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Identification of Blanket design points using an integrated multi-physics approach

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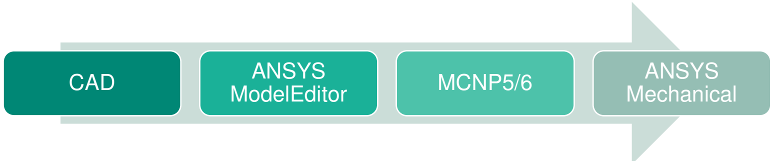
ABSTRACT

The Breeding Blanket (BB) is one of the key components for a fusion reactor. It is expected to sustain and remove considerable heat loads due to the heat flux coming from the plasma and the nuclear power deposited by the fusion neutrons, to breed the tritium consumed in the fusion reactions and to shield the Vacuum Vessel (VV) both from the thermal and nuclear radiation. Therefore, in the design of the BB, the engineering requirements and constraints of nuclear, material and safety kind are involved. In the European DEMO project, several efforts are currently dedicated to the development of an integrated simulation-design tool that is able to carry out a multi-physics analysis, allowing the characterization of BB design points which are consistent from the neutronic, thermal-hydraulic and thermo-mechanical point of view. For this reason, at Karlsruhe Institute of Technology within the framework of EUROfusion activities, a new dedicated research campaign has been recently launched in order to set-up this coupling procedure. The first step of this approach starts with the definition of the reference geometry (from generic CAD files), which has been converted into a more suitable format for neutronic analysis with Monte Carlo codes (i.e. MCNP 5/6). In the second step, once the power density has been calculated, the results have been imported in a Finite Element Code. In this study, the model of Helium Cooled Pebble Bed (HCPB) slice in the equatorial outboard module has been used for the characterization of BB design points.

PROCEDURE

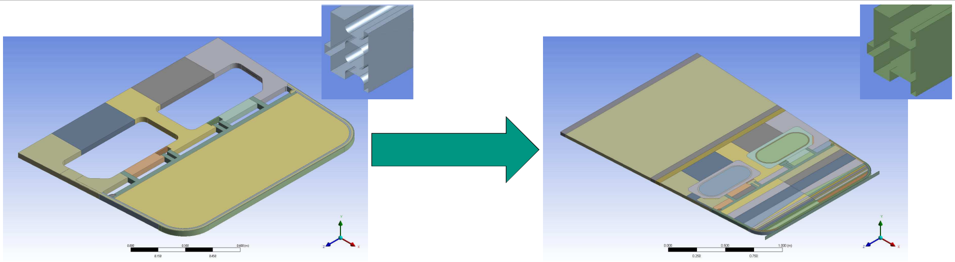
The approach has been articulated in the following phases:

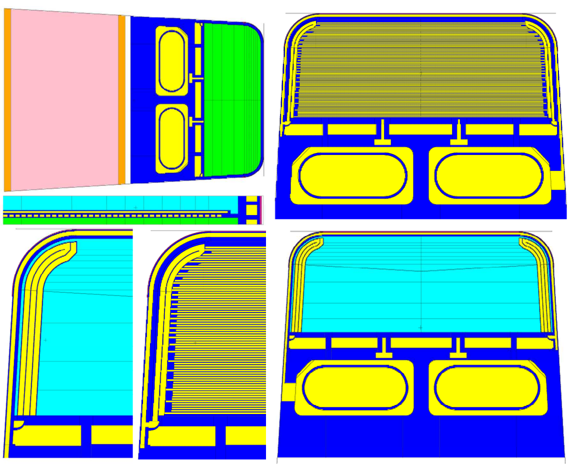
1. Import of the reference from CAD into ANSYS DesignModeler.
2. Geometry decomposition (slicing and reparation of sharp angles, slivers, spikes, etc.) and geometry conversion into MCNP legacy Constructive Solid Geometry (CSG).
3. Performing of neutronic analysis.
4. Mapping of power density calculations into ANSYS Mechanical.



GEOMETRY DECOMPOSITION

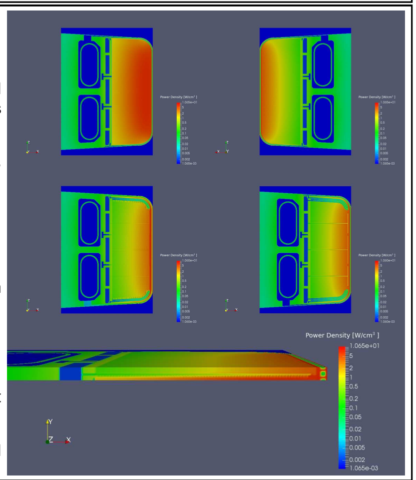
- It has been sliced in order to have simple configuration suitable for the CSG representation;
- The VV, the gap between the VV inner wall and the BB have been introduced;
- The cooling channels have been filled to model the coolant;
- The corners of the cooling channels have been squared;
- An enclosure has been used to shape the Graveyard.

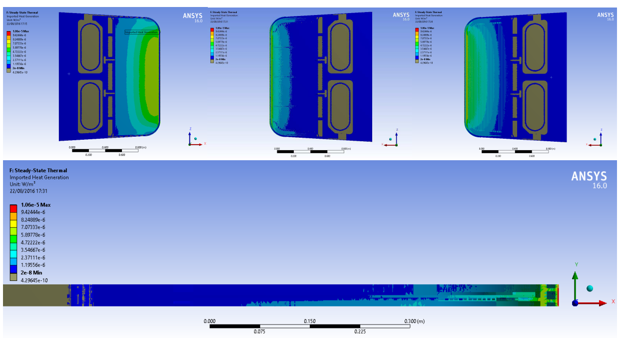




CSG GEOMETRY CONVERSION AND NEUTRONIC ANALYSIS

- The elaborated CAD model has been exported generating a geometric input for neutronic analysis based on the CSG;
- It has been verified the conservation of the volumes using the stochastic estimation on the ray tracing;
- Total volume average error equal to 0.01%;
- Maximum volume error between 0.811% and -0.725%;
- It has been used a mono-energetic test source biased in the angular distribution;
- The reflecting boundary conditions have been imposed in the poloidal direction;
- It has been modelled the VV in order to take into account of the neutron back scattering;
- The power density deposition has been assessed defining a fmesh-tally with 1.88 million of elements.





MAPPING OF HEAT GENERATION

- A mesh sensitivity analysis has been carried out to determine an appropriated spatial discretization;
- A mesh composed of $\sim 6.8 \cdot 10^6$ nodes connected in $\sim 2.8 \cdot 10^6$ tetrahedral elements has been chosen allowing an accurate interpolation of the data between MCNP and ANSYS;
- A complete coupling has been performed admitting to use the neutronic outcomes for thermal-hydraulic and thermo-mechanical calculations.

CONCLUSION

- At theoretical-computational research campaign has been performed by KIT to create an integrated multi-physics approach to be used for the identification and analysis of BB design points.
- A test model has been realised accomplishing the complete coupling between the software.
- The correctness and applicability of the approach have been demonstrated, and the great advantages derived from using the same geometry for all the analyses involved in the design of the BB have been also introduced.

EUROfusion

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