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Editorial: Advanced modeling and simulation of nuclear reactors

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Editorial on the Research Topic
Advanced modeling and simulation of nuclear reactors

Modeling and simulation (M&S) have been playing a significant role in nuclear engineering, since they enable the reproducing of the behavior of nuclear systems through computational models. However, with higher requirements for the safety and economy of nuclear reactors, the traditional M&S methods and tools for reactor analysis are being challenged. In addition, new reactor designs have been proposed, and some new reactors have gradually entered the testing and even engineering stages; the representative new reactor types include the fast-neutron reactor, pebble-bed high-temperature gas-cooled reactor, molten salt reactor, and small modular reactor, *etc.* Research on new pressurized water reactor fuels, and especially research on accident-tolerant fuel, are also in full swing. These new types of reactors and fuels also put forward new requirements for reactor calculation procedures and methods.

Advanced modeling and simulation seek to provide guidance for the design and optimization of current and next-generation reactors with newer and better models, including the ability to incorporate more underlying physics, adopt higher fidelity models, comprise difference scales, and fit various computing hardware (Wang et al., 2017; Chen et al., 2018; Zu et al., 2019a; He et al., 2021; Weng et al., 2021). The new modeling and simulation will benefit the nuclear industry by enabling scientists/engineers to analyze and optimize the performance and reliability of existing and advanced nuclear power plants (Li et al., 2018; Zheng et al., 2018; Zu et al., 2019b; Wang et al., 2021).

We have collected five papers on deterministic, Monte Carlo, and hybrid methods in reactor physics analyses by Than and Xiao, Guo et al., Zhong et al., Zhong et al., and Zhao et al.. Than's work extended the linear prolongation flux update scheme to both regular Coarse Mesh Finite Difference (CMFD) acceleration and partial CMFD acceleration in 2D multi-energy group Monte Carlo k-eigenvalue neutron transport problems. Guo et al.'s work analyzed the convergence characteristic of the neutron source iteration algorithm of the predictor–corrector quasi-static Monte Carlo (PCQS MC) method. It is found that the convergence rate of the iteration algorithm is governed by the effective spectral radius (ESR). The lower the ESR is, the faster the convergence is. In order to reduce the ESR, the asymptotic superhistory method (ASM) was developed for the PCQS MC method in the RMC code. Zhong et al.'s work applied the Monte Carlo code OpenMC to build the Korean system-integrated modular advanced reactor (SMART) full-core model to optimize the SMART power performance effectively and find an efficient neutron reflector choice with good material properties. Zhao et al.'s work analyzed the numerical results of eigenvalues, assembly power distributions, and energy spectrums in the burnup procedure of a small lead-based breeding reactor (SLBR-50) using the Monte-Carlo code RMC.

We have collected three papers on computational fluid dynamics (CFD) and applications by Jiang et al., Wang et al., Li et al.. Jiang et al.'s work carried out an investigation on the vibration response characteristics and influencing factors of the fuel rods of EPR based on ANSYS-APDL. Wang et al.'s work conducted a thermal analysis with helium flow in various channel designs based on CFD methods to determine a dimension-optimized rod bundle channel. An experimental study then followed in order to pick up an appropriate gas flow model through further numerical simulation. Finally, a helium flow in the bundle channels consisting of 217 rods was simulated using this chosen flow model, showing that the method satisfies the requirements of the basic thermal analysis of a newly designed gas-cooled reactor with an open lattice structure. Li et al.'s work analyzed the effect of different ventilation scenes on tritium removal efficiency. The study set up six different ventilation scenes and carried out the numerical simulation of tritium migration and mixing behavior based on Fluent.

We have collected three papers on computer code development, verification, and validation by Zhang et al., Guo et al., and Zhang H. et al.. Zhang B. et al. Developed a lead–bismuth-cooled fast reactor calculation code system named MOSASAUR to meet the simulation requirements of the lead–bismuth-cooled fast reactor (LBFR) engineering design. Guo et al.'s work built a steady-state model of the NuScale reactor and simulated a turbine trip transient using the thermal hydraulic module CESAR of the severe accident code ASTEC. Zhang H. et al.'s work elaborated the main features of SHARK's "resonance-transport-depletion" coupling system and presented and discussed some verification and validation (VandV) results in the current phase.

We have collected one paper on artificial intelligence applications in nuclear energy by Li et al.. Li et al.'s work analyzed the main theory and feasible improvements of the fine-mesh subgroup method (FSM). Several pin cell and lattice problems were applied to test the performance of the FSM, and the particle swarm optimization method was adopted to find the better group structure.

We have collected one paper on other applications related to the advanced modeling and simulation of nuclear reactors by Lei et al.. Lou et al.'s work analyzed the power level and economy of lead-based modular nuclear power and designed and analyzed the economy of fast reactors of different power levels with a 2,000 equivalent full power day (EFPD) lifetime, such as 100 MWt, 300 MWt, 500 MWt, 700 MWt, and 1,000 MWt thermal power.

With the increasing demands of high-fidelity analysis and the development of computer technology, advanced modeling and simulation are becoming more and more attractive. Neutron transport methods (both deterministic and Monte Carlo methods), CFD, artificial intelligence, and so on show very promising potential for the design and analysis of a new-generation nuclear energy system. The calculation time and footprint consumption will hinder the application of these advanced modeling and simulation methods in industry. In the future, these methods should embrace high-performance computing to accelerate their industry application.

Author contributions

SL, JL, JY, QH and YL contributed to conception and design of the study. SL and JL wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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