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High Fidelity Monte Carlo for Fusion Neutronics

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Introduction

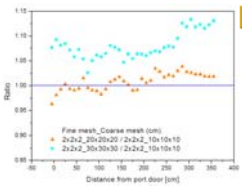
- Advanced modelling and simulation techniques for neutronics analyses of fusion reactors (ITER, DEMO, HELIAS) and experimental facilities (DONES)
- Monte Carlo radiation transport and activation solver (MCNP, R2Smesh).
- Use of detailed 3D geometry models, continuous energy nuclear interaction cross sections and high-resolution mesh results.
- Massive-parallel HPC resources required for large-scale simulations.

Part 1: Development of tools

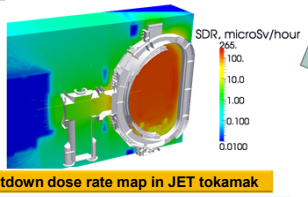
- Coupled radiation transport and activation code system
- Sensitivity to mesh resolution
- Verification and validation of alternative radiation transport codes
- Simulation of self-powered neutron/photon detectors

Mesh convergence in coupled transport and activation

- Twin mesh approach for fluctuations on small and large resolution.
- Sensitivity study on mesh size dependence and convergence of final result.
- Optimum resolution dependent on mesh adaptation level (superimposed mesh).



Mesh resolution study



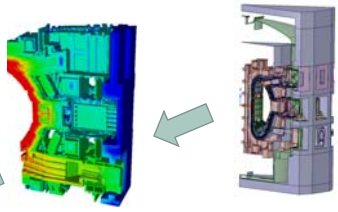
Shutdown dose rate map in JET tokamak

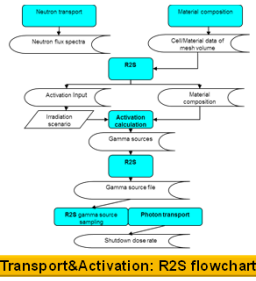
Multiphysics simulation of nuclear detectors

- Sensitivity of self-powered detectors to various incident particles and mode signal generation under typical fusion plasma conditions.
- MC simulations with neutron, photon, electron and proton transport.

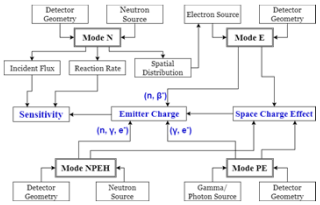
Code system for coupled transport and activation

- Parallel execution of MC particle histories followed by quasi-parallel activation calculations on a mesh grid.
- Improving performance of data processing and distribution by driver script using MPI library.

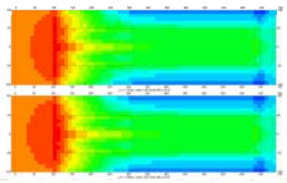




Transport&Activation: R2S flowchart



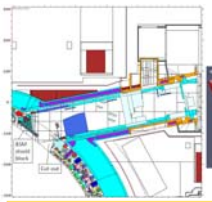
MC simulation of self-powered detector



Shutdown dose rate in cylindrical shield assembly

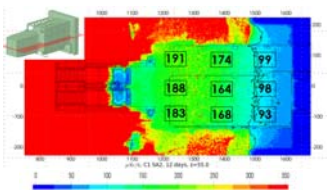
Part 2: Applications to fusion design analyses

- Heating systems of ITER fusion reactor
- Test-Blanket-Modules (TBM) in ITER
- Breeding blankets in DEMO fusion reactor
- HELIAS stellarator reactor
- DONES fusion material irradiation facility

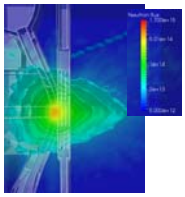


ITER

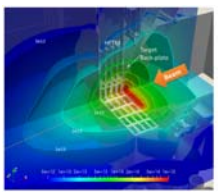
Nuclear heat distribution in EC Heating Plug



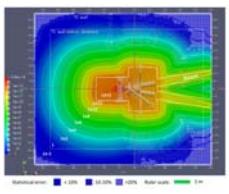
Shutdown dose rate around port

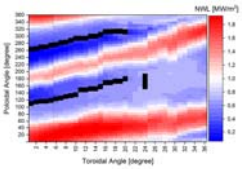


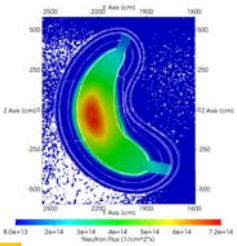
DONES



Neutron flux in test cell







HELIAS

Neutron wall load and flux distribution

Large-scale radiation transport applications

- General: high-detail geometry models, massive-parallel MC radiation transport with mesh-based variance reduction techniques and source biasing.
- ITER: Nuclear heat distributions in water-cooled structures of plasma heating and current drive port-based systems.
- ITER: Shutdown-dose rate distributions in maintenance areas behind a Test-Blanket-Module system.
- DEMO: activation behaviour of breeder blanket materials-
- HELIAS: neutron transport through radiation shield of complex and twisted stellarator geometry.
- DONES: radiation shielding in high-intensity irradiation facility.

Acknowledgements and Disclaimer

This work was performed on the computational resource ForHLR II funded by the Ministry of Science, Research and the Arts Baden-Württemberg and DFG ("Deutsche Forschungsgemeinschaft").
Parts of the work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. Parts of the work were supported by Fusion for Energy (F4E), Barcelona, through the Specific Grant Agreements F4E-GRT-615 and F4E-FPA-395.02. The views and opinions expressed herein do not necessarily reflect those of the European Commission. Parts of the work has been funded by the ITER Organization under contract IO/17/CT/4300001445.
Parts of the work was carried out using an adaption of A-lite and C-Model which were developed as a collaborative effort between AMECFW (International), UKAEA (UK), ENEA Frascati (Italy), F4E (Spain), FDS Team of INEST (PRC), IDOM (Spain), ITER Organization (France), QST (Japan), KIT (Germany), UNED (Spain), University of Wisconsin-Madison (USA).