GEN-FOAM: AN OPENFOAM® BASED MULTI-PHYSICS SOLVER FOR NUCLEAR REACTOR ANALYSIS

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A new open-source multi-physics solver for nuclear reactor analysis, named GeN-Foam (Generalized Nuclear Foam), has been developed by the Laboratory for Reactor Physics and System Behavior at the EPFL and at the Paul Scherrer Institut [1]. The solver features a general applicability to pin- or plate-fuel, or homogeneous nuclear reactors, with a high flexibility in terms of geometrical detail and physical complexity of the problem to investigate.
GeN-Foam tightly couples:

- A multi-group neutron diffusion or SP3 (third order spherical harmonics) sub-solver with user-selected energy groups and provided with a dedicated routine to export nuclear data from the Monte Carlo code Serpent [2] to OpenFOAM-readable input files. The sub-solver includes assembly discontinuity factors and moving-mesh features, as the mesh is deformed based on the displacement field provided by the thermal-mechanics sub-solver. The transport of delayed neutron precursors is accounted for in case of liquid fuel.
- A thermal-hydraulics sub-solver based on the standard k-ε turbulence model for compressible or incompressible flows, but extended to coarse-mesh applications through the use of a porous medium approach [3] for user-selected cell zones inside the mesh. This allows for instance to simulate a full primary circuit using standard CFD techniques for open spaces such as the plena in Pressurized Water Reactors (PWRs) or the pools in Sodium Fast Reactors (SFRs), while employing a coarse mesh with dedicated sub-scale models in complex components like core and heat exchangers. The porous medium approach is alternative to the coupling of 1-D tools for the core and CFD tools for the surrounding components, but it avoids problems of numerical stability associated to external code coupling.
- A displacement-based thermal-mechanics sub-solver to evaluate thermal deformations of structures.
- A finite-difference sub-scale fuel model that can be used in coarse-mesh simulations of the core to evaluate the local temperature profile in fuel and cladding.

A first–order implicit Euler scheme is used for time integration. The coupling between equations is semi-implicit using Picard iteration. Three different meshes are used for thermal-hydraulics, thermal-mechanics and neutron diffusion, while the sub-scale fuel model is solved in each mesh cell within the fuel zones of the thermal-hydraulics mesh. This allows different refinement of the meshes and reduces computational requirements. Currently, only single-phase fluid flow is allowed. GeN-Foam has already undergone basic sanity checks and first verification activities have been performed employing both light water and fast reactors as test cases.

Current developments relate the coupling with the Monte Carlo code Serpent and with the TRANSURANUS fuel behavior code, and extension to 2-phase flow analysis. Inclusion of a two-phase flow sub-solver is a necessary step to extend GeN-Foam to the analysis of Boiling Water Reactors and severe accidents in PWRs and SFRs. A porous-medium approach is envisioned also in this case, using as basis a standard Euler-Euler solver available in OpenFOAM.

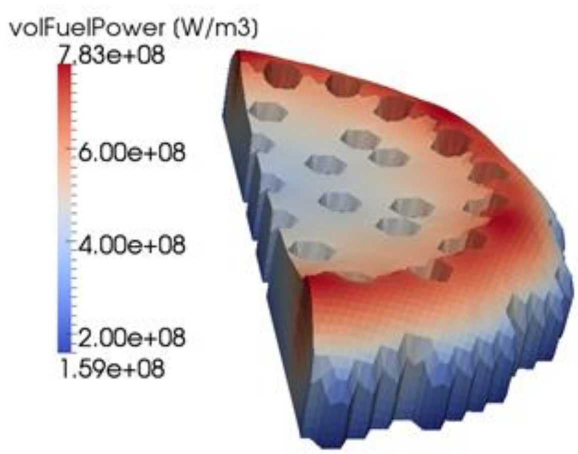

Figure 1: Fuel volumetric power in the core region of a sodium fast reactor as predicted by GeN-Foam. Thermal deformation of geometry is magnified by 100 times

a) **b)**

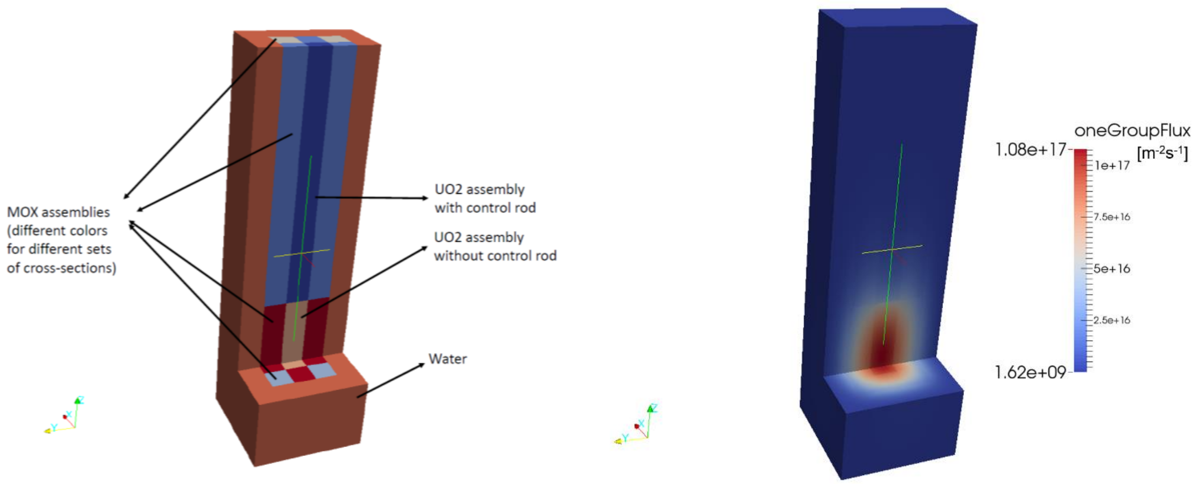

Figure 2: a) Geometry of a mini-core PWR benchmark, and b) flux distribution predicted by GeN-Foam

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References

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