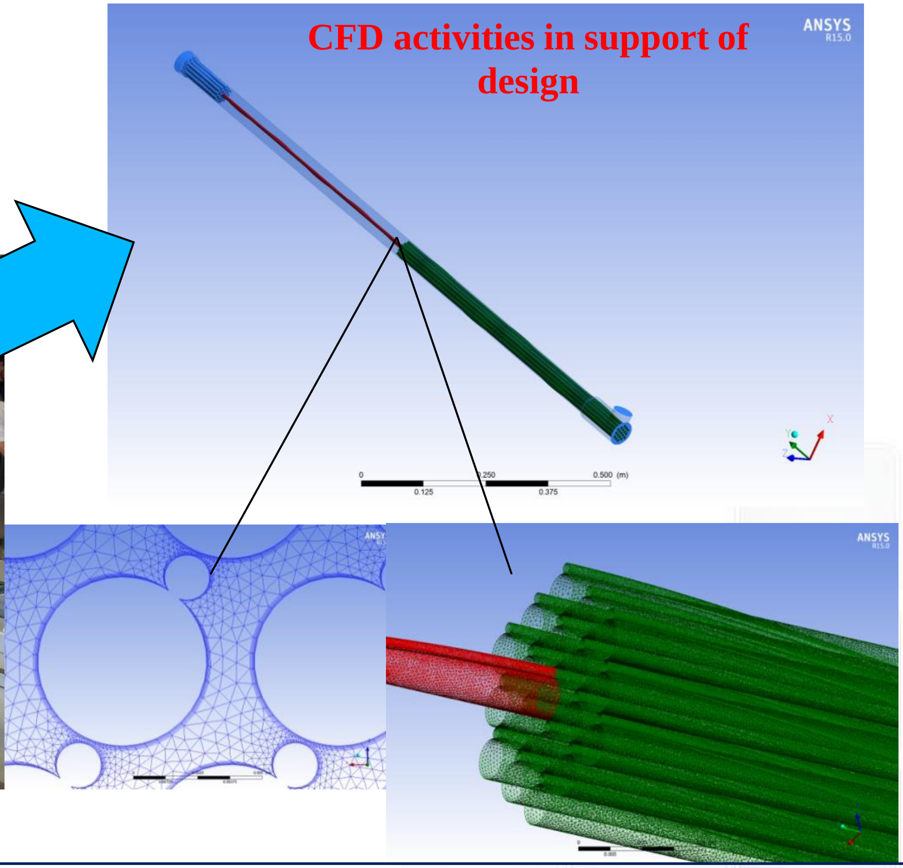
Natural Circulation Experiment



NACIE sketch


NACIE facility

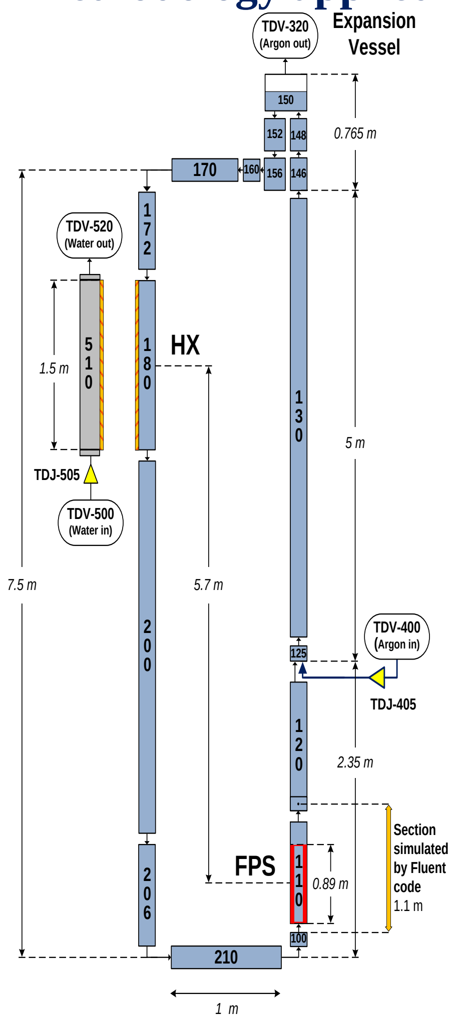

Fuel pin bundle (MYRRHA)



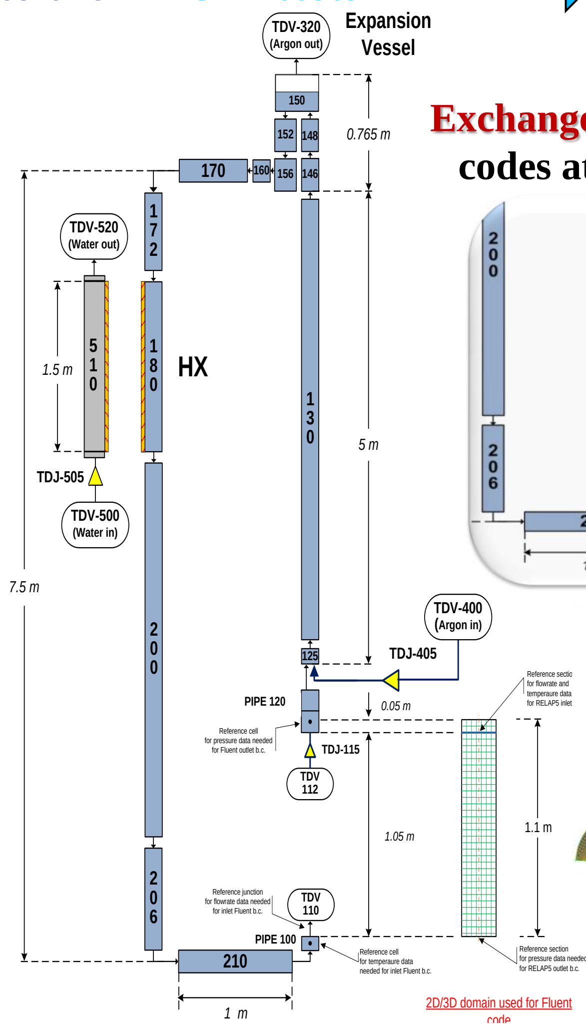
CFD activities in support of design

- 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

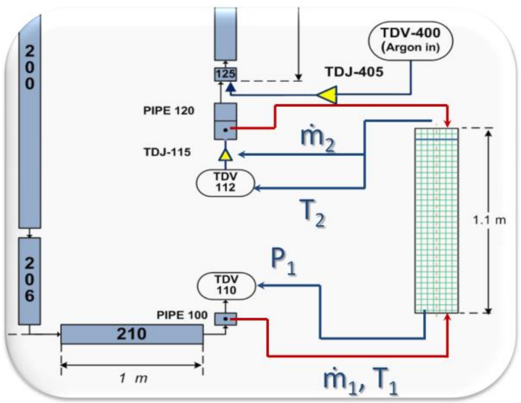


RELAP5 nodalization (stand alone)

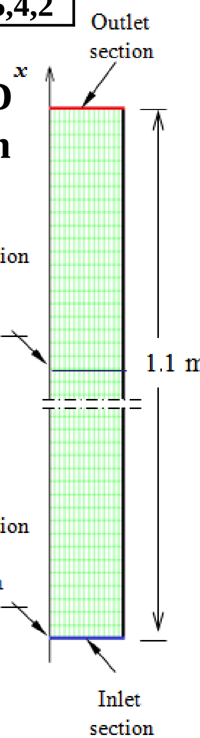


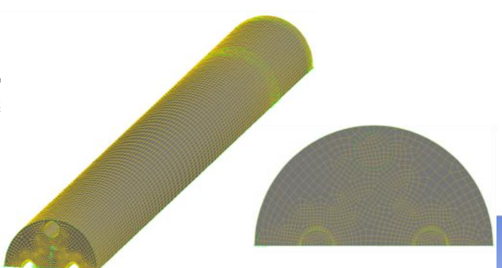
RELAP5 nodalization (coupled)

Exchange parameters among the codes at the interface domains

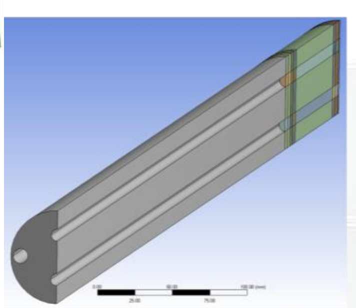


ANSYS FLUENT 2D axisymmetric domain (7200 cells)



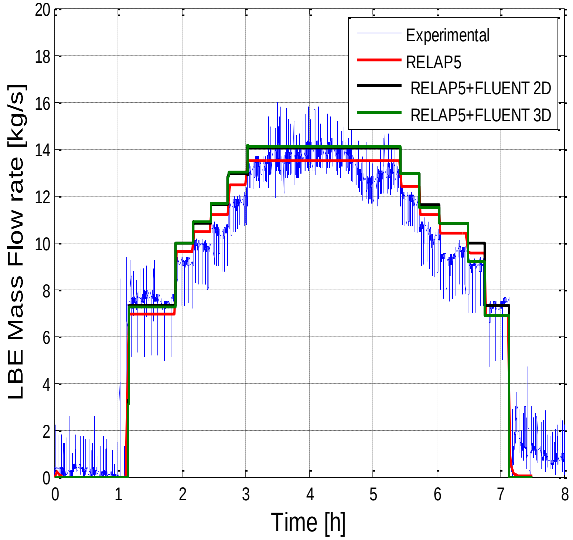


ANSYS FLUENT 3D domain (141045 cells)

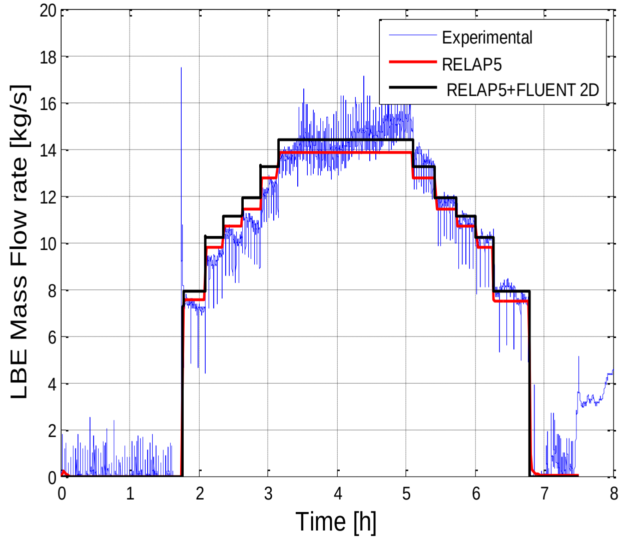


SYS-TH/CFD COUPLING

Test 206 **Mass flow rate LBE** **Test 306**



Overestimation of EXP LBE mass flow rate <12%

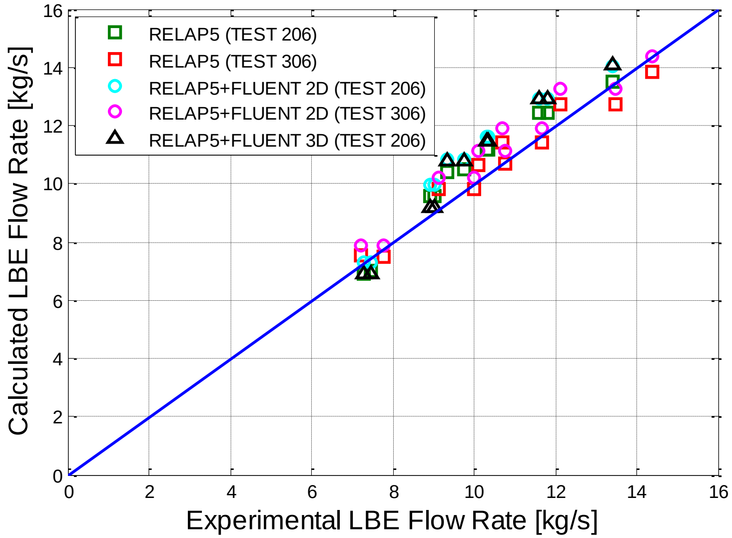


Overestimation of EXP LBE mass flow rate <10%

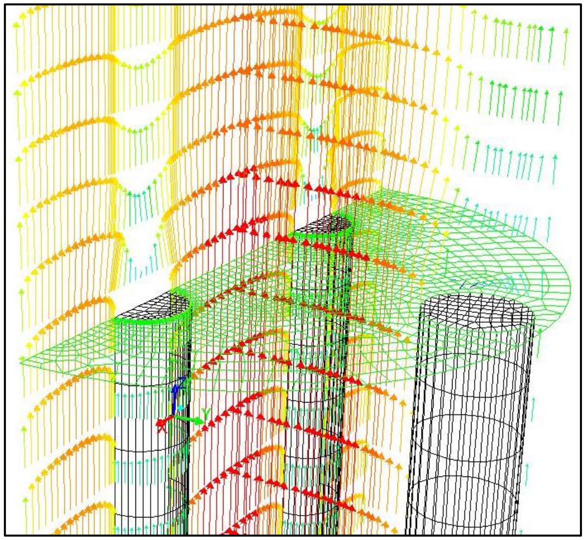
Name	T_{av} [°C]	*FPS* Power %	G_lift [Nl/min]
Test 206	200-250	0	2,4,5,6,8,10, 8,6,5,4,2
Test 306	300-350	0	2,4,5,6,8,10, 8,6,5,4,2

Calculations performed

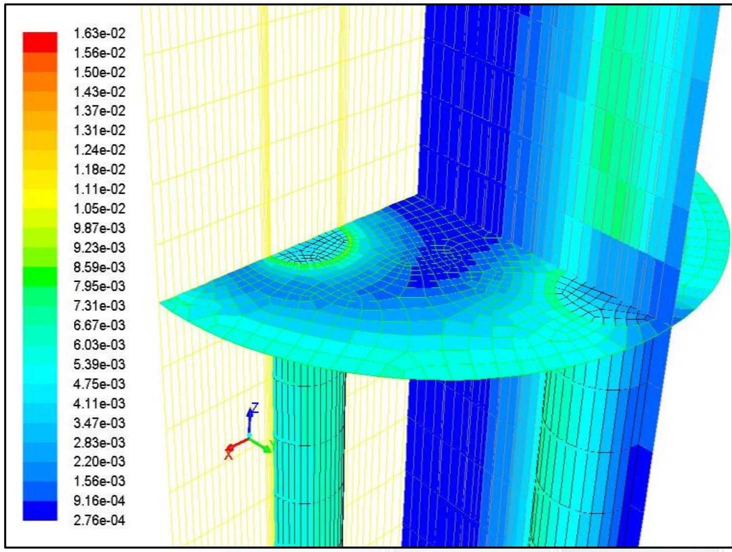
- **TEST 206**
- **RELAP5 stand-alone**
- **Coupled R5-CFD 2D**
- **Coupled R5-CFD 2D**
- **TEST 306**
- **RELAP5 stand-alone**
- **Coupled R5-CFD 2D**



LBE mass flow rate CALC *Vs.* EXP



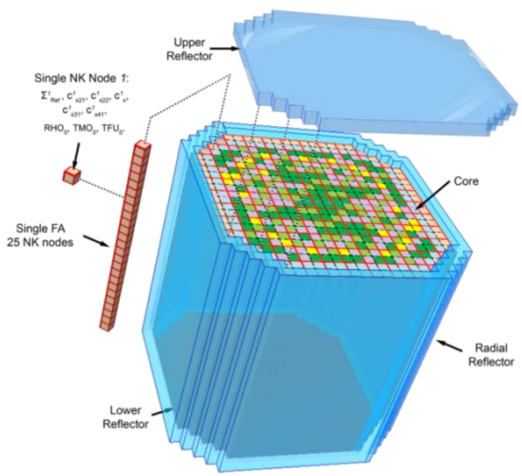
Vertical velocity vectors (z)
0.88 m/s (t = 3.5h Ar flow rate 10 Nl/min)



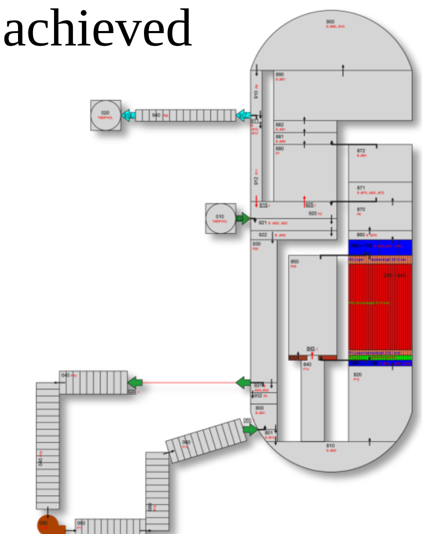
Turbulent kinetic E distribution *k* [m²/s²]

OECD/NEA Oskarshamn-2 BWR Stability Event Benchmark [ENEA CR CASACCIA]

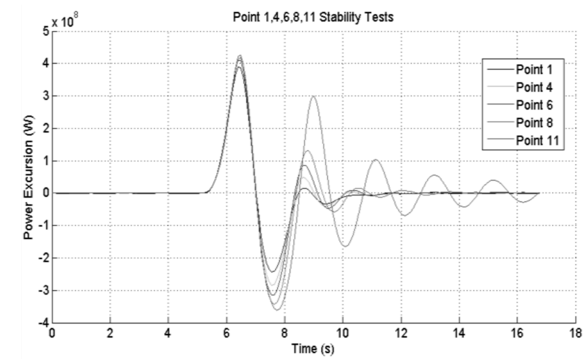
- 3D NK/TH State-of-the-art model has been developed and qualified for the instability analyses
  - ✓ **Feb. 1999 event** Instability event reproduced with good agreement
  - ✓ Core **Axial Meshing** influence on transient solution identified
  - ✓ **HZP** solution and **stability test** at different power & recirculation mass flow rate levels achieved

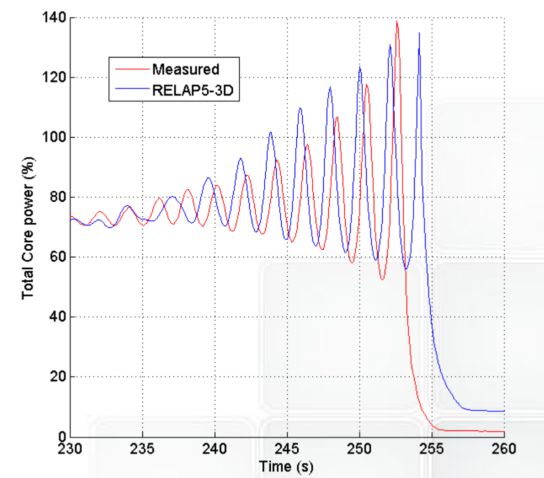


Oskarshamn-2 NPP
Core 3D NK Modelling

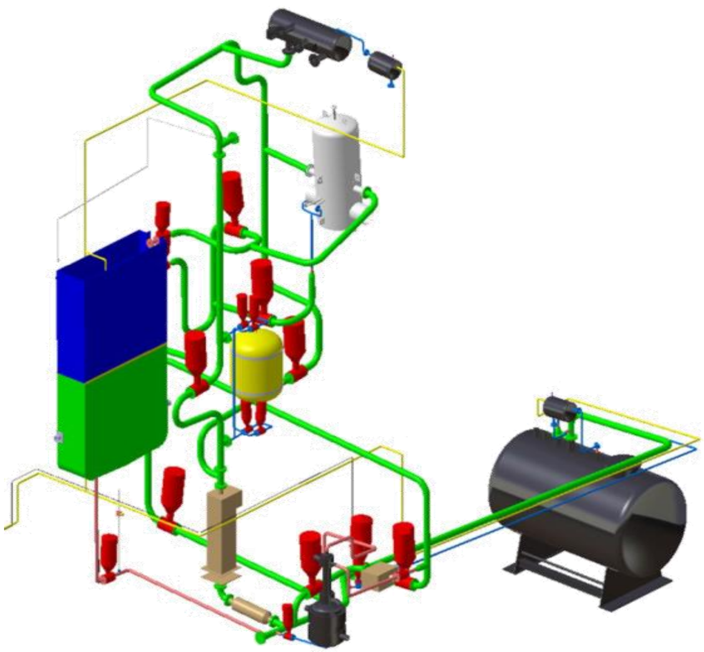


Oskarshamn-2 NPP
R5-3D Nodalization

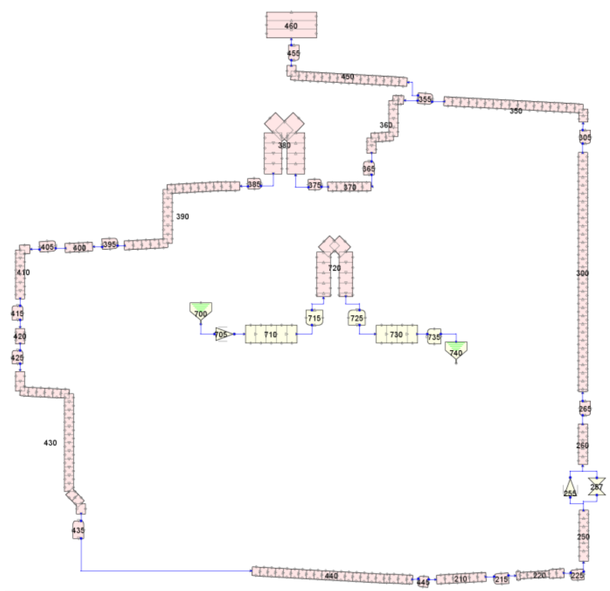




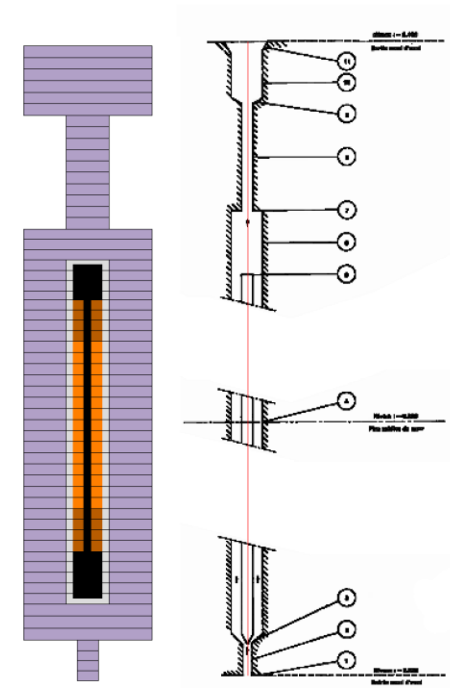
- **ASTEC-Na** *severe code development* → code-to-code calculations → define a set of bounding results, validated using experimental data:
  - ✓ **CABRI** experiments on **PHENIX SFR** pre-irradiated fuel pins → loss of flow and transient overpower
  - ✓ **KASOLA** facility pre-tests → Loss of heat sink, loss of flow



KASOLA Facility

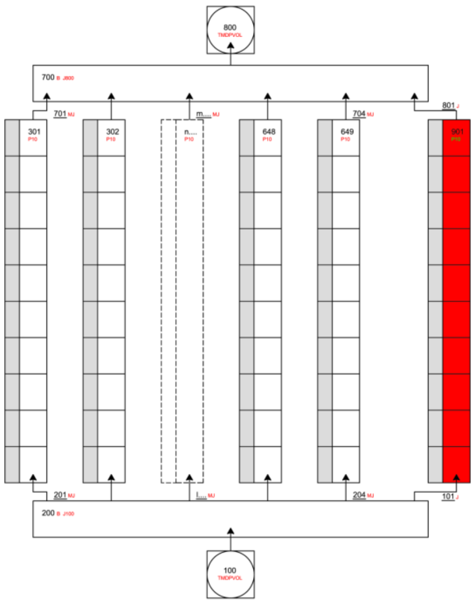


KASOLA R5-3D Nodalization

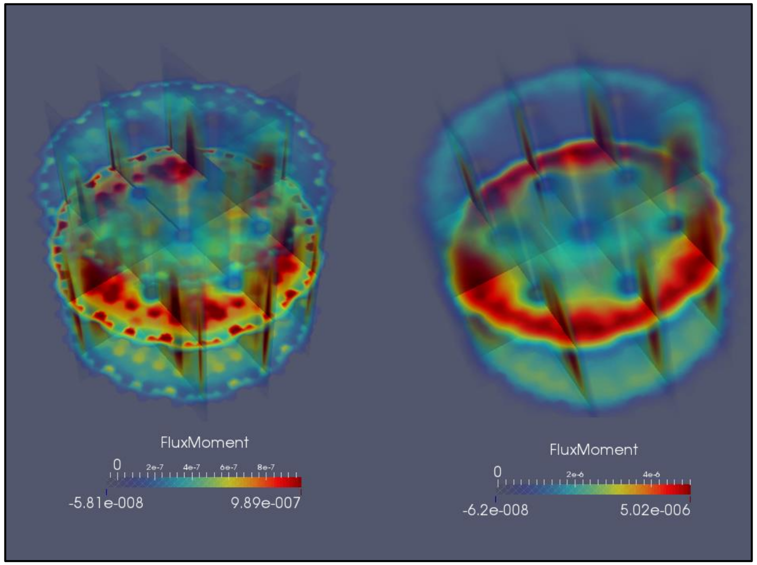


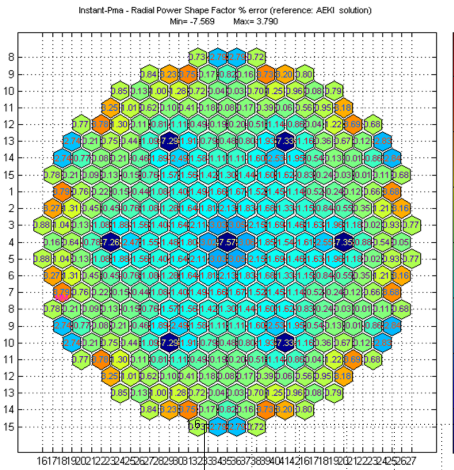
CABRI Test Nodalization

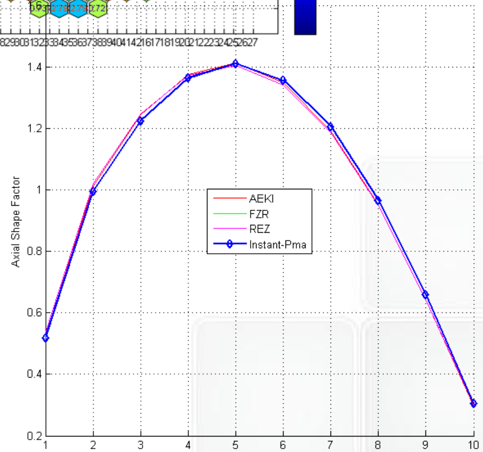
- Testing **RELAP5-3D/PHISICS** capabilities by **AER DYN003** benchmark simulation:
  - ✓ 2G 3D NK standalone simulation → achieved
  - ✓ Initial HZP steady state coupled calculation → similar to the other participant solutions



DYN003 R5-3D Nodalization



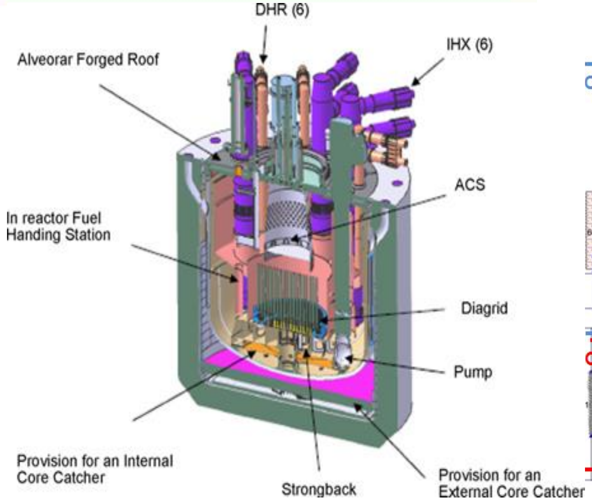




PHISICS Steady State Results

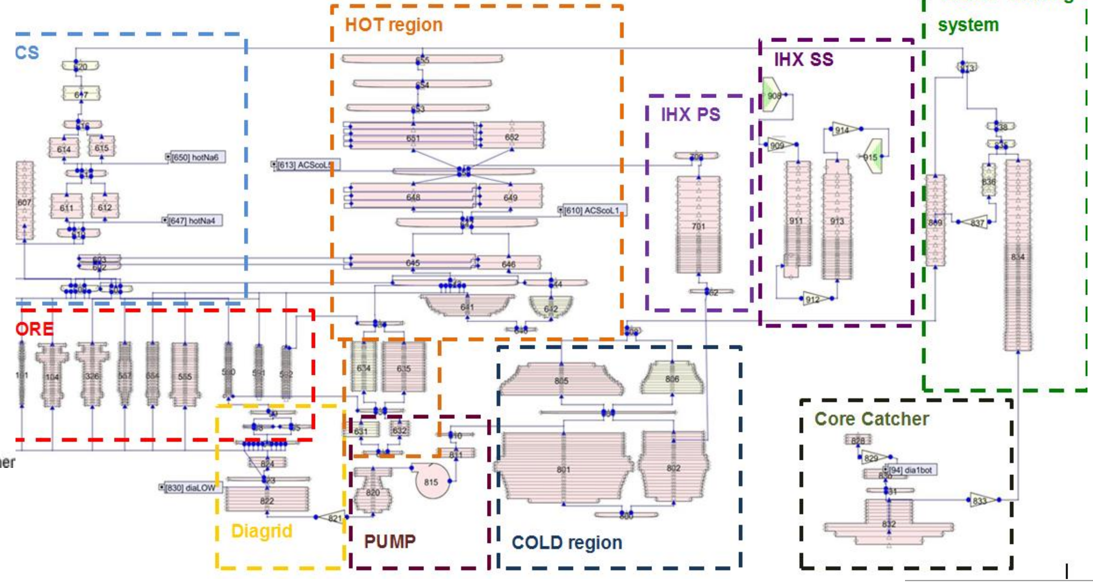
EC PELGRIMM PROJECT: CP-ESFR NODALIZATION

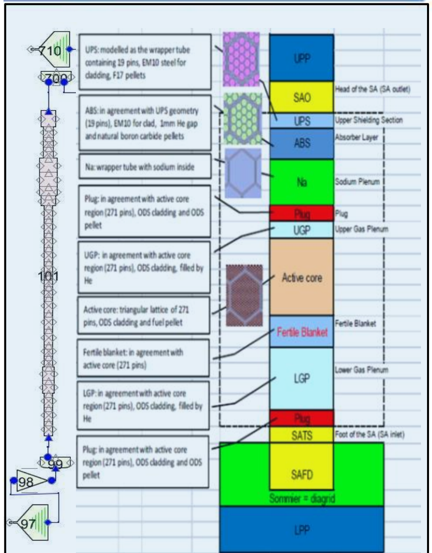
ENEA AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE



AREVA CP-ESFR

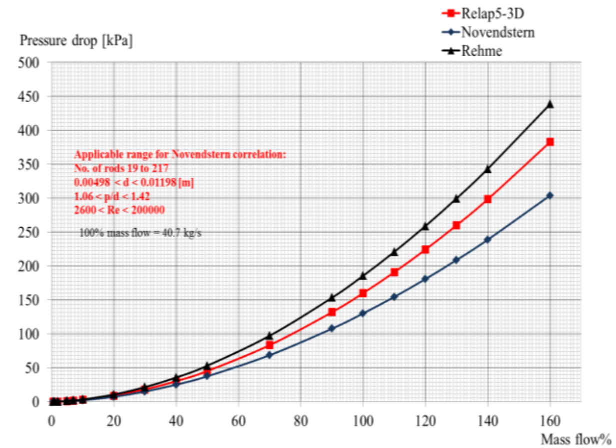
CP-ESFR RELAP5-3D nodalization



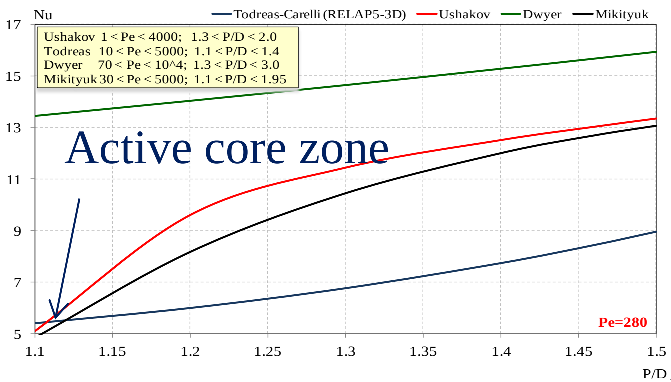


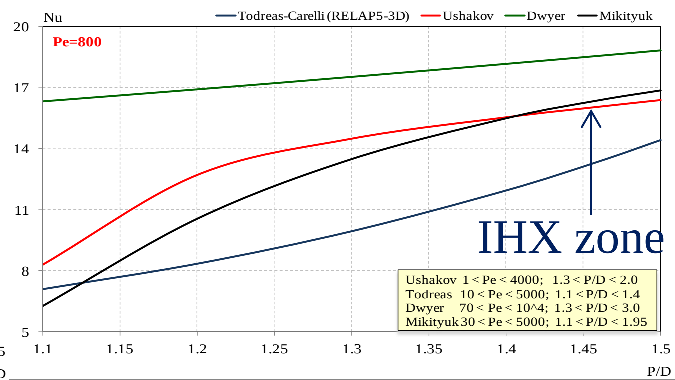
FA: R5-3D vs. design

- TH system model of CP-ESFR for SS and Trans calculations
- Assessment of core TH parameters for different core configurations and design choices (pelletized MOX and MA MOX fuel)
- Boundary conditions for fuel pin mechanics analysis



Friction losses in wire wrapped FA vs. mass flow – R5-3D results and



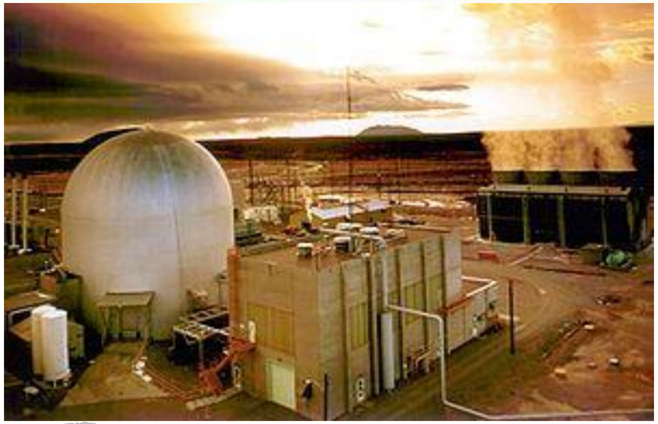


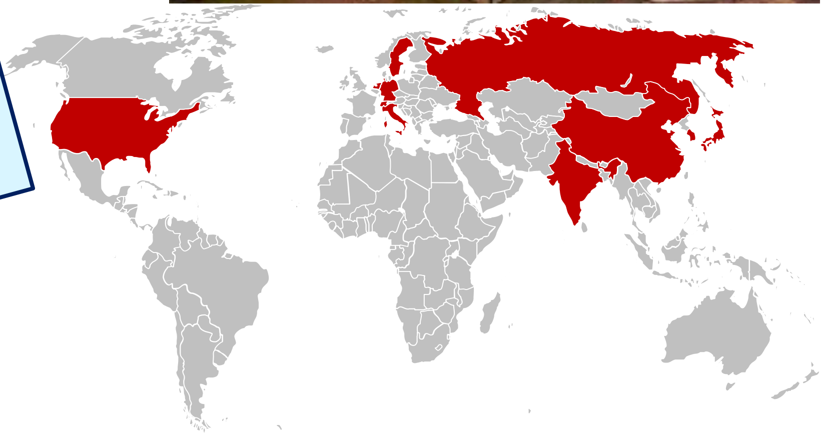
Nu vs. (P/D) @ Pe values corresponding to active core and IHX zones

- R5-3D underestimate Nu, if compared with correlations
- RELAP5-3D© convective HTC @ nominal steady state are in agreement with AREVA NP design data

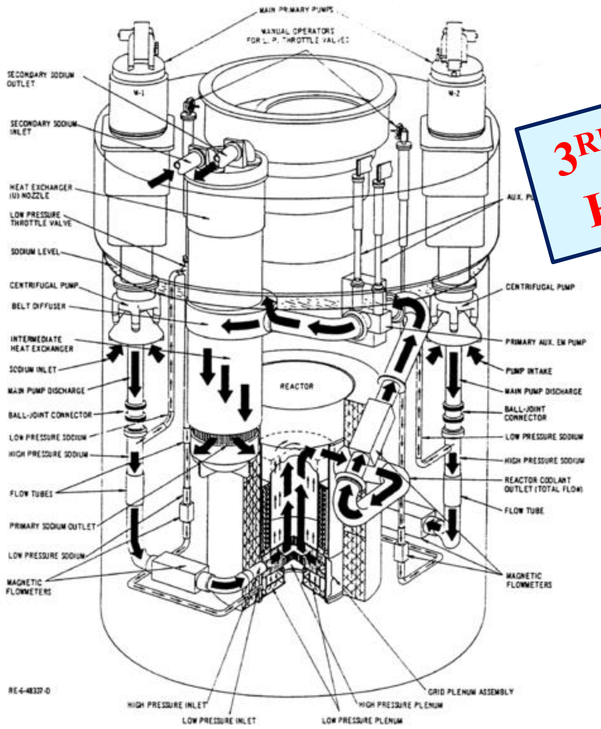
IAEA CRP Benchmark on EBR-II

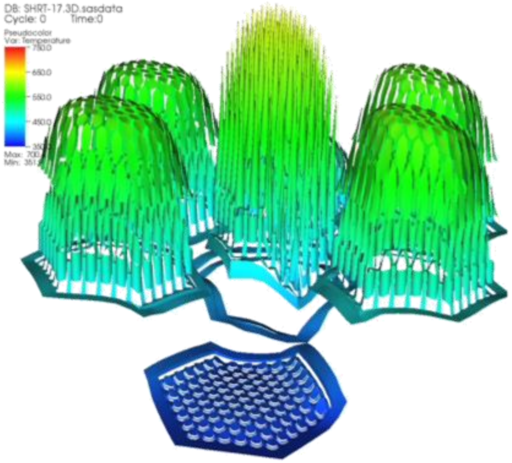
- Stefano Monti, IAEA
- ANL, US providing data and technical coordination
- EBR-II SHRT-17 and SHRT-45R provided by ANL
  - Protected and Unprotected Loss of Flow
  - Multi-physics activity based on experimental data





3RD CRP TM MEETING WILL BE HOSTED BY ENEA, March 2015





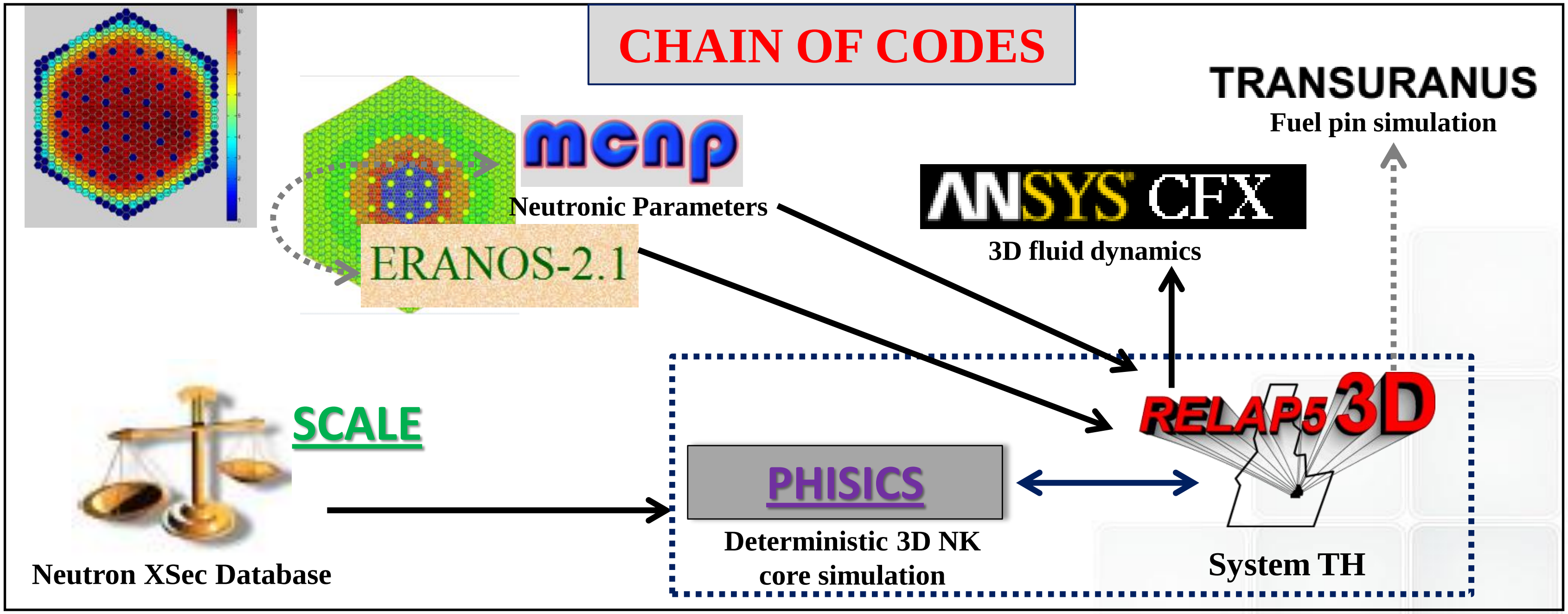
Participants	
China	France
Germany	Italy
India	Japan
Korea, republic of	Netherlands
Russian Federation	Sweden
Switzerland	**USA**

IAEA CRP Benchmark on EBR-II

- ENEA participates
  - performing SYS-TH calculation by R5-3D code
  - exploiting the use of a chain of codes involving SYS-TH, neutron physics and CFD

Activities in progress:

- Development of **MCNP6** model of EBR-II reactor → calculations of 0D NK parameters (K_{eff}, β_{eff}, reactivity coefficients, 3D power maps)
- Calculations of Neutron XSec Database by **SCALE** code
- Development of **PHISICS** 3D NK model & coupling with **RELAP5-3D©** TH model
  - **SS** and **SHRT-45r** transient execution



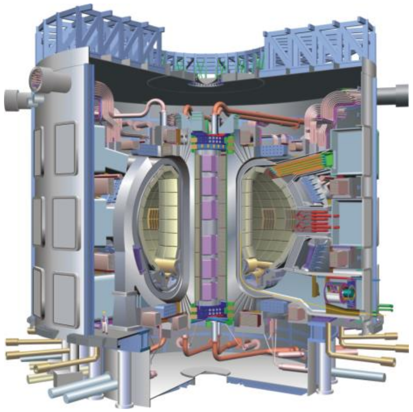
Objective: to illustrate ***R&D And Experimental Activities at ENEA Connected With The Use Of RELAP5-3D Code***

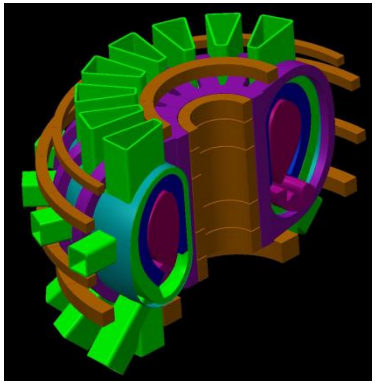
Framework: **National and International collaborations and projects in a wide spectrum of R&D fields**

ITER AND DEMO

Design activities

R&D activities





National (ITA) Program (PAR)

EU Projects

ITER Project

F4E

EFDA

LEADING TH FUSION FACILITIES @ ENEA CR BRASIMONE

EBBTF (European Breeding Blanket Test Facility)

HeFus

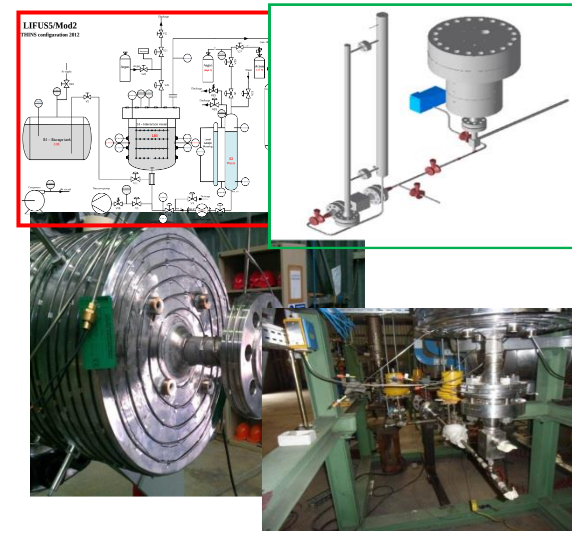
He cooled loop aimed at qualifying mock-ups HCPB/HCLL of the ITER TBM

IELLO

PbLi cooled loop aimed at qualifying mock-ups HCLL of the ITER TBM

TRIEX

Investigation on Tritium Extraction Systems for HCLL/WCLL blanket (ITER and DEMO)



LIFUS5

To investigate safety in WCLL breeding blanket (i.e. PbLi water reaction, set up of chemical reaction model in SIMMER-III code)

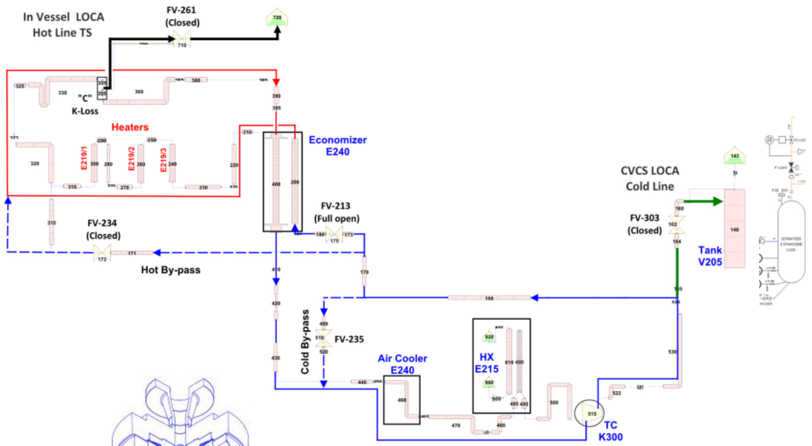
CFD
SYS-TH
SIMMER-III and IV

↔

Neutronic
Fuel
Coupling

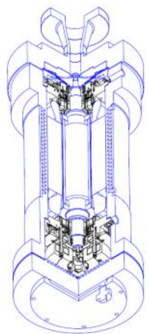
Other large and small scale exp facilities

RELAP5-3D He-FUS3



<u>Framework:</u> experimental activities in support of *HCLL* and *HCPB* TBS. T/H tests on **He-FUS3** will be used for validation and benchmarking suitable dedicated tools.

- R5-3D facility model was generated to simulate the experimental conditions.
- Post Test analysis will be used for the qualification of the model and validation of the code capability in reproducing He system T/H

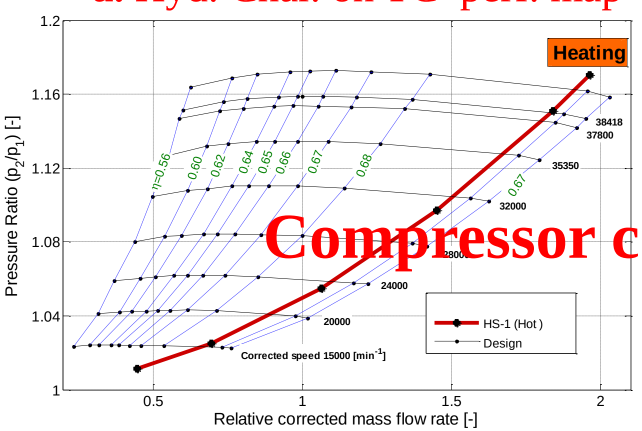


Turbo circulator schematic view

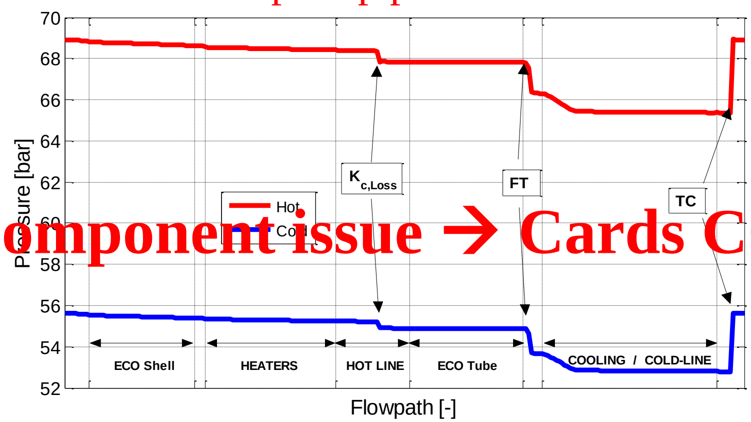
<u>R5-3D model of He-FUS3</u>: TC (40000 rpm, 1.4 kg/s), Heaters (210 kW) ,Economizer, Air Cooler, Water HX, "In Vessel" hot LOCA , "CVCS" cold LOCA lines, Piping /Valves; Cold /Hot By-Pass

- COLD and HOT loop conditions
- TC modeled with R5-3D compressor component (***cprssr***):→ N from 8000 to 41000 rpm.

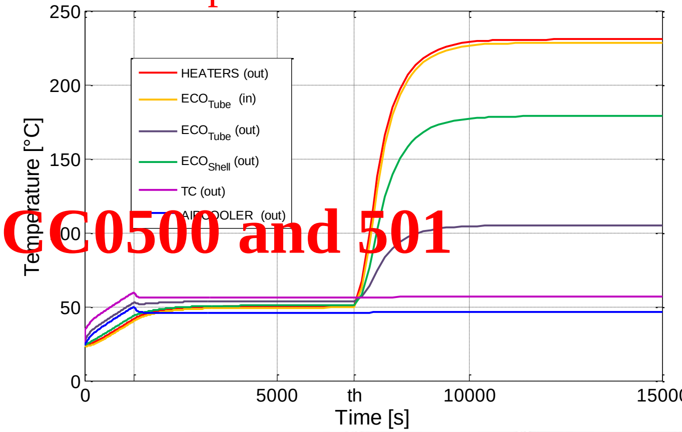
a. Hyd. Char. on TC perf. map



b. T and p loop profile



c. Temperature trend

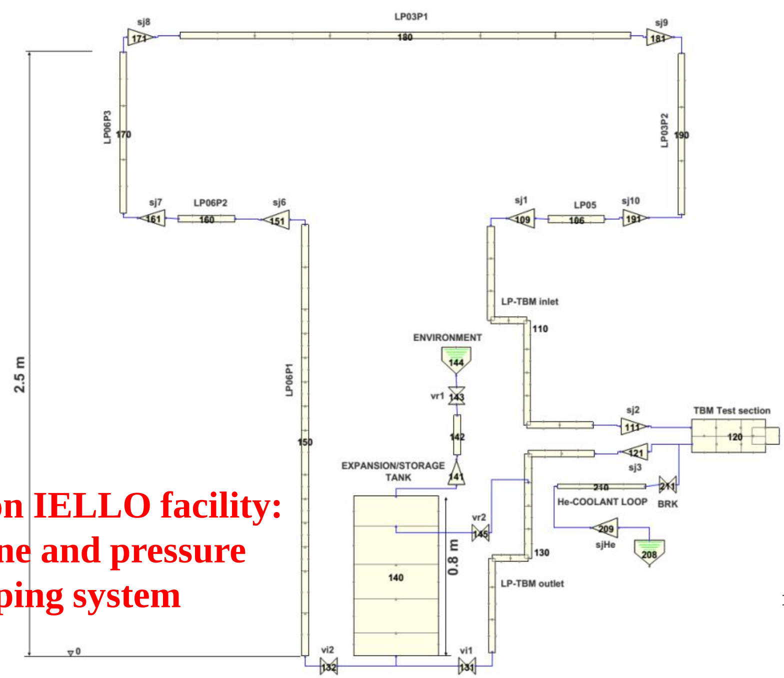


Compressor component issue → Cards CCC0500 and 501

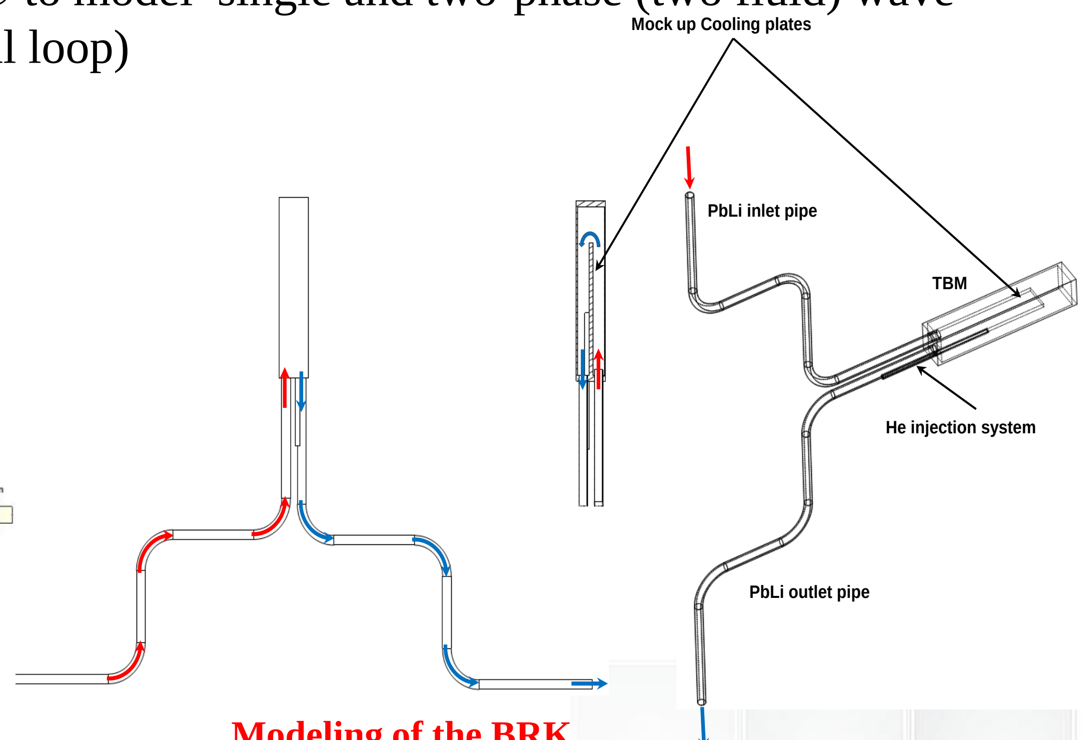
RELAP5-3D ANALYSES OF HCLL IN-TBM LOCA TESTS IN IELLO FACILITY

ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

- F4E Framework Partnership Agreement (FPA 372) for the conceptual design of European Test Blanket System
- HCLL-TBS IN–TBM LOCA test in IELLO facility
- RELAP5-3D© model in support of the activity
- Test Objectives
  - Pressurization and the compression wave propagation into the Pb-Li loop in case of injection of helium at 80 bar, due to the rupture of a cooling plates.
  - Demonstrate capability of RELAP5-3D © to model single and two-phase (two fluid) wave propagation (fast transients in liquid metal loop)

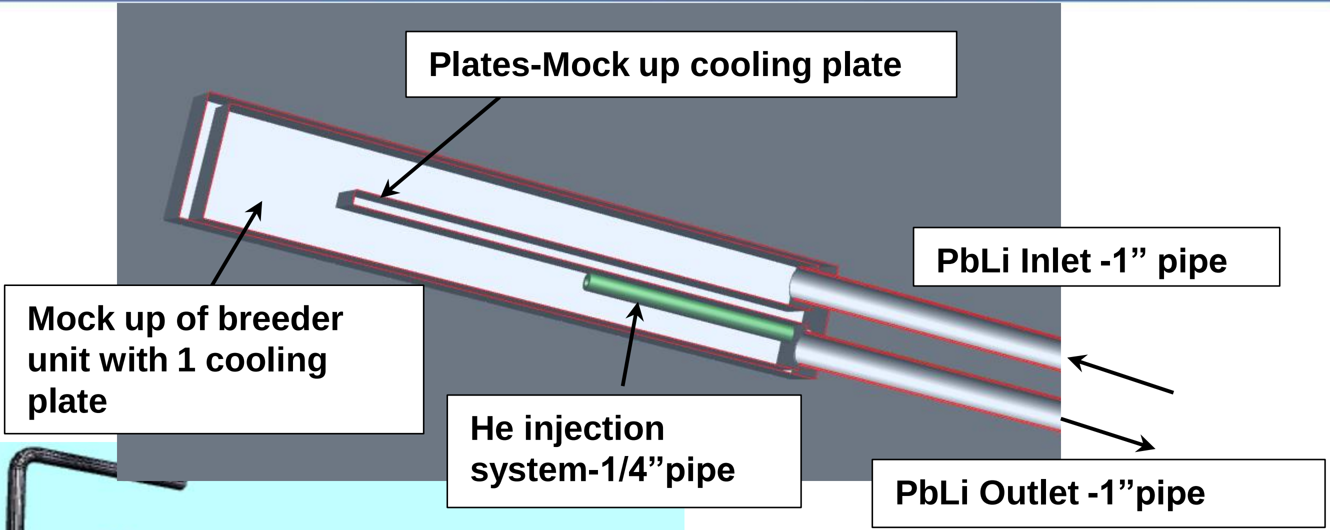


Nodalization IELLO facility: break zone and pressure damping system

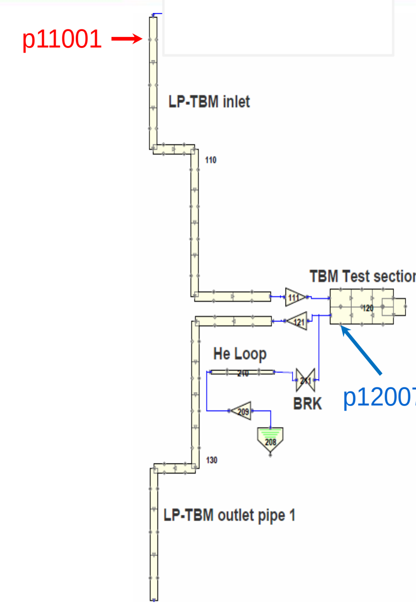


Modeling of the BRK

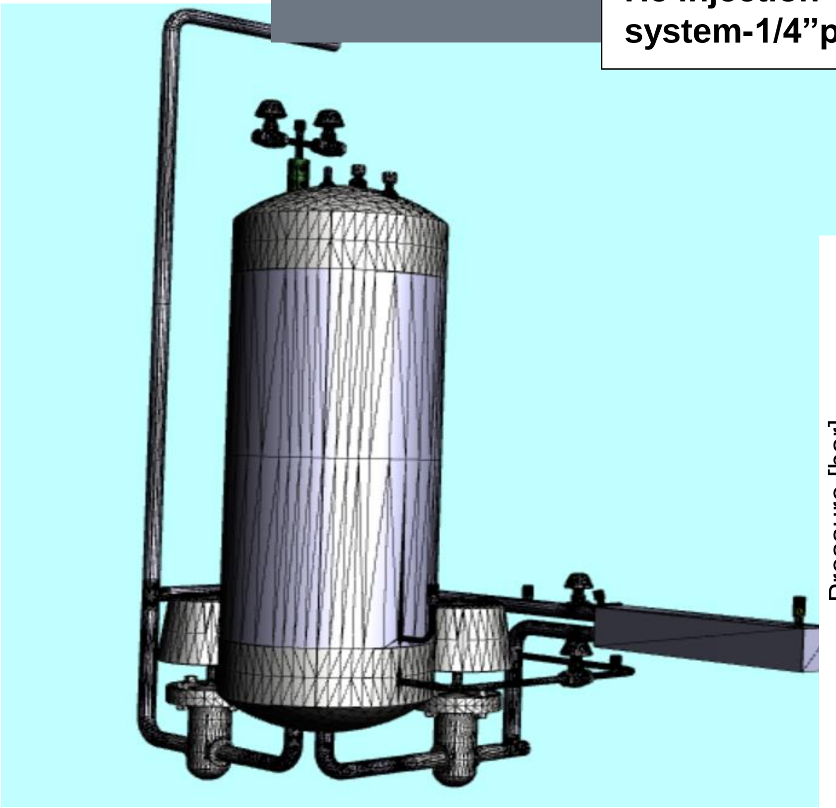
RELAP5-3D ANALYSES OF HCLL IN-TBM LOCA TESTS IN IELLO FACILITY



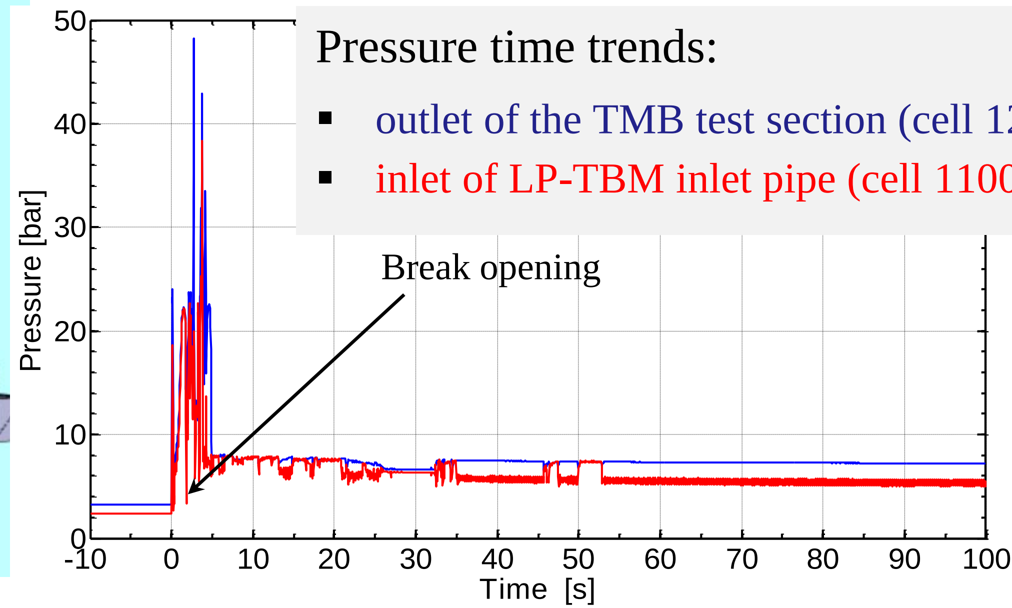
Design of the test section



Modeling of the BRK



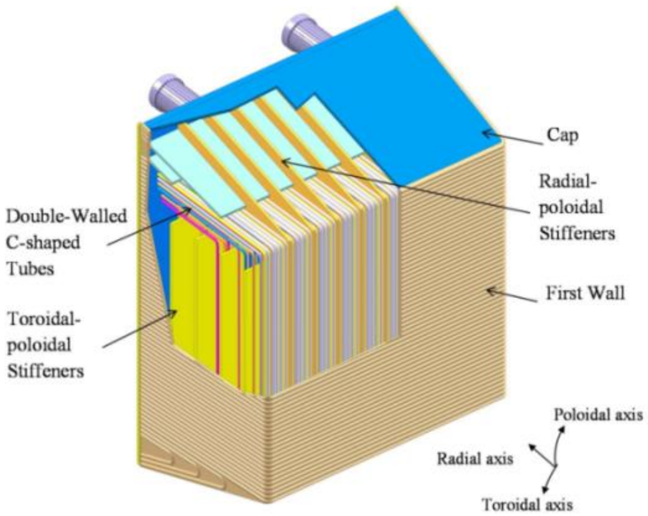
Design of the test section



Design of the test section pre-test analysis

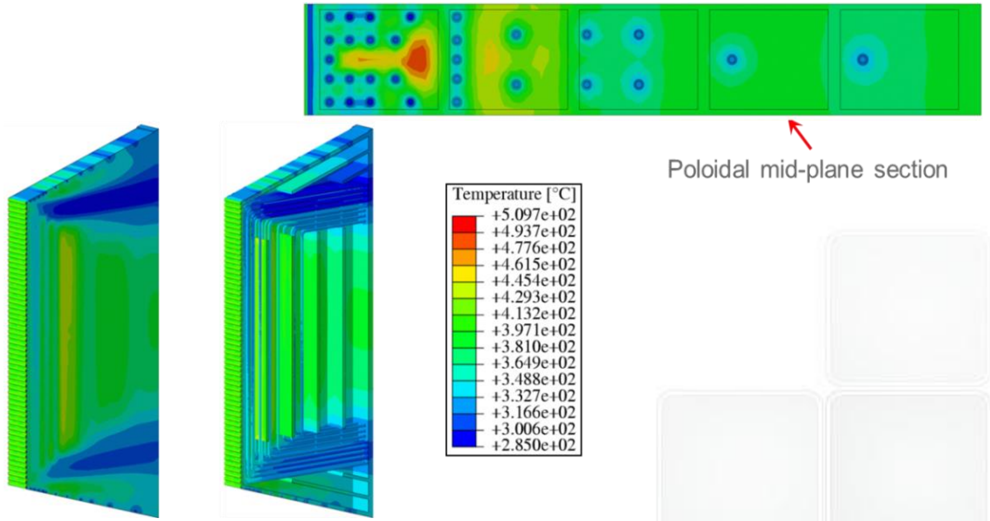
EFDA Project 2014: WCLL DESIGN

- WCLL BB Design (*2014-2018*)
  - **Objectives** is <u>to deliver feasible and integrated concept design</u> of the WCLL BB for the DEMO Plant at the Concept Design Review meeting the Plant Requirements
  - ENEA leading organization of the design team
  - RELAP5-3D (and RELAP5) is one of the numerical tools proposed for supporting the design activities



WCLL design (CEA, 2013)

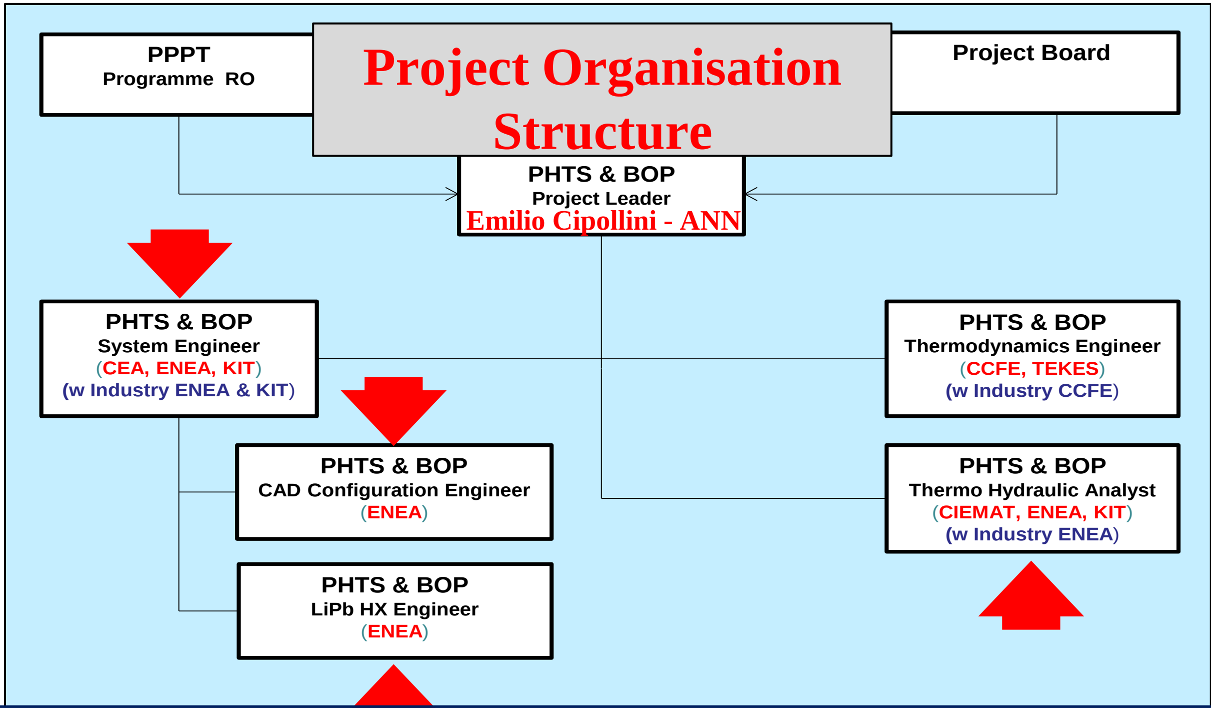
- Activity in progress (started in 2014):
  - preparation, set-up and documentation of RELAP5-3D© nodalization for steady state and transient SYS-TH analyses
  - identification and planning of future coarse mesh and local three dimensional CFD analyses



Thermo-mechanical analysis - normal condition (University of Palermo, 2013)

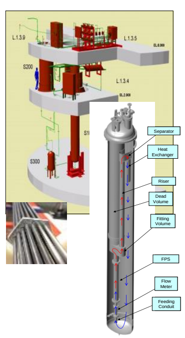
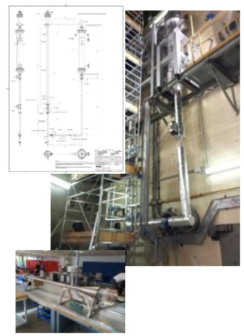
EFDA Project 2014: Primary Heat Transfer, Balance of Plant & Site Systems

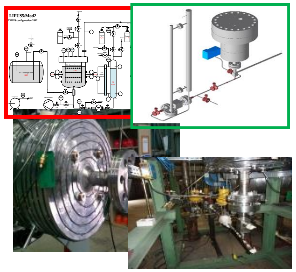
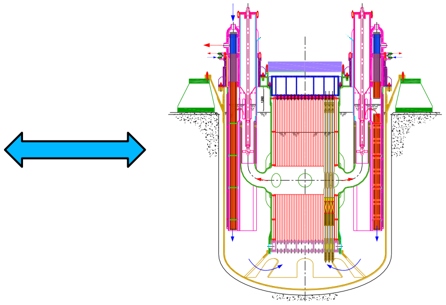
- **ENEA activities**, *in cooperation with ANN (linked partner) and SRS srl (sub-contrator)*
  - System Requirements Documents (*including System Functions; System Design Criteria; System Operation Modes; Component Requirements; Layout Requirements; Interfacing System Requirements; Maintenance Requirements*)
  - System TH and thermodynamic modelling of BoP configurations in coherence with Breading Blanket conceptual designs
  - Conceptual design of the BoP systems and preliminary design of main components (according with SRD specifications)
- Current **Main Challenges**
  - Feasibility of Steam Turbine (life and cost) ➡ *Heat Storage Facility*; *Water Cooling Option difficult – Sizing Criteria*
  - DHR during periods other than plasma operation ➡ less than 2%
  - Energy Internal Demand ➡ Define priority
  - System Boundaries / Functions (*Cooling Capability / Power Generation*)



Conclusive Remarks

- National and International collaborations and projects connected with LFR & ADS and ITER & DEMO reactors

- Experimental facilities in operation @ Brasimone research center devoted to TH investigation as well as safety investigations

- Numerical activities are carried out i.e SYS-TH, NK, . CFD, Fuel, including Coupling