A MULTIPHYSICS APPROACH TO LFR ANALYSIS

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Technical Meeting on the Benefits and Challenges of Fast Reactors of the SMR Type, Milan, Sept. 26th, 2019

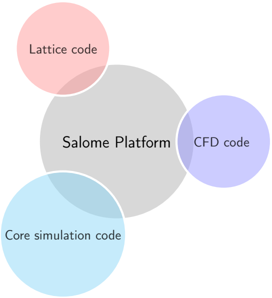
Key-words

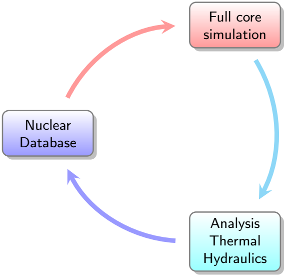
- Open-source
- Multiphysics, coupling different aspects
- Wrapping unifying environment
- Allowing the management of large amount of data

Introduction of multiphysics approach

Development of computational platform that integrates different computational tools, into the common wrapping framework given by the **SALOME platform**:

- Lattice code, **DRAGON**
- Full core simulation code, **DONJON**
- 3D-porous thermal-hydraulic CFD code, **FEMus**





Targets of multiphysics approach

- Investigate the coupling between neutronic code (at lattice level and full core model) and a thermal-hydraulic CFD code
- Extended use of Hyerarchical Data Format structures (HDF5)
- Implementation of multiphysics approach into preliminary model of a Fast Small Modular Reactor (SMR)
- Choosing as case study a lead cooled reactor conceptual design, ALFRED (that can be qualified as SMR), characterized by small axial and large radial core dimensions

Perspectives

A coupled neutronics and thermal hydraulics analysis to better supporting the fast core behavior (in both fields) at design level

Neutronic Code

The neutronic code are the open-source reactor physics codes `Dragon and Donjon Version 5` developed at Ecole Polytechnique de Montréal (Canada), designed around methods to solving transport equation of neutron and, in Version 5, explicitly modified for Salomé compliance. Both codes are able to tackle hexagonal geometries and fast cores from Version 4, f.i. used in ASTRID modeling benchmarks (2013)

Lattice code, DRAGON

Simulate the neutronic behavior of the fuel assembly in the reactor core and create the proper nuclear database, called MULTICOMPO (that inherited also the role of the conventional SAPHYB data files)

Full core simulation, DONJON

Interpolate information contained in MULTICOMPO, simulate the comprehensive neutronic behavior of core and compute power and flux distribution

Nuclear Database - MULTICOMPO

MULTICOMPO

- **data structure** which contain nuclear properties of assembly's materials.
- possibility to recovery data concerned parameters as **nuclide's temperature and density or depletion calculation**.
- necessity to create an optimal nuclear database for a correctly use of full core simulation code.

1. Isotopic cross-section library: for this specific example on ALFRED `JEFF 3.1.2` SHEM DRAGLIB with 315 energy groups (as reworked as group structure by Santamarina, Hebert and Hfayed)
2. Lattice calculation
   - Burn-up calculation
   - Temperature and density modification
   - Homogenization and collapse to 33 energy groups
3. Saving macroscopic cross sections in the MULTICOMPO structure

Computational fluid dynamics code - 1

FEMus

is a an open-source library, developed at the University of Bologna, based on the LIBMESH library with parallel MPI-PETSC (i.e. with improved scalability) and multigrid solvers, recently extended to hexagonal geometries

For details or if you are willing to contribute, see:

https://github.com/FemusPlatform/femus

or ask to:

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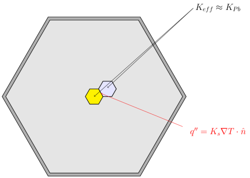
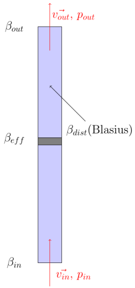
Computational fluid dynamics code - 2

The CFD solvers

have the function to solve energy and temperature equations starting from a given neutronic power density distribution



Assumption for solution of energy equation (only) is porous medium



Reactor channel (closed core)

Computational wrapping platform

The main purpose

is to obtain the solution of a multi-physics and multi-scale three-dimensional problem inside a simplified and more comprehensive framework.

The Salomé project

facilitates the coupling of scientific mesh-based codes thanks to its architecture and suite of tools that provide several data interfaces and exchange across the different codes

The integration of a code on the Salomè platform is obtained by generating an interface with functions available in the MEDMem library that allows a data transfer from the platform to the code and then from the code to the interface

Main SALOME' modules used in wrapping

MED (Modelisation et Echanges de Données) module

provide a library for **storing** and **recovering** computer data in a suitable format

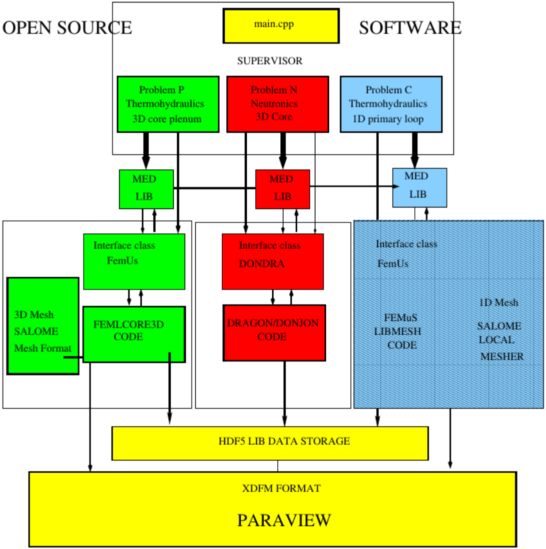
GEOM and MESH modules

have the main function to **draw** and **create meshes** in MED format, respectively.

YACS module

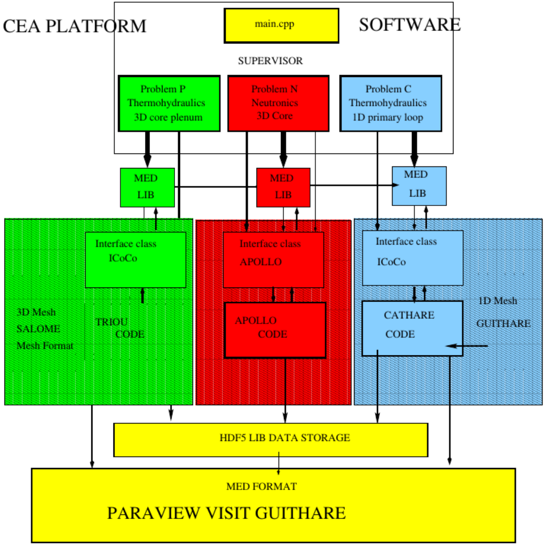
is a tool to **supervise execution** of complex interconnected scientific applications as object structure available during execution of DONJON code.

Computational platform
Open source codes

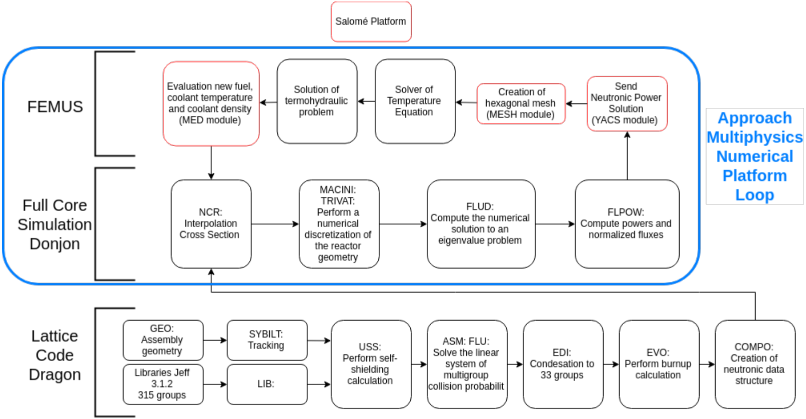


Computational platform

Proprietary codes



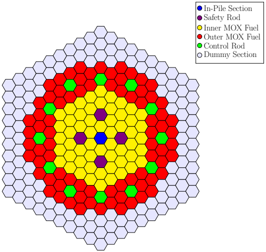
Summary flowchart



The ALFRED Lead Cooled SMR concept model

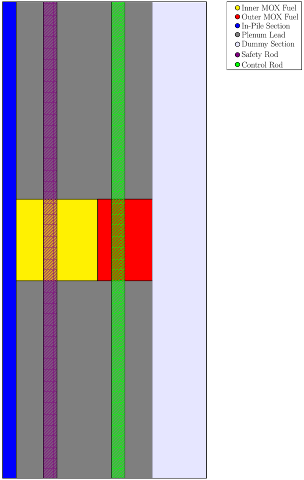
Data and Modeling

Parameters	Unit	Value
Thermal Power	MW	300
Total height vessel	mm	3500
Inner vessel inner/outer radius	mm	1475/1525
Lattice pitch (hexagonal)	mm	13.86
Wrapper thickness	mm	4.0
Distance between to wrappers	mm	5.0
Pins per FA	-	126
Total FA	-	134
Inner/Outer FA	-	56/78
Inner/Outer enrichment	%	20.5/26.2
Control/Safety Rods	-	12/4
In-pile section	-	1
Average Core Flow	m/s	1.28
Coolant Inlet/Outlet Temperature	^oC	400/520



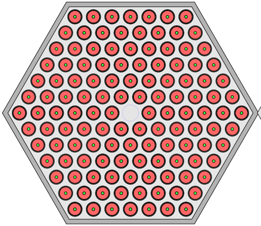
Reactor core fuel map

Sketch of the reactor core

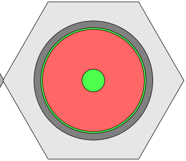


Fuel pin and assembly
Data and Modeling

Parameters	Unit	Value
Pellet hollow diameter	*mm*	2.0
Pellet radius	*mm*	4.5
Gap thickness	*mm*	0.15
Clad thickness	*mm*	0.6
Pin diameter	*mm*	10.5
Bottom plug length	*mm*	50
Gas plenum height	*mm*	550
Bottom plug length	*mm*	10
Active height	*mm*	600
Upper insulator height	*mm*	10
Spring length	*mm*	120
Upper plug length	*mm*	50



Fuel Assembly

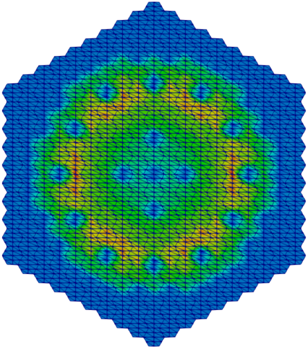


Fuel pin

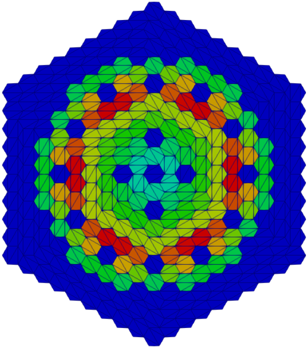
Finite element geometry for neutronic and CFD codes

CFD: each assembly element is divided in such a way that each sub-element has quadrangular surfaces. This coarse mesh is then refined by using midpoint refinement algorithm several times. Each hexagonal element has constant properties but several field points

CFD Solver Mesh



Neutron transport equation Mesh



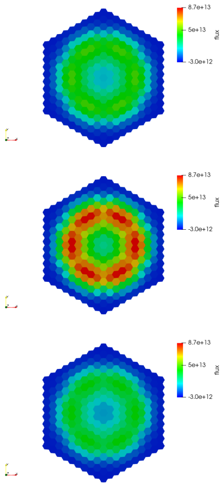
Preliminary results of the multiphysics approach

Comparison with reference ERANOS (+ECCO cell code) and MCNPX calculations for ALFRED (both performed by ENEA using the JEF3.1 libraries), k-eff

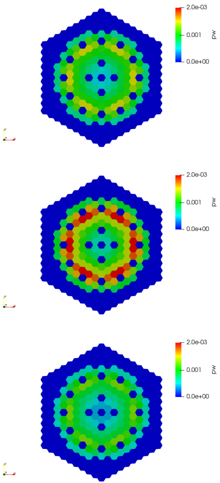
Time (days)	DONJON	ERANOS	MCNPX
0	1.0924	1.0804	1.0525
365	1.0645	1.0510	1.0229
730 (BOC)	1.0338	1.0247	0.9964
1095 (EOC)	1.0094	0.9988	0.9703

Preliminary results of the multiphysics approach

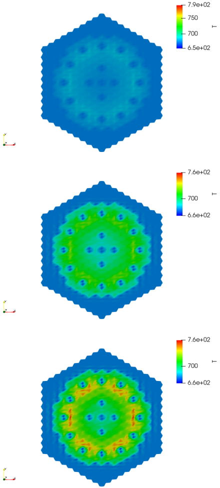
Flux distribution



Power distribution

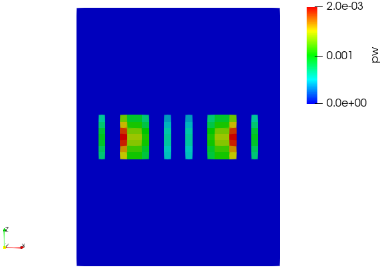


Temperature field

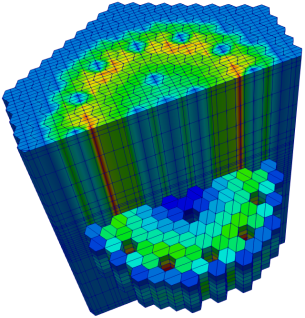


Preliminary results of the multiphysics approach

Power generation distribution, vertical section



Wrapping power distribution with temperature field on reactor section



Conclusions

- The solution is obtained after several iterations between the thermo-hydraulic and the neutron code with temperature and density feedback corrections.
- The results obtained in this simple case study, open a perspective of an extensive similar approach to other models: SMRs look as ideal candidates due to their size and compactness (mainly in terms of core dimensions in the FR case).
- The whole procedure is able to give to the user an extreme flexibility, also with respect possible implementation of modules thanks to the complete open-source approach.
- This can be useful in that special case that is represented by Fast SMR conceptual design: our feeling is that we are still (apart from a few cases that are in a licensing or near licensing path) in a phase that requires an open and diffuse contribution in terms of ideas and innovation.