Foreword

Special issue featuring papers from the 25th Topical Meeting on the Technology of Fusion Energy (TOFE 2022)

Guest Editor

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We are delighted to bring you this *Fusion Science and Technology* (*FST*) special issue featuring papers derived from the 25th Technology of Fusion Energy topical meeting (TOFE 2022). TOFE 2022 was organized as an embedded topical in the American Nuclear Society Annual Meeting and conducted June 12–16, 2022, with in-person attendance in Anaheim, California, at the Anaheim Hilton. The *FST* editors appreciate the tireless efforts of the TOFE 2022 organizers to manage all the intricate conference processes. The dedication and commitment of the conference general chair (Dr. Ales Necas) and technical program chair (Dr. Paul Humrickhouse) contributed to a smooth and enjoyable experience for the conference attendees.

TOFE 2022 attracted worldwide specialists in fusion technology whose efforts may make possible, in the not-too-distant future, the harnessing of energy from thermonuclear reactions. Meeting highlights included the executive plenary session moderated by Dr. Scott Hsu, the U.S. Department of Energy (DOE) lead fusion coordinator. Above all, the TOFE 2022 participants experienced joyful face-to-face communications and networking, which were sorely missed, as the previous TOFE was held online only in 2020 because of the COVID-19 pandemic. Attendees were happy to connect with other professionals in the field and learn about the latest advancements and research in fusion technology.

This special issue of *FST* presents 27 peer-reviewed articles including 24 research articles and 3 student papers showcasing cutting-edge fusion technology. The issue's contents span the breadth of the topics at TOFE 2022 across five subjects:

1. Neutronics of fusion devices with assessment of their safety and environmental impacts.
2. Design development of fusion research facilities.
3. Modeling and simulations (thermo-fluid, plasma, electromagnetic, and structural).
4. Plasma-facing components (PFCs) and plasma–material interactions (PMI).
5. Breeding blanket technology and tritium transport.

The papers in this issue are organized according to these subjects and are summarized below.

Subject 1: The first 10 articles in this special issue are on the subject of fusion neutronics. These articles explore the latest neutronics advancements and provide valuable insights into the challenges that researchers are currently facing. The issue opens with an overview article by Laila El-Guebaly titled "Managing Fusion Radioactive Materials: Approaches and Challenges Facing Fusion in the 21st Century." It presents the peculiarities of radwaste materials generated by large tokamaks, with a comparison of activated material volumes generated by the ITER experiment, JA-DEMO, EU-DEMO, China's CFETR, and the U.S. ARIES-ACT2 power plant. The article proposes a strategy for radwaste recycling and clearance to minimize the radwaste requiring disposal. It is evident that in progressing fusion technology based on the D-T nuclear reaction with emission of 14.1-MeV neutrons, much investigation of neutron sources and neutron interactions with materials will be necessary to conduct. To this end, the U.S. Fusion Energy Science Advisory Committee and the National

Academies of Sciences recommend concentrating the research efforts on the Fusion Prototypic Neutron Source (FPNS) experimental facility.

The second article in this issue, by Laila El-Guebaly and Mohamed Sawan, highlights the accuracy in the definition of the neutron energy spectrum for calculations of radiation damage, gas production, and transmutations in fusion materials as tested by FPNS, for a fusion pilot plant, DEMO, and future power plant. The third article of the issue, written by Chase N. Taylor et al., answers positively the question of whether blanket materials require irradiation testing in FPNS, particularly for the materials that require the high-energy part of the fusion energy spectrum, such as testing the (n,2n) neutron multiplication reactions in beryllium or energy-threshold reactions with charged particle emission. Regarding generating high-energy neutrons for FPNS, the fourth article (by Eric J. Pitcher et al.) presents a conceptual study to use tungsten targets irradiated by an accelerated proton beam established at the Los Alamos Neutron Science Center (LANSCE). The neutrons are produced from the tungsten nuclei via spallation nuclear reactions, with the neutron energy spectrum extended beyond the requested 14.1-MeV peak in FPNS. That means the LANSCE could supply neutrons with a margin on their energy.

Felipe S. Novais et al., authors of the fifth neutronics article, parametrically examine the tritium breeding performance for several solid breeder concepts of the Fusion Energy System Studies Fusion Nuclear Science Facility (FESS-FNSF), the purpose of which is to close the gap between ITER and a future US-DEMO leading toward fusion power plants. The theme of FNSF neutronics studies continues in the sixth article, our first student paper, titled "Activation Analysis for the Inboard Region of FNSF Using SERPENT," authored by Son N. Quang et al. It presents the activation calculation results of the FNSF components after facility shutdown using the SERPENT 2 Monte Carlo code, with the activation characteristics applicable for radwaste classification. The radiation damage analysis for the FNSF components is given in the seventh neutronics paper, by Marina Rizk et al. The analysis has been performed by converting the 3D CAD model of FNSF using the McCad geometry conversion software and the MCNP6.2 Monte Carlo radiation transport code. The eighth article, titled "Initial Neutronics Investigation of a Chlorine Salt–Based Breeder Blanket," by Tim D. Bohm and Ben A. Lindley, discusses advances in liquid chlorine salts as the potential breeding blanket material of FNSF, with particular concerns about increasing the tritium breeding ratio (TBR). This article presents interesting comparisons of TBR depending on the salts' compositions, demonstrating that chloride salts (LiCl mixed with $BeCl_2$ and/or $PbCl_2$) enriched in ^{37}Cl can potentially achieve a higher TBR than can fluoride molten salts (FLiBe).

The narrative of the neutronics subject changes to more methodological, code-developing aspects in the ninth article, titled "Advancing Methods for Fusion Neutronics: An Overview of Workflows and Nuclear Analysis Activities at UKAEA," by Alex Valentine et al. This paper is devoted to the neutronics methodological developments practically realized in software interfaces of 3D CAD-based radiation transport and activation analyses suitable for accurate assessment of the radiation environment throughout the fusion facility's lifetime operation and subsequent decommissioning. In the 10th neutronics article, A. Iiyoshi et al. describe the environmental benefits of the thorium subcritical reactor activated and controlled by muon-catalyzed fusion (MuCF). With the recently available theoretical explanations of the MuCF process and the new design proposals of the hybrid muonic fusion-fission thorium reactor, the presented hybrid scheme is interesting and worth further study.

Subject 2: The subject of design development of fusion research facilities encompasses four articles, beginning with Thomas R. Barrett et al.'s article "CHIMERA Fusion Technology Facility: Testing and Virtual Qualification." The paper gives an overview of the capabilities and test program of the facility CHIMERA (Combined Heating and Magnetic Research Apparatus), which is under construction by the United Kingdom Atomic Energy Authority, and presents the strategy for qualification using engineering simulations. The next article, by M. C. Thompson et al., "Engineering Paradigms for Sheared-Flow-Stabilized Z-Pinch Fusion Energy," was presented in the Industry Focus session of TOFE 2022. The paper introduces the sheared-flow-stabilized Z-pinch approach to fusion energy from the engineering perspective of developers at Zap Energy, Inc. The third design development article, titled "UNITY: Kyoto Fusioneering's Unique Integrated Testing Facility for Fusion Power Generation," is written by Shutaro Takeda et al. It complements the capabilities of the CHIMERA facility with heat extraction from a fusion blanket, including Kyoto Fusioneering's blanket SCYLLA. The UNITY facility provides high-temperature heat transfer and exchange, making possible electricity generation from blanket heat and tritium extraction and management under commercially relevant conditions. The fourth article on the fusion facilities subject is "Initial Commissioning Test Results of the Wendelstein

7-X Continuous Pellet Fueling System," by S. J. Meitner and L. R. Baylor. It presents the laboratory experimental setup of the continuous pellet fueling system and the results of commissioning tests completed at Oak Ridge National Laboratory (ORNL) for future installation on the Wendelstein 7-X stellarator.

Subject 3: The modeling and simulations subject features three papers. The first one is titled "Bayesian Parameter Estimation of the *k*-ω Shear Stress Transport Model for Accurate Simulations of Impinging-Jet Heat Transfer," by Michael L. Lanahan et al. It relates to the numerical simulation of thermo-fluid performance of PFCs. The objective of this paper is to evaluate the Bayesian parameter estimation of turbulence closure constants in the ANSYS Fluent code to model heat transfer in impinging jets. It adopts the Bayesian approach to inversely calibrate parameters in the Reynolds-averaged Navier-Stokes turbulence model for a jet impingement cooling problem. The second paper, "ORNL Progress in Disruption Mitigation Technology in Support of ITER," by L. R. Baylor et al., presents the ORNL technology to inject material into the plasma to rapidly radiate the thermal energy and start a fast plasma current ramp down to dissipate the magnetic stored energy. The paper describes the technological evolution that has been employed for disruption mitigation and runaway electron prevention in the plasma. The third paper, by Arthur Brooks et al., describes the results of the 3D electromagnetic and structural analysis of disruptions in the COMPASS upgrade vacuum vessel.

Subject 4: The subject of PFCs and PMI includes five articles. In the first, D. Andruczyk et al. give an overview of liquid metal PFC R&D at the University of Illinois Urbana-Champaign (UIUC). The paper summarizes the results of the experiments undertaken at UIUC as part of the U.S. DOE liquid metal PFC development program with the direct aim of eventually designing a flowing liquid metal divertor suitable for FNSF or compact pilot plant (CPP).

With the second paper on this subject, J. Rapp et al. open a series of four papers devoted to the development of the Material Plasma Exposure eXperiment (MPEX) at ORNL. Rapp et al.'s paper gives an overview of the MPEX final design. The MPEX facility will allow investigation of PMI for a fusion prototypic divertor, with PMI conditions dominated by the erosion and deposition processes. The details of the MPEX high heat flux microwave absorber design are described by A. Hussain et al. in the second paper of the MPEX series. It explains the need to install microwave absorbers in MPEX to minimize stray microwaves leaving the region where the electron cyclotron heating (ECH) system heats the MPEX plasma. In the third paper of the MPEX series, Adrian S. Sabau et al. present a thermohydraulic evaluation of a new MPEX target assembly design to assess appropriate MPEX operation. The fourth MPEX series paper, authored by Jonathan Perry et al., provides an in-depth analysis of the final design of the MPEX vacuum pumping systems. The vacuum system needs to minimize the pressure in the plasma heating region to improve the coupling of the ECH and ion cyclotron heating to the MPEX plasma. This paper closes the subject of PFCs and PMI.

Subject 5: The subject of breeding blanket technology and tritium transport includes five articles and opens with a paper by Cody S. Wiggins et al. The authors discuss the design, commissioning, and preliminary performance of a helium flow loop experiment (HFLE) providing a flow of helium at up to 4 MPa. The paper presents the HFLE results of the initial thermal-hydraulic tests of an additively manufactured rifled-rib test section. Results are compared to smooth pipe correlations, and plans are described for future HFLE measurements for the study and optimization of blanket coolant channel geometries.

The next two papers are student papers, and both are devoted to the EU-DEMO blanket technology and tritium transport. In the first of these, Luigi Candido et al. elaborate on the tritium inventory and tritium permeation fluxes in the water-cooled lithium-lead breeding blanket of the EU-DEMO fusion reactor. The tritium transport analysis is essential for the evaluation of the tritium retention in LiPb and in the structural components, as well as tritium permeation fluxes into the cooling water. In the second student paper, Jonas C. Schwenzer et al. present modeling results of the helium-cooled pebble bed helium coolant purification system for the EU-DEMO breeding blanket. The coolant purification system is designed to counteract the buildup of tritium and adverse impurities.

The tritium subject continues with a paper by M. Sharpe and W. T. Shmayda studying the influence of the metal surface microstructure on the absorption of tritium into gold-plated stainless steel type 316 (SS316). A comparison is given between tritium inventories in nonplated SS316 to the inventories in SS316 samples electroplated with gold by various laboratories. It was found that the microstructure of the gold layer significantly impacts the absorption of tritium into the samples.

Finally, the issue and the tritium subject conclude with the article "Parametric Study of the Vacuum Permeator for the Tritium Extraction eXperiment" (TEX), authored by Thomas F. Fuerst et al. TEX is a forced-convection loop under construction at Idaho National Laboratory that is designed to test the vacuum permeator tritium extraction system. This paper describes an updated transport model of the vacuum permeator tritium extraction system designed for PbLi breeder blankets that includes surface reactions on the vacuum-facing permeator surface. The presented results are useful for the development of the dual-cooled lead-lithium breeder blanket concept considered for FNSF.

Sketching out the circle of the potential readers of this TOFE 2022 special issue, we assume this collection to be worth reading by fusion nuclear technology specialists, nuclear scientists, engineers, postgraduates, and educated people who are interested in recent achievements in fusion technology. Readers from many perspectives will discover the contemporary challenges, design solutions, and horizons of future developments in fusion technology, which are stretching every day to reach toward unlocking this new source of energy.

Disclosure Statement

No potential conflict of interest was reported by the author.

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