Karlsruhe Institute of Technology

Integrated approach for hybrid CAD and mesh geometry based fusion multi-physics coupled analyses

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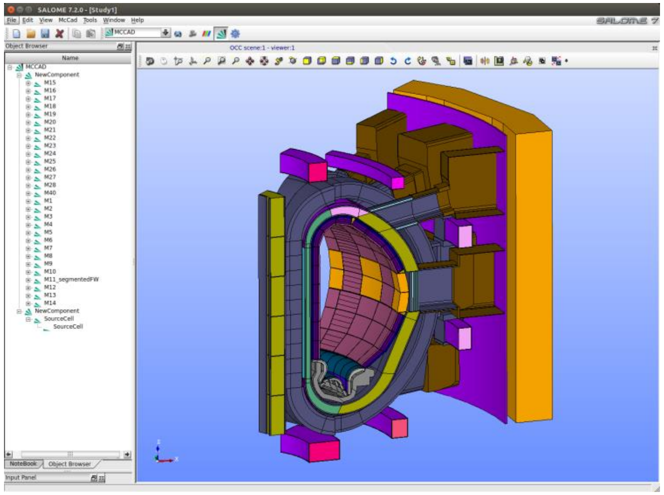

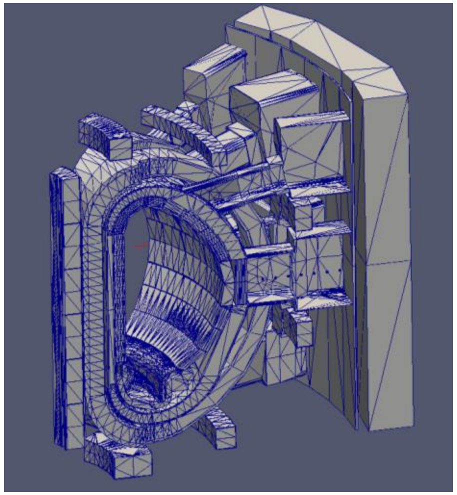

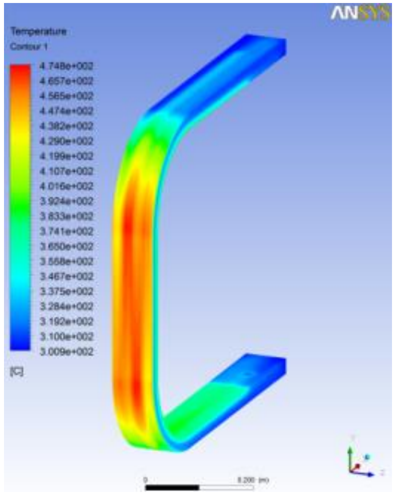

Outline

- Introduction
- Coupling approach
- Implementation details
- Test verifications
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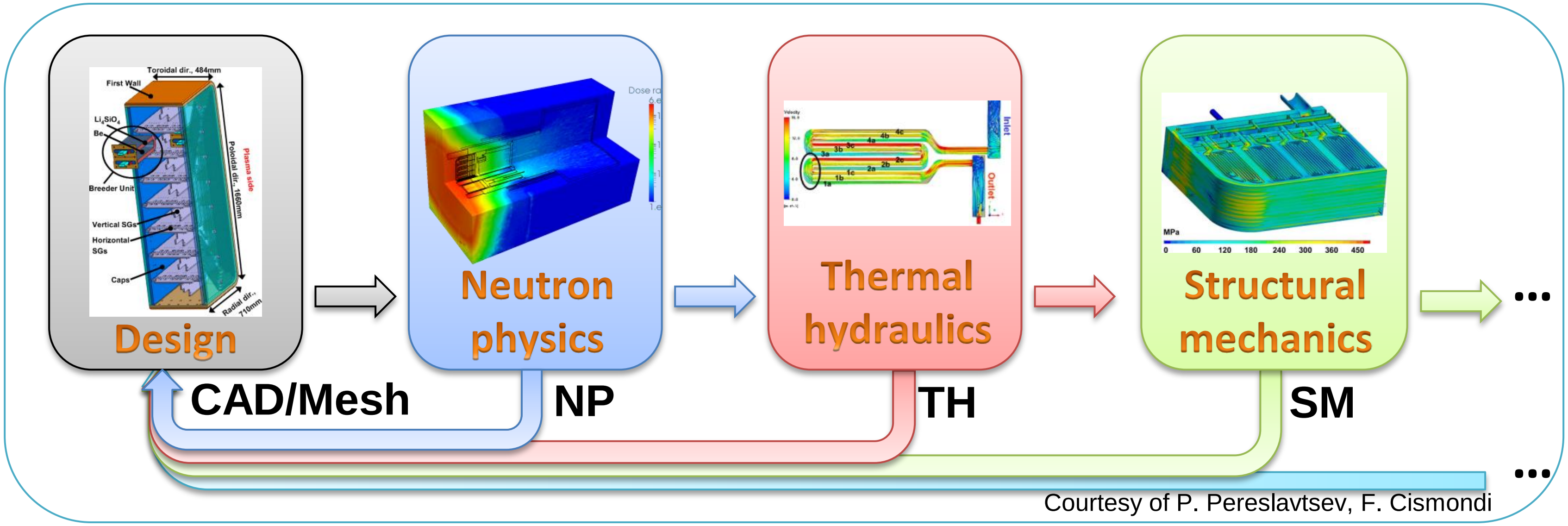
Introduction

Introduction

- Coupled multi-physics analyses for fusion device component



- CAD/Mesh conversion tool for Monte Carlo (MC) neutronics codes;
- Data transfer tool for translating MC results for TH/SM codes;
- Implementation and integration of tools into a suitable platform;

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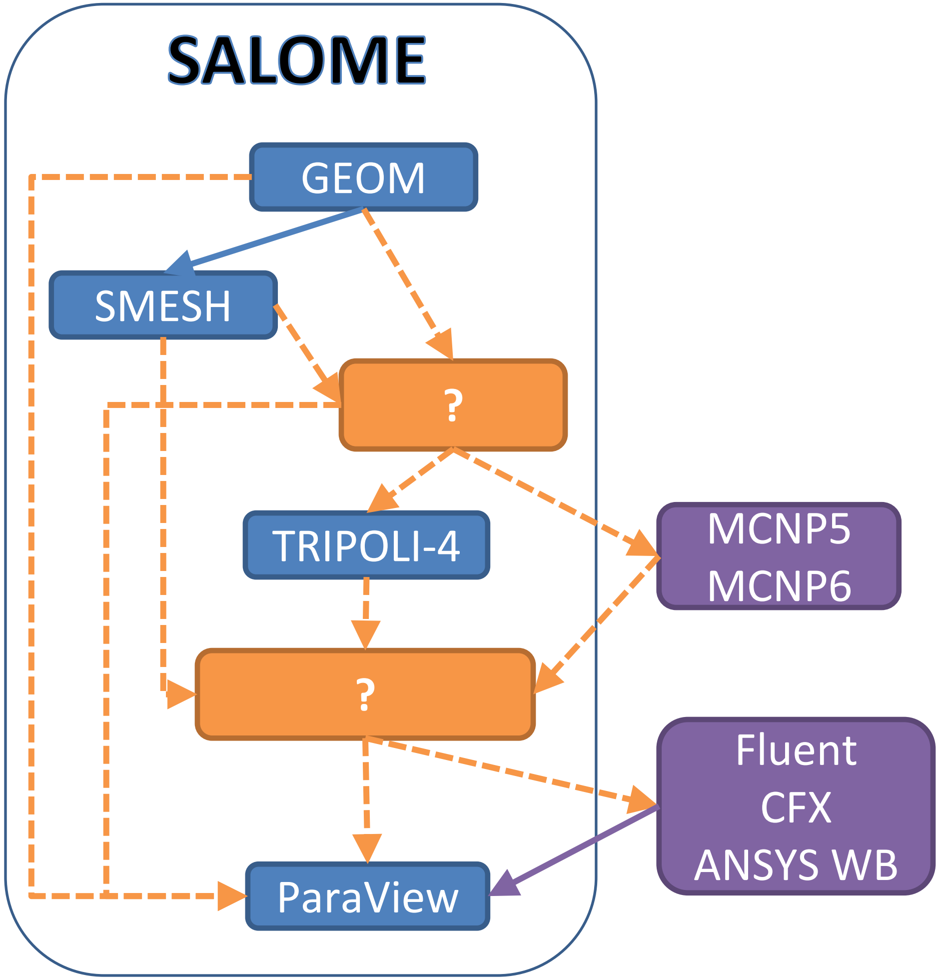
Coupling approach

- SALOME
  - Open-source integration platform;
  - GEOM module: CAD modelling;
  - SMESH module: Mesh generation;
  - ParaView module: Data visualization.
- MC codes
  - MCNP5/6
  - TRIPOLI-4
- TH/SM codes
  - Fluent
  - CFX
  - ANSYS Workbench
- To be developed and integrated
  - MC geometry conversion tool
  - MC data transfer tool
  - All the missing links



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  - MC geometry conversion
  - A novel meshing approach
  - MC data translation
  - Data Visualization
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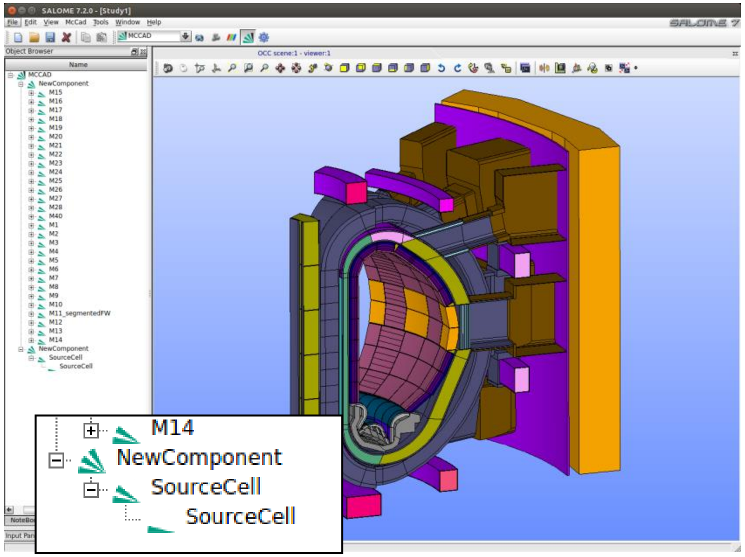
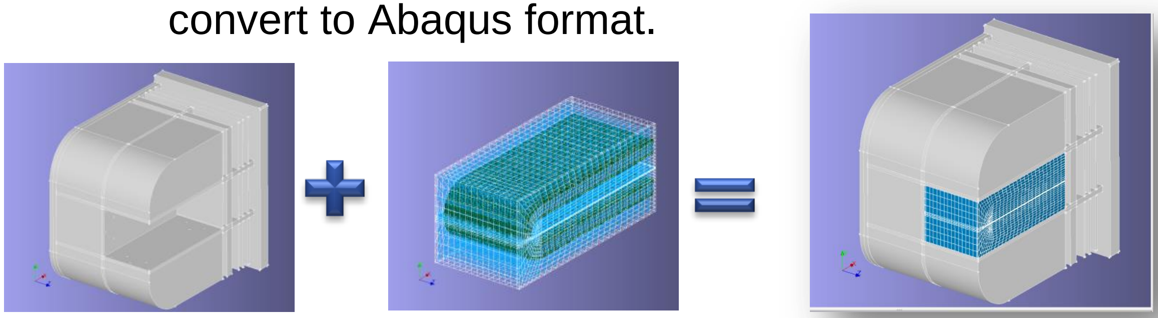
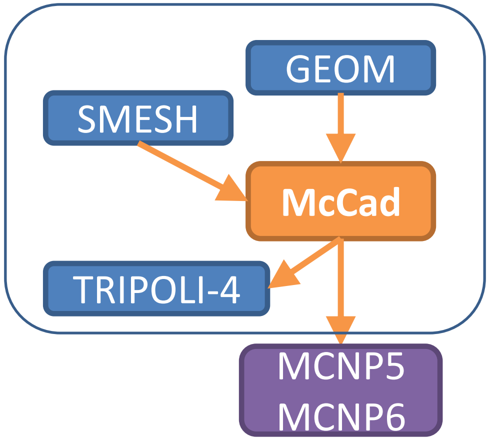
MC geometry conversion

- McCad
  - MC geometry conversion tool developed at KIT
- New McCad in SALOME
  - Geometries are managed in a new tree structure;
  - Model persistency using a project file.
  - Internal data sharing with GEOM and SMESH modules.
- Hybrid geometry conversion
  - New interface for MCNP6
  - Import/generate unstrucutred mesh and convert to Abaqus format.



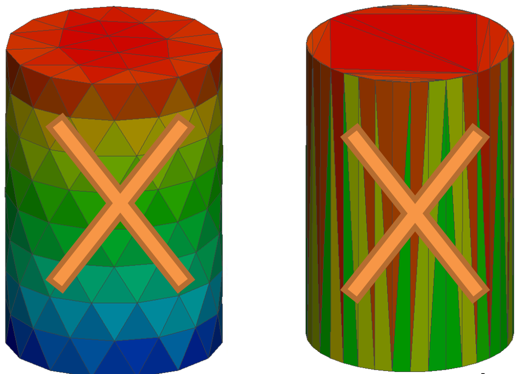


CAD Mesh Hybrid geometry



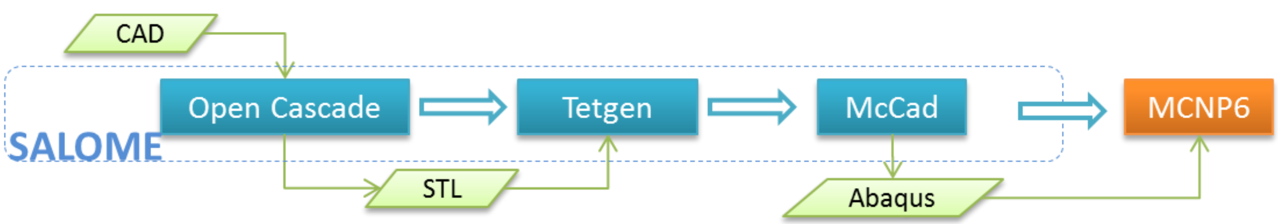
A novel meshing approach

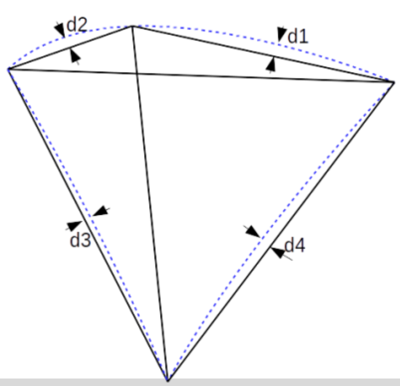
- Mesh application in MC codes
  - Results scoring
  - Geometry description
- A meshing approach for MC geometry
  - Tessellation-Tetrahedralization (TT) approach
  - Tessellation: Triangulating solids into surface meshes
    - Deflection: maximum allowable chordal deviation for a mesh edge to the surface
    - Relative Deflection (**RD**): Deflection value adjust to the size of the solid
  - Tetrahedralization: Tetrahedral mesh generation conforming to the surface mesh



ANSYS Mesh   TT mesh

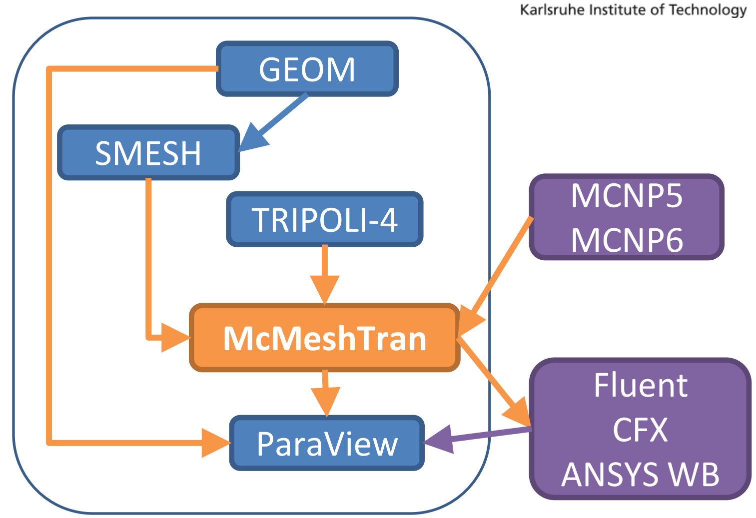
	ANSYS mesh	TT Mesh
Elements	901	102
Volume diff.	2.2%	0.5%

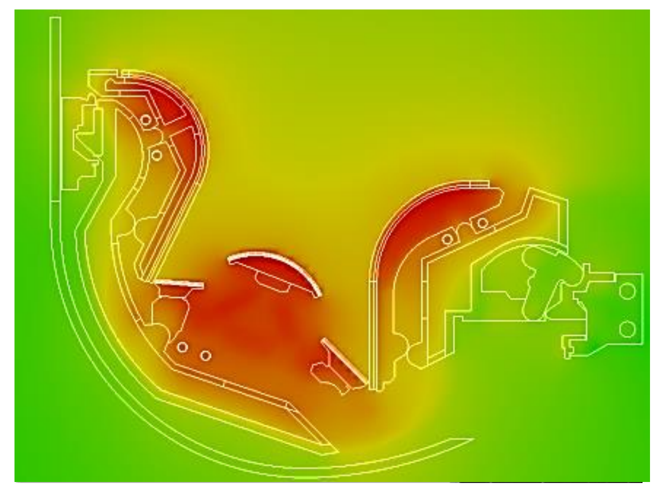


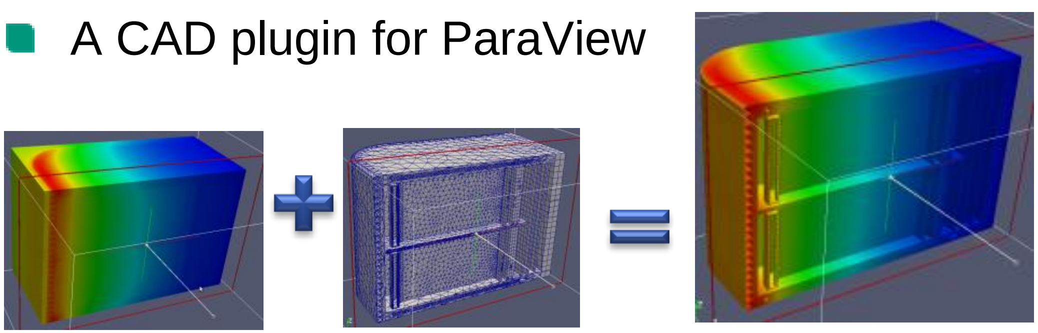


MC data translation

- McMeshTran
  - A MC Mesh and data Transformation/ Translation/ Transfer tool
  - Physical conservative data mapping using volume-weighted interpolation
  - Interacting with SMESH, ParaView
- MC/TH/SM interfaces
  - MCNP Mesh tally
  - MCNP6 unstructured mesh results
  - TRIPOLI Mesh tally
  - Fluent user-defined function (UDF)
  - CFX user fortran
  - ANSYS Workbench CSV data
- A CAD plugin for ParaView







Physical conservative data interpolation

Outline

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- Test verifications
  - Verification of the TT meshing approach
  - Verification of hybrid geometries
  - Verification of CFD interfaces
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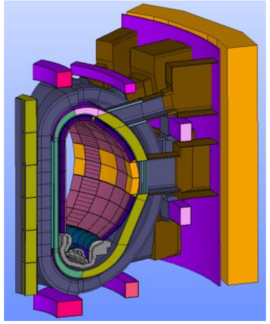
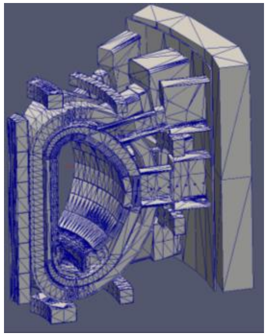
Verification of the TT meshing approach

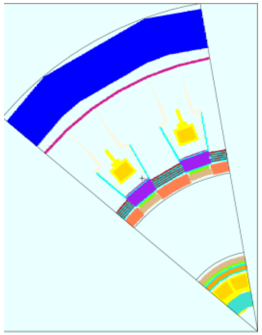
- ITER Benchmark model
  - simplified 40° ITER sector



CAD



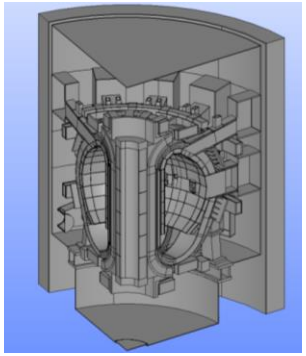
TT Mesh



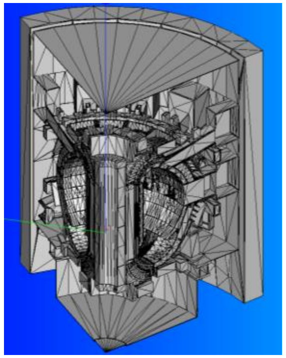
MCNP6 plot

	RD=0.01	RD=0.001
CAD Solids	932	
CAD volume(m^3)	6.2282×10^3	
Mesh volume(m^3)	6.2211×10^3	6.2275×10^3
Volume difference	0.11%	0.01%
Mesh elements	1.511×10^5	5.534×10^5
Meshing time (s) *	4.6	17.1
Lost particles **	$33/10^8$	$156/4\times10^8$

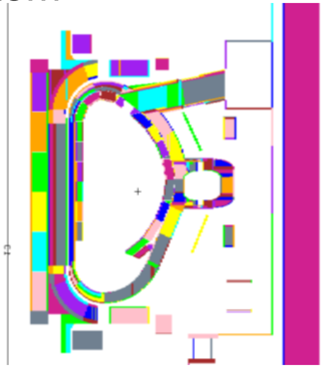
- ITER Alite 80°
  - Based on the A-lite 40° reference model for analyzing Neutral Beam system



CAD



TT Mesh



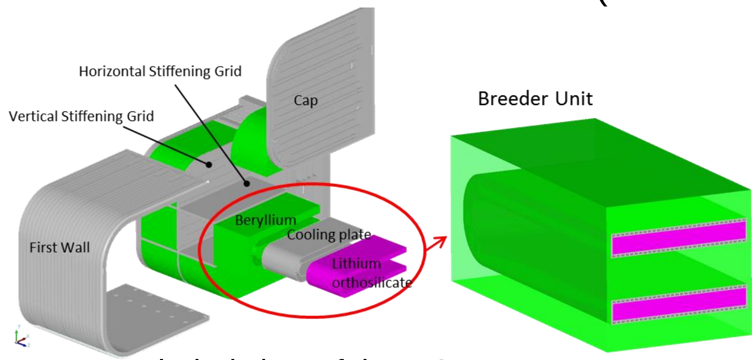
MCNP6 plot

	RD=0.01	RD=0.001
CAD Solids	4296	
CAD volume(m^3)	1.7804×10^4	
Mesh volume(m^3)	1.7836×10^4	1.7801×10^4
Volume difference	0.18%	0.02%
Mesh elements	4.485×10^5	2.157×10^6
Meshing time (s) *	19.9	45.2
Lost particles**	$2/10^8$	$11/3\times10^7$

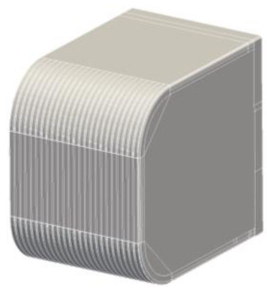
*PC with Intel Core i7-4770 (3.40 GHz) processor
** MCNP6 calculation with void material and volume source

Verification of the TT meshing approach

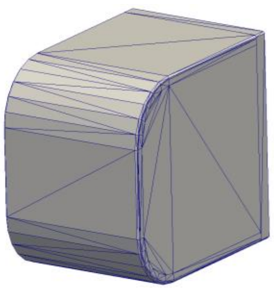
- TBM test case
  - a test case model derived from Helium Cooled Pebble Bed Test Blanket Module (HCPB TBM)



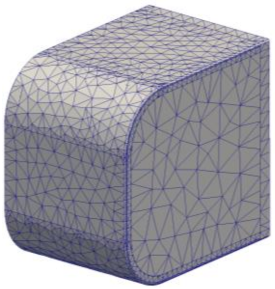
Exploded view of the HCPB TBM test case



CSG model (5692 cells)



TT Mesh



ANSYS Mesh

	RD=0.01	RD=0.001	ANSYS (coarsest sizing)
CAD Solids		77	
CAD volume(m^3)		1.6519×10^{-1}	
Mesh volume(m^3)	1.6494×10^{-1}	1.6517×10^{-1}	1.6277×10^{-1}
Volume difference	0.15%	0.01%	1.46%
Mesh elements	1.410×10^{5}	3.238×10^{5}	7.624×10^{5}
Meshing time (s)	4.8	8.6	630
Lost particles	$0/10^{6}$	$0/10^{6}$	$0/10^{6}$

MCNP6 test calculation

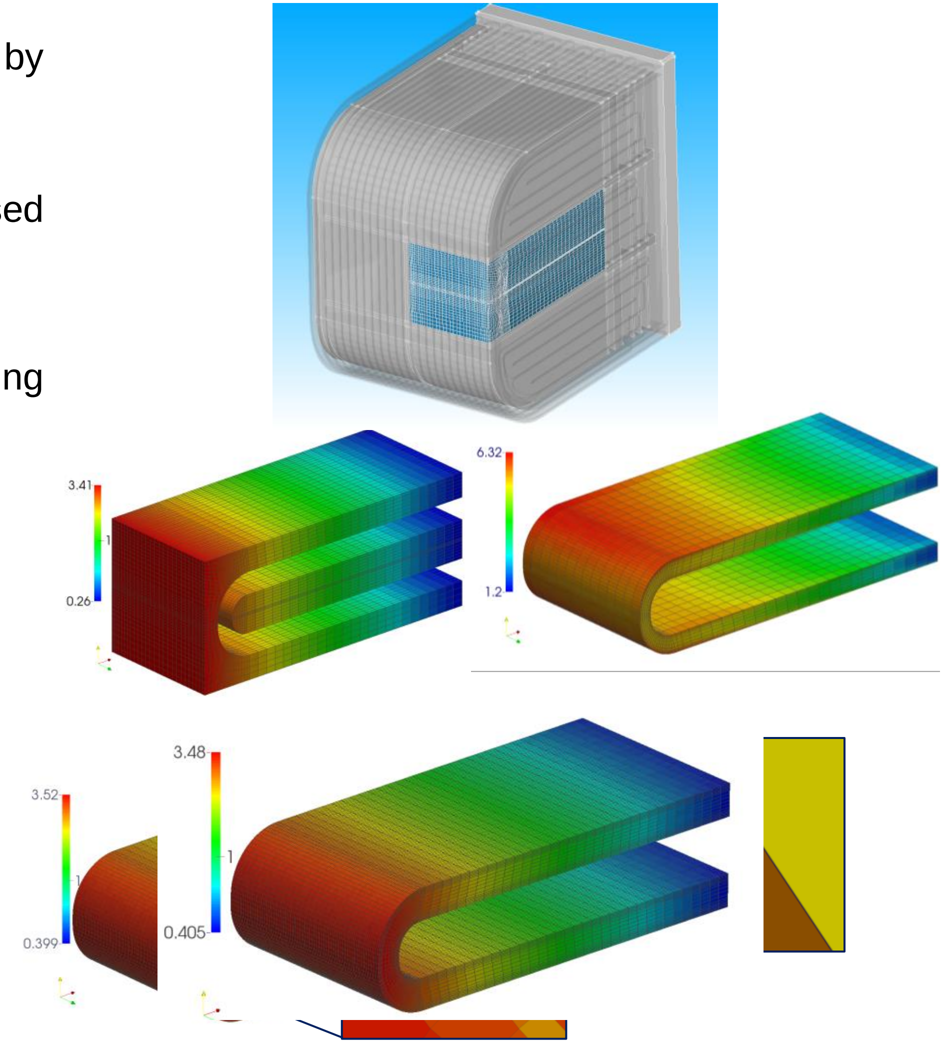
	CSG	TT mesh RD=0.01	TT mesh RD=0.001	ANSYS mesh
Preproc.	0.94	0.37	0.88	136.45
Simulation	93.09	483.38	684.14	4646.17

- TT approach: fast, accurate, economic

Verification of hybrid geometries

- TBM test case
  - Mesh of a breeder unit is generated by ANSYS ICEM
  - Hybrid model converted by McCad
  - Heating results compared with cell-based heating tallies of CSG model
- Tiny overlap problem
  - A tiny overlap (~3e-5 mm) found in cooling plate
  - MCNP6 failed in handling the tiny overlap

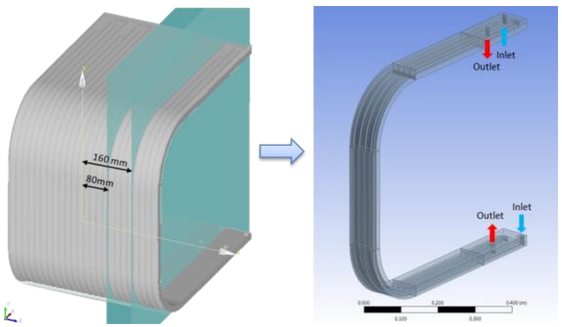
Subcom-ponent	MCNP tally result (W)	MCNP UM result(W)	Diff.
Beryllium	1.5555×10^4	1.5787×10^4	1.49%
Cooling plate	1.8036×10^3	1.7596×10^3	2.44%
Lithium orthosilicate	1.0862×10^4	1.0821×10^4	0.38%



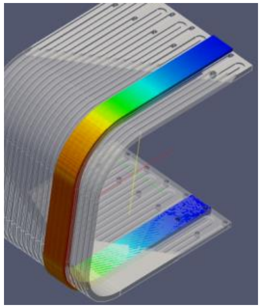
Verification of CFD interfaces

- CFD analysis of TBM First Wall (FW)
  - Mesh of 1/6 FW was geneated by ANSYS Workbench
  - Heat source is translated by McMeshTran from nuclear heating mesh tally of CSG model to Fluent and CFX interface files

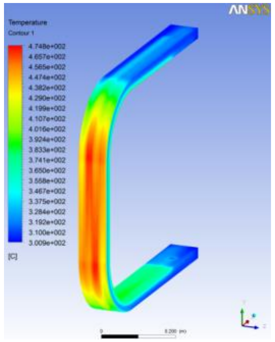
Temperature	CFX (°C)	Fluent (°C)	Diff. (°C)
Solid Max.	474.81	473.55	1.26
Fluid Max.	421.47	423.59	2.12
Outlet Avg.	335.45	334.94	0.51

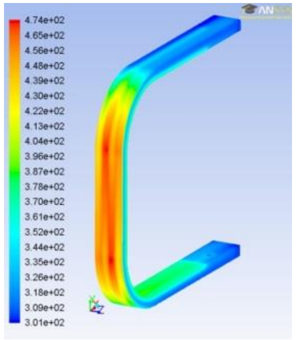


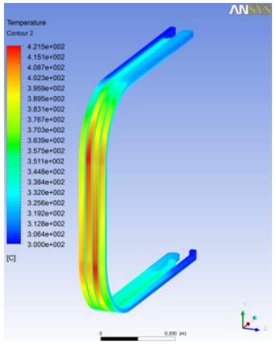
1/6 FW model

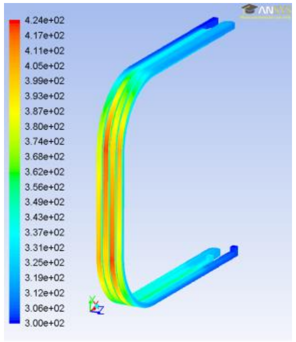

Nuclear heating

- Fluent and CFX comparison
  - Fluent and CFX simulation based on the identical mesh and conditions
  - The temperature results of the two CFD codes agree very well


CFX-solid


Fluent-solid


CFX-Fluid


Fluent-Fluid

FW temperature(°C)

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Summary

- An integrated approach has been developed for coupled fusion multi-physics analysis
- Two key modules — MC CSG and Mesh geometry conversion tool McCad and MC data translation tool McMeshTran, have been integrated into SALOME;
- Interfaces has been developed for MC codes MCNP5/6, TRIPOLI, CFD codes Fluent and CFX and SM software ANSYS Workbench;
- A novel TT meshing approach has been proposed for generating MC geometry meshes in a fast, accurate and economic way;
- Several test verifications have been carried out, the reliabilities of the developed tools and interfaces has been proven.

MC + TH/SM

McCad &
McMeshTran

SALOME

Courtesy of hypothyroidmom.com