THE GEN-FOAM MULTI-PHYSICS SOLVER AS A COLLABORATIVE EFFORT TOWARDS AN OPEN-SOURCE PLATFORM FOR REACTOR ANALYS: A HISTORICAL PERSPECTIVE AND LESSONS LEARNT

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The GeN-Foam (Generalized Nuclear Foam) [1] open-source software is an OpenFOAM [2] based solver for the steady-state and transient analysis of nuclear reactors.

The development of the solver was started in 2014 in the frame of a postdoc activity at the Paul Scherrer Institut (PSI) (Switzerland). The objective was to develop a modern HPC tool that could complement legacy codes with additional flexibility and computing power, as well as to provide the community with a transparent and easily accessible tool for research and education.

The choice of an open-source approach and, in particular, of employing OpenFOAM as base numerical library, allowed building the solvers upon previous effort towards OpenFOAM-based multi-physics nuclear solvers [3], [4]. The main developers associated with these efforts were both present at PSI at the time, which provided a critical mass of know-how and previous coding, which combined with the use of a modern and well written numerical library like OpenFOAM to enable the development of the base functionalities of the code already by early 2015.

In 2015, the development of GeN-Foam was mainly migrated to the EPFL, where it became a central development effort for the Laboratory of Reactor Physics and System Behavior. The open-source nature of GeN-Foam allowed both for a simple transfer of the code between institutions and for a continuous collaboration with PSI afterwards.

Beside PSI and EPFL, several institutions have been involved in the last several years in the development of GeN-Foam, making it a truly collaborative and international project. Notable examples of collaborations are:

- Development of the diffusion sub-solver (LPSC-IN2P3-CNRS Grenoble) [5];
- Development of an adjoint diffusion solver (UC Berkeley) [6];
- Development and application of GeN-Foam for Molten Salt Reactor (MSR) Applications (North Caroline State university) [7];
- Development of a point kinetics solver for MSRs (Politecnico di Milano) [8];
- Development of reduced order methodologies (TexasA&M University) [9]–[13];
- Application and verification of the thermal-hydraulic sub-solver (Xi'an Jiaotong University);
- Coupling of GeN-Foam with fuel behavior tools (University of Cambridge) [14];
- Use of GeN-Foam for education and training, in particular in the frame of the OPENER summer school (Politecnico di Milano and Milano Multiphysics).

With a growing network of users and developers, the necessity has soon materialized to start employing effective tools for collaborative development. As a first essential step, a git code versioning system was set up. This allowed a well-ordered development with tracked (versioned) modifications and a creation of various code “branches”: a stable “master” branch; a more advanced “develop” branch that would merge into the master branch after a testing phase; and several branches associated with single developers or specific development efforts that would merge into the develop branch after completion of the planned work. This allowed to better coordinate and integrate developments from various authors and institutions.

Seamless integration of various developments has also been made possible by the adoption of an object-oriented programming paradigm. According to this approach, the code is subdivided into “classes” that completely isolate (encapsulate) different functionalities of a code. As an example, in GeN-Foam, thermal-hydraulics, neutronics and thermal-mechanics are enclosed in three different classes. Each one of these classes is provided with derived classes for specific models, such as point kinetics, diffusion, SP3 and SN. This allowed for instance an author to develop and contribute the adjoint-diffusion solver of GeN-Foam as a standalone class, without having to interact with any other part of the code beside deriving this new class from the existing neutronics class.

To facilitate the communication among users and developers, a private discussion forum was also opened, which proved invaluable to compensate for the initial lack of documentation and the limited number of tutorials. In this sense, interaction with users led to the choice of limiting the documentation to a relatively synthetic wiki while focusing on the creation of a well-commented and comprehensive set of tutorials, which were clearly perceived by the community as the best way to lower the entry step for the use of GeN-Foam. As a next step, the possibility is being considered to open a public discussion forum, possibly shared with other OpenFOAM-based developments in the nuclear community. This is expected to greatly support the community in the use of a code that is relatively well developed, but still quite complex due to its multi-physics nature and due to the use of very general (CFD-like) numerical methodologies. Very successful examples of such kind of public discussion forums are provided by the Serpent2 code and by CFD Online.

The growing number of tutorials allowed in 2018 to provide GeN-Foam with a sound regression test consisting in a sequential run of a representative sub-set of tutorials to verify the consistency of results after code modifications. The availability of a regression test proved to be essential to improve the quality of the code. It also accelerated development by avoiding time-consuming searches through previous code versions in case bugs had been inadvertently included in the code.

The growing availability of tutorials, a more comprehensive documentation, and the improves quality assurance introduced by the regression test led to a first Beta release of GeN-Foam in 2020, followed by an official public release in 2021.

Git versioning and a regression test are also proving to be essential to limit maintenance efforts. In this sense however, the most important aspect is represented by the adoption of a the above-mentioned object-oriented programming. This allows for instance to modify sub-solvers and other classes without affecting the others. As a matter of fact, one should mention that it was decided to break the encapsulation in specific parts of the code, though always using one single and very specific mechanisms (lookup to object registries associated to the meshes).

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