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EDITED AND REVIEWED BY
Shripad T. Revankar,
Purdue University, United States

*CORRESPONDENCE
Tao Wan,
wantao@impcas.ac.cn

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Editorial: Technological Frontiers in Gen4 nuclear energy systems and small reactors

Tianji Peng[1,2,3,4], Yaoli Zhang[5], Han Zhang[6], Jianjun Xiao[7] and Tao Wan[1,2,3]*

[1]Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China, [2]Advanced Energy Science and Technology Guangdong Laboratory, Huizhou, China, [3]School of Nuclear Science and Technology, University of Chinese Academy of Sciences, Beijing, China, [4]Huizhou Ion Science Research Center, Huizhou, China, [5]College of Energy, Xiamen University, Xiamen, China, [6]Institute of Nuclear and New Energy Technology, Tsinghua University, Beijing, China, [7]Institut für Thermische Energietechnik und Sicherheit, Karlsruher Institut für Technologie, Karlsruher, Germany

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Editorial on the Research Topic
Technological Frontiers in Gen4 nuclear energy systems and small reactors

Nuclear power will play an important role in a carbon-constrained world, and new concepts of advanced nuclear energy systems have been proposed and developed. Due to their significant superiority over current-generation and evolutionary systems in the areas of sustainability, safety and reliability, and economics, Gen4 nuclear energy systems and small module reactors have been significantly developed in recent years. Specifically, sodium-cooled fast reactor (SFR), lead-cooled fast reactor (LFR), gas-cooled fast reactor (GFR), very high-temperature gas reactor (VHTR), molten salt reactor (MSR), supercritical water-cooled reactor (SCWR), accelerator-driven system (ADS), and small modular reactor (SMR) are the subjects of greatest concern. With the progress of technology, in developed and developing countries, parts of the advanced reactor types have been in the phase of prototype reactor construction and demonstration project construction.

There are many innovations in the design of reactor physics, thermal-hydraulics, power conversion systems, and coolants, which help Gen4 nuclear energy systems and small reactors achieve the expected superiority and obtain new applications. Meanwhile, new computational analysis methods and software, including artificial intelligence, have been applied to the design and analysis of advanced reactors, bringing new possibilities to this field. To provide a platform for the discussion of recent developments in the design, analysis, and key technologies of these innovations, a Research Topic has been organized to bring cutting-edge research of the advanced technologies of Gen4 nuclear energy systems and small reactors. Four up-to-date articles on innovative research, including opinion and review articles, on Gen4 nuclear energy systems and small reactors are showcased.

The lead-based reactor is a kind of fast neutron reactor that uses liquid lead or lead–bismuth alloy as coolants. Due to its excellent safety, economy, and design flexibility, it is one of the most popular small modular reactor types in the world. Chen et al. Tang, and Qian presented a 100 MWe small modular LBE-cooled reactor concept developed by the Shanghai Nuclear Engineering Research and Design Institute CO., LTD., which aimed to meet the market demand for an advanced small-scale nuclear plant. Based on this conceptual scheme, the authors used the best-estimate code ATHLET/MOD 3 to establish a safety analysis model of the lead–bismuth reactor and analyzed representative design basis conditions (PTOP, PLOF, and PLOHS) and representative design extension conditions (UTOP, ULOF, and ULOHS). The results showed that the reactor can meet the safety criteria under these representative accident transients. The work of this article demonstrated the excellent passive safety of the lead-based reactor with a negative temperature coefficient and strong natural circulation capability.

Micro gas-cooled reactors with inherent safety characteristics offer extensive benefits across multiple applications. Zhang el al., Li, and Zhao built a system model of a micro gas-cooled nuclear reactor with the Modelica language. The accuracy of the reactor core model was verified by high-fidelity CFD simulation results, demonstrating good agreement. Further investigations were then conducted on the safety and operational characteristics of the whole system. Typically, two simulations were conducted on the gas-cooled micro nuclear reactor design: one focused on anticipated transients without a scram accident scenario and the other on a load-following operation. The simulation results demonstrated that the reactor possesses excellent inherent safety, even during extreme accidents. Furthermore, a passive air-cooling mechanism was investigated and successfully demonstrated within the model. The reactor also exhibits good load-following performance, which can be achieved by simply adjusting helium inventory, pressure, or control drum position while maintaining a constant core temperature and power generation efficiency. The work of this article can be leveraged to provide guidelines for further detailed designs of micro gas-cooled reactors.

The supercritical carbon dioxide Brayton cycle is one of the optional energy conversion cycles for Gen IV advanced reactors. However, there are still many problems to be solved before the supercritical carbon dioxide Brayton cycle can be used in operation. Zhou et al., Xu, and Zhang et al. performed a numerical simulation of Rayleigh–Bénard convection with supercritical carbon dioxide in a shallow cavity. The influences of the bottom heat flux on the flow stability, flow pattern evolution, and heat transfer ability of Rayleigh–Bénard convection were analyzed. The transient and steady-state fluid behaviors were obtained. The results showed that the bottom heat flux played a dominating role in the stability of the convection. A transition from stable evolution to significant oscillation was found with the increase of the heat flux. The flow pattern evolution also strongly relied on heat flux. A four-cell structure to a six-cell structure transformation accompanied the orderly multicellular flow was observed with increasing heat flux. The fundamental study of Rayleigh–Bénard convection with supercritical carbon dioxide can give hints for the development of high-efficiency supercritical dioxide compressors and turbines.

Rotating mechanical equipment is a key component of Gen IV advanced reactors. Sun and Wang proposed diagnosis models for rotating machinery in advanced reactors based on a deep learning model. The diagnosis model was tested by identifying the faults of bearings and gears. Normalization, augmentation, and splitting of data were applied to prepare the datasets for the classification of faults. Multiple diagnosis models containing the multi-layer perceptron, convolutional neural network, recurrent neural network, and residual were compared and investigated with the Case Western Reserve University datasets. An improved transformer model was proposed, and an enhanced embedding generator was designed to combine the strengths of the CNN and transformer. The effects of the size of the training samples and the domain of data preprocessing, such as the time domain, frequency domain, time–frequency domain, and wavelet domain, were investigated. Sun and Wang found that the time–frequency domain is most effective, and the improved transformer model is appropriate for the fault diagnosis of rotating mechanical equipment.

We hope that readers will find the articles of this Research Topic to be a useful reference that can inspire researchers in the field of Gen4 nuclear energy systems and small reactors.

Author contributions

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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.

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