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UNIVERSITÀ DEGLI STUDI DI PALERMO

Integral approach to the safety design of the Helium-Cooled Pebble Bed EU-DEMO with reference to the associated relevant systems

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INTRODUCTION

In view of the final development of the EU-DEMO fusion reactor, to fulfil its potential features in terms of low accident potential and good operational safety, it has to be considered as pivotal to incorporate the needed provisions to further improve the overall plant safety and reliability performances as well as to analyse possible mitigation actions. Indeed, a complete investigation of the reactor safety performances is currently being promoted and supported within the scientific community actions paying attention to the Safety and Environmental (S&E) aspects. The PhD research project finds its place within this framework, being mainly focussed on the theoretical-numerical investigation of the safety performances of the EU-DEMO reactor systems. In particular, the main objective of the research project is to perform a realistic assessment of the reactor system performances under steady state, operational and accidental transient conditions, selecting the most representative accidental scenarios and evaluating their potential consequences in terms of plant failure to give proper feedback to designers for their mitigation.

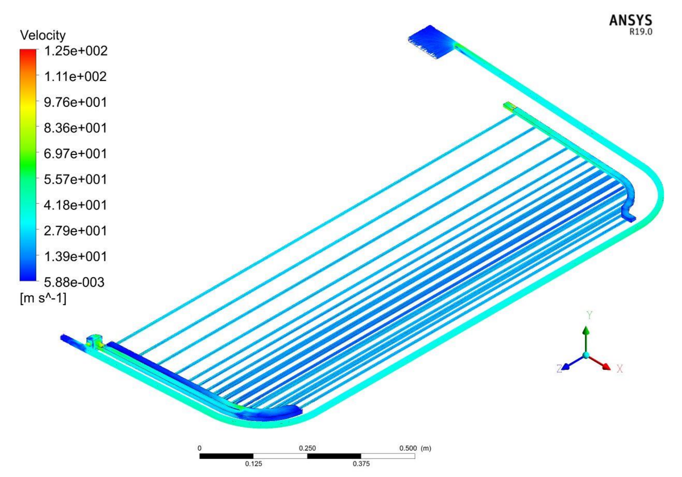
Finite Volume Model Set-up

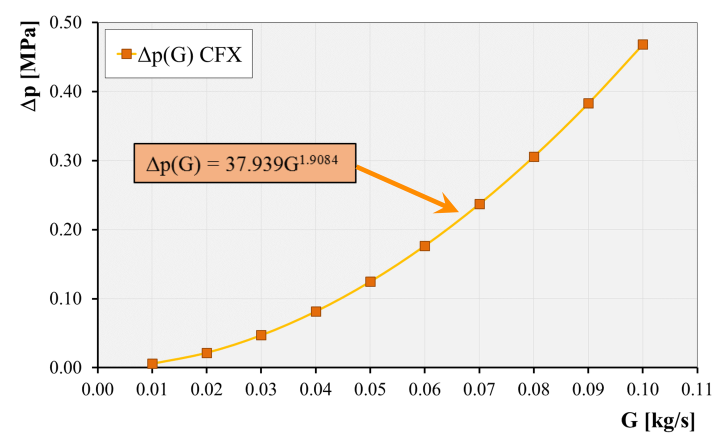
The activity has been carried out following a theoretical-computational approach based on the Finite Volume Method and adopting a suitable releases of the RELAP5-3D system code and the ANSYS-CFX code which have been properly integrated in order to achieve a more detailed and realistic simulation of the EU-DEMO plant thermal-hydraulics.

The Finite Volume Model developed consists of four main sub-models:

- the **flow domain model**, reproducing in a quasi-2D approximation the lay-out of the cooling circuit;
- the **constitutive models** provided by the system code to describe the thermo-dynamic behaviour of the helium circulating inside the cooling system;
- the **hydraulic model** intended to simulate the fluid flow along the cooling system.

The hydraulic resistances have been modelled by considering their functional dependence on velocity. Indeed, it has been performed a parametric analysis by means of the ANSYS-CFX code, assessing the hydraulic characteristic function of the components: $\Delta p = \alpha G^{\beta}$



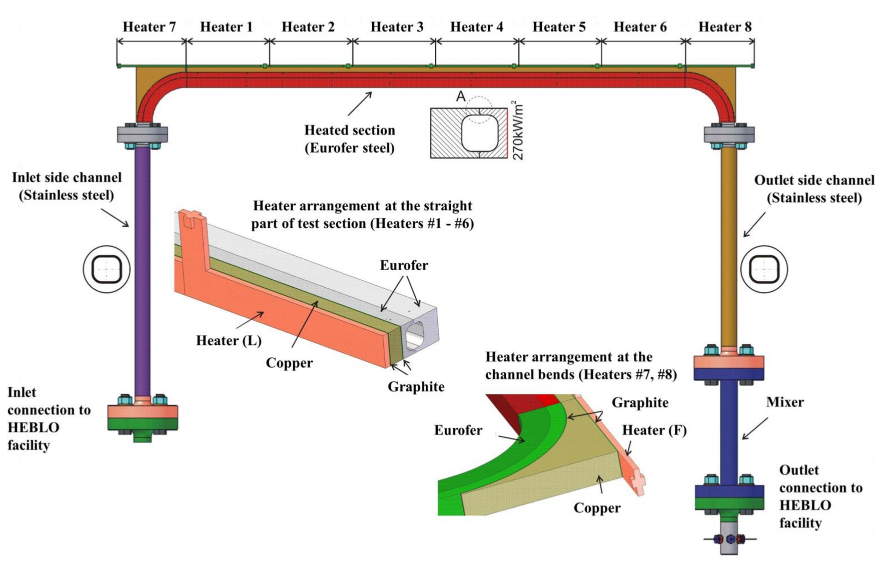


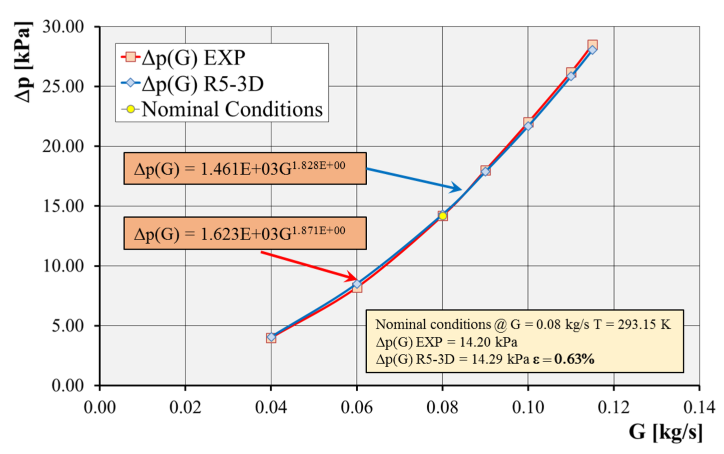
in order to derive the dependence on mass flow rate of the effective concentrated hydraulic loss coefficient to be given as input to the RELAP5-3D code: $K = B\,Re^{-C}$

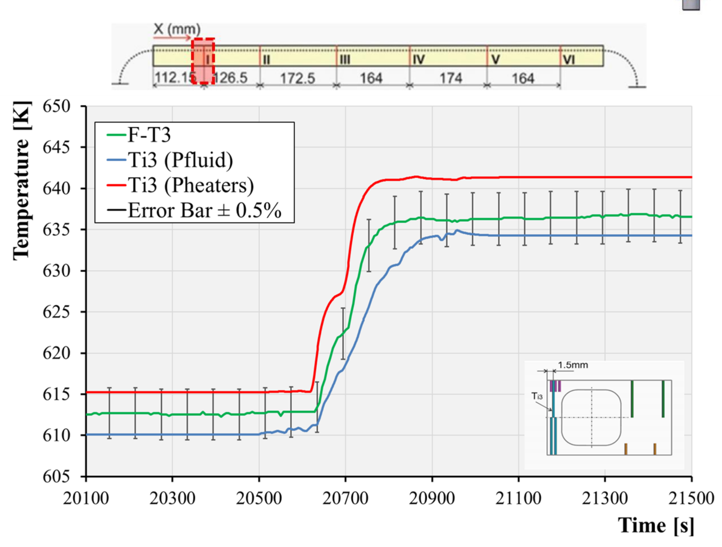
$$\Delta p = \alpha G^{\beta} = K\rho\frac{u^2}{2} \qquad K = \frac{2^{(3-\beta)}\alpha\,\rho\,(l_1 l_2)^2}{\mu^{(2-\beta)}(l_1+l_2)^{(2-\beta)}}\,Re^{-(2-\beta)} \qquad \begin{cases} B = \dfrac{2^{(3-\beta)}\alpha\,\rho\,(l_1 l_2)^2}{\mu^{(2-\beta)}(l_1+l_2)^{(2-\beta)}} \\ C = (2-\beta) \end{cases}$$

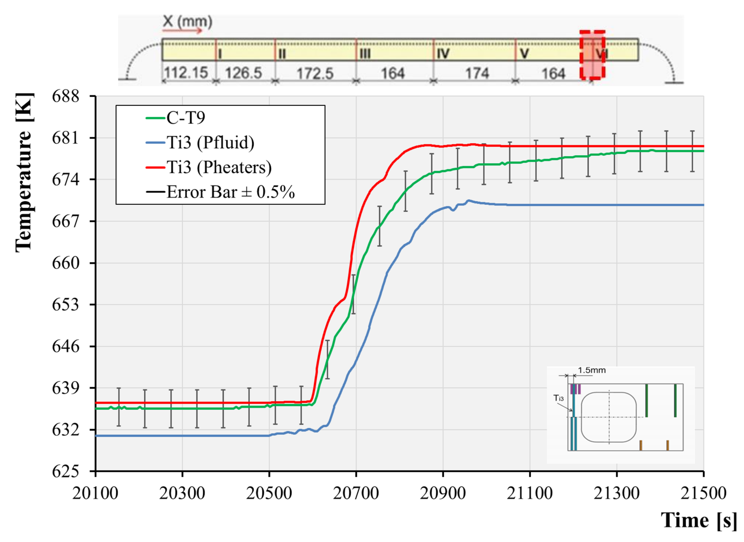
- the **thermal model** articulated in different sub-patterns aimed at realistically reproduce the heat transfer phenomena which take place along the cooling system.

It has been assessed by performing a benchmark with the experimental data coming from a proper experience conducted on the HETRA facility.





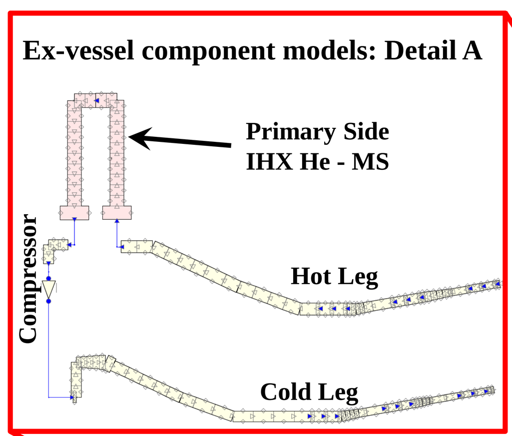


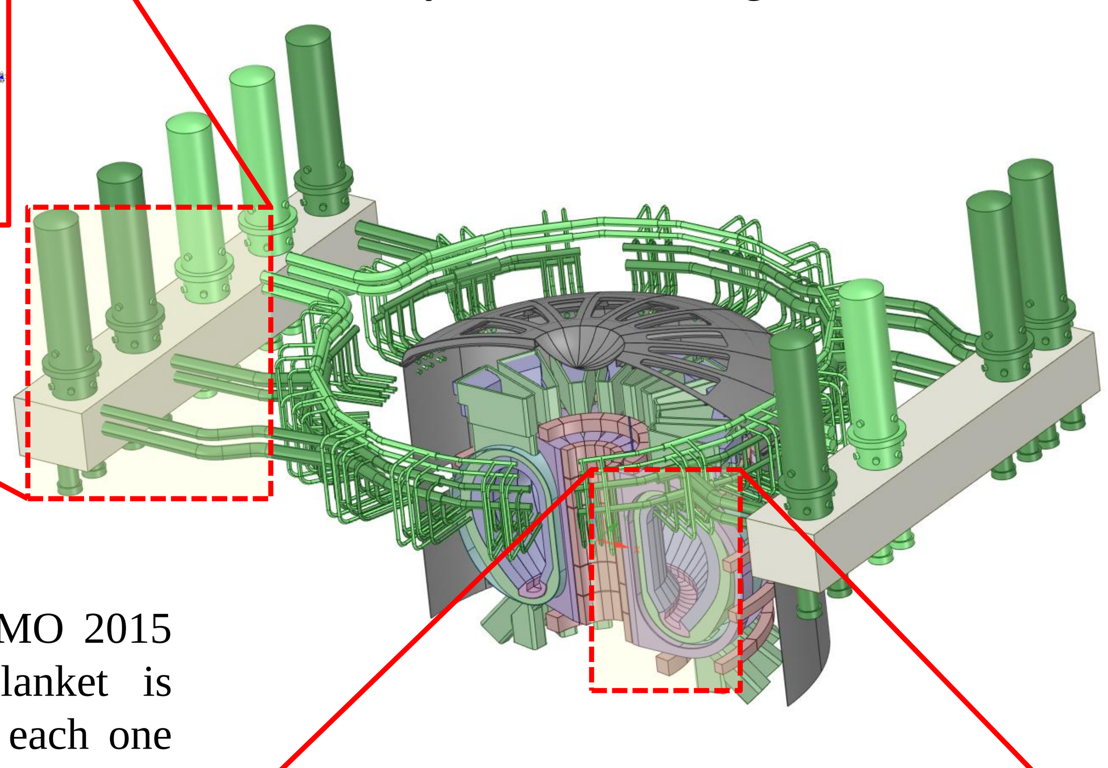


RELAP5-3D Finite Volume Model

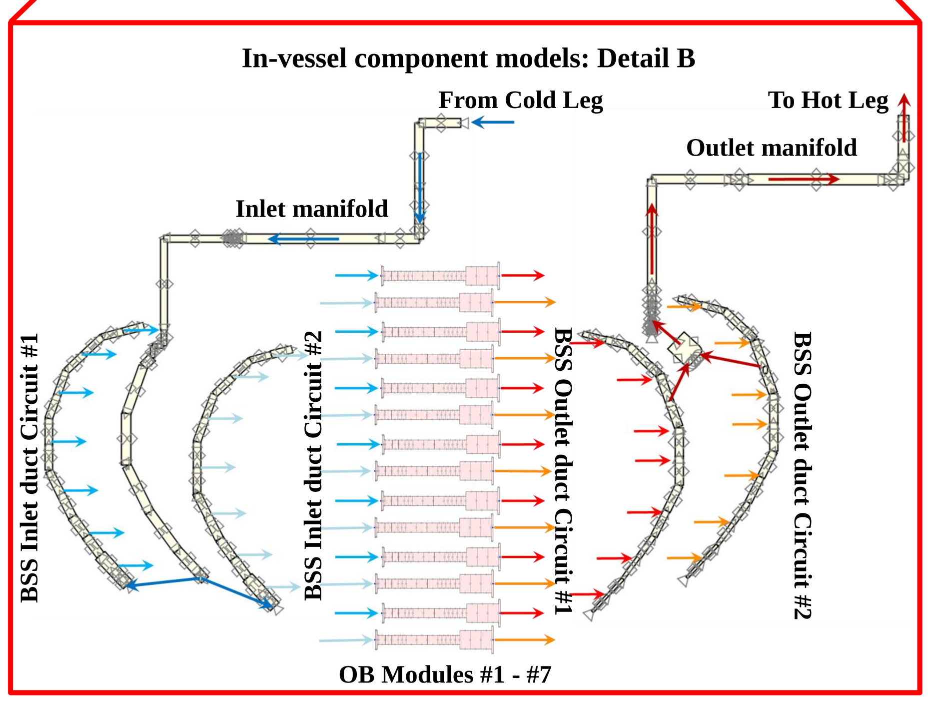
It has been developed a realistic finite volume model for the safety relevant loop of the Breeding Blanket Primary Heat Transfer System (BB-PHTS) simulating the normal operational conditions.

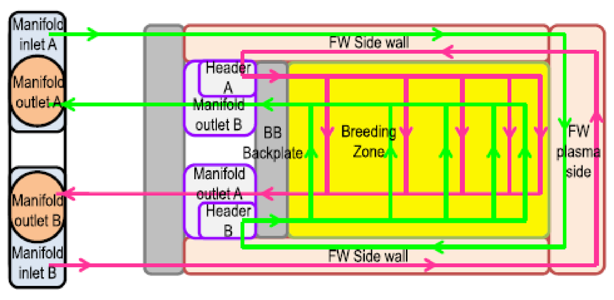
The BB-PHTS is one of the main systems of the EU-DEMO Balance of Plant (BoP) since it is devoted to the extraction of ~85% of the generated thermal power and to its conversion into electricity delivered to the grid.





According to the EU DEMO 2015 tokamak baseline the blanket is subdivided in 18 sectors, each one of 20° including two IB segments and three OB segments. An IB/OB segment is subdivided in seven blanket boxes, following a multi-module structure where FW and BZ cooling channels are housed. Their cooling system foresees a parallel, counter-flow scheme.





Main Results				
	Unit	Design Values	RELAP5-3D	Variation [%]
BB Power per Loop	[MWt]	252.306	252.306	-
Mass flow rate per Loop	[kg/s]	242.834	242.705	-0.053%
BB Inlet Temperature	[°C]	300.000	301.924	0.637%
BB Outlet Temperature	[°C]	500.000	499.045	-0.191%
Compressor Inlet Temperature	[°C]	289.460	288.240	-0.423%
Compressor Outlet Temperature	[°C]	300.000	301.623	0.538%
Compression ratio	[-]	1.046	1.057	1.025%
BB Inlet Pressure	[MPa]	8.000	7.926	-0.930%
Pressure drop FW	[MPa]	0.063	0.064	1.402%
Pressure drop CP	[MPa]	0.091	0.092	0.655%
Pressure drop Piping	[MPa]	0.057	0.057	-0.177%
Pressure drop IHX	[MPa]	0.085	0.086	1.161%