Vacuum Technology
Room 321 - Session VT+FUS-WeA

Vacuum Technology Fusion

Moderators: Freek Molkenboer, TNO Science and Industry, the Netherlands, **Dr. Alan van Drie**, TAE Technologies

4:15pm **VT+FUS-WeA-9 The "Wall" in Fusion Reactors***, **David Ruzic**,* University of Illinois at Urbana-Champaign **INVITED**

Due to the recent invention of flexible high-field super-conducting magnets which can sustain fields up to 20 Tesla, commercial magnetic fusion energy may soon be a reality.These fields will contain a thermonuclear plasma that could have equivalent heat loads to the surface of the sun – some 60 MW/m^2.Nothing can withstand that power load, so much effort has gone into designing systems that will "only" experience on the order of 10 MW/m^2.That wall material is not allowed to contaminate the plasma or the fusion reaction will stop.This issue of the plasma-facing-component is one of the most serious engineering challenges.However, there are more challenges.A fusion device must make more tritium than it uses, and that includes tritium permeation.A breeder blanket will surround the plasma which will contain lithium.Neutrons from the D-T reaction will hit lithium and make more T.That tritium needs to be recovered and contained.Finally the structure of the fusion device must be able to withstand enormous transient loads from magnetic excursions and not fall apart due to transmutations and atomic displacements from the copious neutron flux.And, by the way, the whole system has to e vacuum tight.This talk will explain all of these challenges and describe the leading solutions and largest uncertainties.

4:45pm **VT+FUS-WeA-11 Overview, Construction Status, and Engineering Challenges of the Vacuum Systems for the Material Plasma Exposure eXperiment (MPEX)***, **Jonathan Perry**, Aftab Hussain, Adam Aaron, Ted Biewer,* ORNL

The Material Plasma Exposure eXperiment (MPEX) is under construction at Oak Ridge National Laboratory. MPEX will be a first-of-its-kind steady-state linear plasma device that will enable neutron-irradiated materials to be exposed to fusion reactor-relevant divertor plasma conditions for the study of plasma-material interaction. This facility will be capable of generating high heat fluxes and high ion fluences to test fusion divertor prototypic plasma-facing materials at steady-state for up to 10^6 seconds with in-situ diagnostics and magnetic fields up to 2.5 T. This presentation will provide an overview and construction status of the MPEX vacuum systems that promote efficient heating of the plasma, create an environment for prototypic divertor plasma conditions, enable in-situ diagnostics, and maintain vacuum during transportation and post-exposure diagnostic examination of the tested material. Due to the operating environment and performance requirements of MPEX, many engineering challenges came up during the design, fabrication, and assembly phases of the MPEX vacuum systems. This presentation will also discuss the lessons learned and implemented, as well as the knowledge leveraged from the ITER project and other facilities around the world, to develop, manufacture, and assemble the vacuum systems for MPEX. Unique cleaning and assembly techniques to ensure cleanliness is maintained throughout the assembly and installation process will also be discussed in this presentation.

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5:00pm **VT+FUS-WeA-12 Miniaturized, Fully Shielded High-Voltage Vacuum Feedthroughs from 50 kV to 300 kV***, **Moein Borghei**,* Avalanche Energy

High-voltage vacuum feedthroughs rated above 100 kV are rarely available as commercial off-the-shelf products, and those at 100 kV or below are often oversized and unshielded, i.e., have exposed electrodes at high voltage. These gaps limit researchers and engineers building fusion machines, electron guns, X-ray sources, ion beam systems, and other high-voltage vacuum platforms, who must either tolerate poor component fit or resort to lengthy custom procurement cycles.

To meet the diverse high-voltage needs of Orbitron fusion machines [1], we developed a suite of four fully shielded, CF-flanged feedthroughs. These models -the Thresher, Bigeye, Mako, and Hammerhead- span a wide voltage range from 50 kV to 300 kV. All designs utilize low-outgassing ceramic insulators, such as aluminum oxide and MACOR. The ceramic component is hermetically sealed to standard stainless steel conflat flanges, with leak rates lower than 1×10^{-9} atm·cc/s of He. The feedthroughs are fully shielded, eliminating exposure of high-voltage surfaces on the outside, thus enhancing integration within compact systems and operator safety.

The primary design objective was to minimize the footprint while ensuring reliable, steady-state operation. Mako and Hammerhead are within 15 cm and 20 cm flange sizes, respectively, both half the volume of the designs provided in the literature for the voltage class [2]. Similarly, Bigeye transmits 100 kV through a 7 cm flange compared to the 15 cm flange of the COTS feedthrough. Thresher does the same for 50 kV in a 3.4cm instead of 7 cm.

In this talk, we present experimental results and design methodology for insulator geometry, electrode designs, and electric-field stress mitigation that simultaneously enable achieving the rated voltage while maintaining hermetic seal integrity. We also present measured performance metrics across these feedthroughs, including dark current, bakeout impact, role of contaminants, and the conditioning process.

[1] M. Borghei, M. Vorenkamp, R. Langtry, and B. Riordan, "An Overview of Vacuum Insulation Technology for the Orbitron Fusion Device," in *2025 31st International Symposium on Discharges and Electrical Insulation in Vacuum (ISDEIV)*, Chengdu, China: IEEE, Sep. 2025, pp. 1–5. doi: 10.1109/ISDEIV60861.2025.11256035 [https://doi.org/10.1109/ISDEIV60861.2025.11256035] .

[2] M. Borghei, M. Vorenkamp, N. Van Moon, R. McMullen, R. Langtry, and B. Riordan, "Hammerhead: a compact 300 kV vacuum bushing," *Nature Communications*, vol. 16, no. 1, p. 11391, Dec. 2025, doi: 10.1038/s41467-025-66194-w [https://doi.org/10.1038/s41467-025-66194-w] .

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