Foreword

Selected papers from the 23rd Topical Meeting on the Technology of Fusion Energy (TOFE 2018)

Licensing, New Facilities, and Safety

Jeanette Berry

Guest Editor
Associate Editor, Fusion Science and Technology

This special issue of *Fusion Science and Technology* is the first in a series of topical special issues featuring expanded research presented at the 23rd Topical Meeting on the Technology of Fusion Energy (TOFE 2018), held November 11–15, 2018, in Orlando, Florida. The papers in this issue focus on the response of the nuclear community to the urgent need to deploy and commercialize advanced nuclear technology, because it is a key to fighting climate change by significantly reducing carbon emissions.[a] This special issue describes steps being taken to move advanced fission and fusion reactors toward commercial deployment and draws on presentations given during a TOFE 2018 session titled "Licensing and Safety of Fusion and Gen IV Reactors." We begin with descriptions of the licensing process for advanced reactors that consider revolutionary safety aspects of these designs. Following this, we turn to safety advancements and then describe design changes needed to commercialize these reactors. These advanced designs incorporate safety through the regulatory licensing process as well as with the use of tools to analyze and inform designs for safety.

Advanced fission and fusion reactors must "[align] with the regulator on acceptance criteria and means to establish proof of safety of innovations critical to success," per Bergman in a TOFE 2018 presentation.[b] Bergman's presentation concluded that, "The challenge of innovations arises from the extent the innovations depart from what was contemplated in creating the regulatory framework." This conclusion seems counterintuitive since a primary purpose of innovation is to improve the safety of reactor design. For example, inherently safe designs are being implemented for small modular reactors, non-light-water reactors (e.g., high-temperature gas cooled reactors and molten-salt-cooled fission reactors), and fusion reactors. The implementations of three types of regulatory frameworks are demonstrated: (1) a U.S. prescriptive regulatory framework (see presentation by Kinsey[c]); (2) a French goal-oriented regulatory framework (see Perrault's paper in this issue); and (3) Italian licensing using the category applicable to particle accelerators (see Sandri et al.'s paper in this issue). All reinforce that licensing is an iterative process. The U.S. Department of Energy, the U.S. Nuclear Regulatory Commission, the Institut de Radioprotection et de Sûreté Nucléaire, and six Italian ministries work closely with the designers of advanced reactors as well as public and regional governments to demonstrate the safety and radiation protection of the advanced design.

The European Union (EU) DEMO reactor is scheduled to produce net electricity from fusion by the 2050s—a timeframe that could result in fusion assisting in the fight against climate change. As discussed by Hernández et al. in this issue, the project adopts a system engineering approach with lessons learned from fission reactors to guide the preconceptual design. The work describes design development of heat transfer in a helium-cooled breeding blanket by use of prismatic beryllide blocks as well as consideration of the balance of plant and

[a] "Characteristics of Four Illustrative Model Pathways," in "Global Warming of 1.5°C: Summary for Policymakers," Intergovernmental Panel on Climate Change (2018); https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/ (current as of May 24, 2019).

[b] T. BERGMAN, "NuScale: Innovation and the Regulator," presented at TOFE 2018; see Supplemental material online.

[c] J. KINSEY, "Safety and Licensing Approaches for Modular Gas Cooled Reactors," presented at TOFE 2018; see Supplemental material online.

interfacing systems that results in lower plant power requirements, reduced cost, and improved safety. Advances in the EU DEMO design are also described by Froio et al.'s paper. This work discusses improved one-dimensional computational fluid dynamic modeling of a helium-cooled pebble-bed breeding blanket by using system-level tools to better estimate conditions, such as pressure and mass flow rate, at the blanket boundaries (e. g., blanket supporting structure manifolds). The analysis shows that a uniform pressure boundary condition results in nonconservative results. The authors recognize that experimental data should be collected to verify these findings. Advances being made by the EU in fusion reactor design are on track to support commercialization.

Another fusion reactor DEMO is being developed in Japan. This special issue includes a paper by Tobita et al. on a design that uses a water-cooled, solid breeding blanket that builds on lessons learned from ITER and from fission reactor design of pressurized water reactors. Design evolution over the past decade is described, including improvements in divertor heat removal with simplification of the breeding blanket, analysis of the material of construction of the magnetic coils, facilitation of remote maintenance, and consideration of reducing the size of radioactive waste facilities and waste storage in the plant layout. In their paper, Tamura et al. describe a commercial/demonstration, conceptual design of a force free helical reactor (FFHR). The mechanical design of the magnet system was developed to ensure that deformation remains within the required values and that access for maintenance is sufficient. The Large Helical Device design was improved by evaluating the electromagnetic force, superconductor, and structural material and the stress resulting in the first iteration of the FFHR-c1. By scaling this design, FFHR-d1 was further improved by modifying the coil and support structure and weight. Japan is making significant progress toward commercializing fusion reactors.

A theme throughout this special issue is the importance of incorporating safety early in the design phase. Two works specifically describe safety improvements being considered. Zucchetti et al. propose an optimized waste management strategy that includes careful selection of materials and careful assembly systems for components. Also, early development of recycling processes and reuse routes are proposed according to various international requirements. Various international standards are considered to promote the work's safety goals: to avoid underground disposal as much as possible, maximize recycling of activated materials within the nuclear industry, and/or clear and release to commercial markets materials that contain only slight traces of radioactivity. In their paper, Iwai et al. focus on the safety of the detritiation system by describing a design that does not require heating of the catalyst reactor for tritium oxidation and does not require frequent switching of adsorption columns for tritiated vapor collection. Experimental work and findings regarding the design of the catalyst (e.g., noble metal species, particle size, and pore size) that could improve the safety of tritium removal from the atmosphere of nuclear containment are described. These design considerations can improve fusion safety by thoughtful management of waste and by suppression of production of tritiated hydrocarbons.

Nuclear facilities are designed using advanced safety analysis tools. Elbèze et al. show that results of three analysis methods compare favorably when used to analyze reliability, availability, maintainability, and inspectability (RAMI): reliability block diagram analysis, quantitative schedule risk analysis, and analytical formulas. Functional analysis followed by a failure mode, effects, and criticality analysis (FMECA) identifies the most significant failure modes according to their criticality. The methods are compared, and how the analyst can effectively use the methods is described. Finally, Bonifetto et al. explain a systematic assessment to the safety-informed design of the EU DEMO magnet design and manufacturing, with special attention paid to the toroidal field coils. Postulated initiating events were identified by completing a functional analysis and a FMECA. The results identified research and development needs, informed the design, and pointed to the need to consider toroidal field coil replacement during the reactor lifetime. By using these rigorous tools iteratively, designers and developers of nuclear reactors ensure the safety and maintainability of their designs.

Development and commercialization of advanced reactor designs is progressing. As shown in this special issue of *Fusion Science and Technology*, nuclear projects incorporate safety into their designs beginning at the preconceptual level: they conduct experiments and are required to gain regulatory acceptance at all design phases, as well as construction, through comprehensive processes and required procedures. By disseminating information regarding the safety of these designs, the nuclear community should be able to increase public support for nuclear energy to fight climate change.