TYPE Editorial
PUBLISHED 09 June 2023
DOI 10.3389/fenrg.2023.1233257

OPEN ACCESS

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RECEIVED 01 June 2023
ACCEPTED 05 June 2023
PUBLISHED 09 June 2023

CITATION
Tiselj I and Giusti V (2023), Editorial: Light water reactor technology of the next decade.
Front. Energy Res. 11:1233257.
doi: 10.3389/fenrg.2023.1233257

Editorial: Light water reactor technology of the next decade

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KEYWORDS

light water reactor science, LWR technology, PWR, BWR, small modular reactors based on LWR technology

Editorial on the Research Topic
Light water reactor technology of the next decade

Light water reactors (LWRs) serve as the basic technology for global nuclear electricity generation, and it is highly improbable that any other technology will pose a significant threat to their dominance in the next decades. And while Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs) exist for over half a century, ongoing advancements and optimizations continue to take place. These enhancements are being implemented in existing power plants classified as Generation II, as well as in the development of Generation III reactors currently under construction. Furthermore, the main types of Small (Modular) Reactors (SMR), which are the closest to the realization and expected to be built in the near future, utilize LWR technology. Nuclear fuel will see some significant advancements paving the way for enhanced efficiency, safety, and sustainability in nuclear power generation. One area of focus is the improvement of fuel design and composition. Scientists and engineers are exploring novel fuel materials, cladding materials, and geometries to enhance fuel performance and extend fuel burnup. The goal is to develop fuel assemblies that can withstand higher temperatures, pressures, and neutron fluxes, resulting in longer operating cycles and increased energy output. These concepts, known as accident-tolerant fuels (ATFs), have gained considerable attention in recent years. Although the ATFs do not preclude fuel melting (as the name might suggest), they are designed to withstand extreme conditions during accidents, offering improved resistance to overheating, oxidation, and hydrogen production. These fuels aim to enhance the safety margins of LWRs and reduce the likelihood of core damage under severe accident scenarios. The availability of reliable modeling and simulation tools to perform uncertainty quantification and sensitivity analysis of fuel performances will be a key point for the success of the above actions as discussed in the article by Faure et al.

Life extension research for light water reactors (LWRs) is focused on maximizing the lifespan and efficiency of existing nuclear power plants. Most of the power plants that were initially planned for 40 years lifespan are today known to be able to operate for 60 years. Further extensions are being discussed. Research efforts involve studying aging mechanisms, inspecting critical components, and developing advanced materials. Non-destructive examination techniques detect degradation or damage, informing maintenance decisions. Advanced materials with improved corrosion resistance and protective coatings are explored to enhance component resilience. Safety margins and operational limits are evaluated to establish updated guidelines. To allow a safe and continuous operation of a nuclear power reactor, the control-rod reactivity worth is a safety-related parameter that has to be accurately monitored. A method based on the signal of ex-core detectors and neutron redistribution factors is well described by Goričanec et al. Computational modeling aids in simulating scenarios and assessing long-term behavior. The goal is to extend safe and reliable LWR operation beyond initial design lifetimes, ensuring their continued contribution to clean and sustainable electricity generation.

The most vibrant research area in the field of LWR technology today, is very likely the development of Small Modular Reactors. These compact reactors, typically with a power output of less than 300 MW, capitalize on the proven principles of LWRs, while at the same time open opportunities for simplification or even elimination of certain systems, which cannot be avoided in large-scale reactors. This familiarity enables leveraging existing infrastructure, operational expertise, and regulatory frameworks, simplifying licensing and deployment. The advantages of SMR LWRs might extend beyond their size. Their modular design could enable standardized manufacturing, streamlined construction, and reduced capital costs. It remains to be seen whether these advantages will overweight the economies of scale advantage of the standard, gigawatt size nuclear reactors. Ongoing research and development efforts will certainly continue to advance SMR LWRs, paving the way for their adoption in the global energy landscape. Moreover, they could offer flexibility in load-following capabilities, facilitating integration with renewable energy sources and enhancing grid stability. With such a perspective, the load-following operation mode is currently a very active Research Topic as shown by the review article by Žerovnik et al.

Next to the three Research Topic explicitly addressed above, the field of LWR technology continues to see active research also in other areas. Multi-physics models, virtual reactors, and optimization of LWR thermal-hydraulics are among the ongoing endeavors to enhance the resilience and performance of these reactors. The possibility to adopt high-fidelity multi-physics couplings for LWR modeling and simulation is currently deeply investigated and new tools that include reactor physics, thermal hydraulics, fuel performance, structural mechanics, and materials chemistry analyses are under development. However, as discussed by Vaglio-Gaudard et al., there is a lack of suitable experimental data towards which they can be validated. Thus the necessity to start planning new ad-hoc experimental campaigns. Additionally, advancements in inherent safety characteristics are being explored for large-scale and SMR reactors. These efforts aim to improve the understanding and operation of LWRs, ensuring their continued progress in the realm of nuclear power generation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

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