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.

This work was supported by the Oak Ridge National Laboratory managed by UT-Battelle, LLC for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.

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] .

Vacuum Technology
Room 321 - Session VT-ThM

Vacuum Technology Big Vacuum Systems and Accelerators

Moderators: Prof. Dr. Sefer Avdiaj, University of Prishtina, **Eleni Marshall**, STFC Daresbury Laboratory

8:00am **VT-ThM-1 Ultra-High Vacuum Systems for Next Generation Gravitational Wave Detectors*, Jordan Vanosky,*** LIGO Laboratory, California Institute of Technology **INVITED**

LIGO, the Laser Interferometer Gravitational-wave Observatory consists of two, 4-kilometer long, L-shaped interferometers, which operate under Ultra High Vacuum conditions in order to detect gravitational waves from cosmic sources. The next generation of gravitational wave detector, Cosmic Explorer, targets a 10x increase in sensitivity and will consist of two 40 kilometer long beamtubes, a potential 90 million liter UHV system. Cosmic Explorer will enable a greater survey of the universe for gravitational wave sources, but this scale brings unique challenges for fabrication and qualification of the ultra-high vacuum system. Improving on the methods and techniques that built LIGO is essential in order for an 80-kilometer long vacuum system to be feasible. New materials, fabrication methods, installation procedures, and bakeout techniques must be considered in order to reduce costs and installation time.

8:30am **VT-ThM-3 New Method for Bake-Out of Large Vacuum Systems*, Freek Molkenboer,*** *Corné Rijnsent, Thom Oosterveer, Han Velthuis, Herman Bekman, Andrey Ushakov, Dirk van Baarle,* TNO Science and Industry, the Netherlands

Thermal bake-out is a well-known and commonly used method for removing contaminants from the inner surface of a vacuum system. However, the economic and practical scalability of this method for very large systems or systems with a high thermal mass poses quite some challenges.

The Einstein Telescope will be the largest vacuum system on Earth and will require the removal of water and other contaminates after installation underground. The currently foreseen method is thermal bake-out using Joule heating of the beam tube. The beam-pipes have a diameter of 1 meter, and due to the layout of the Einstein Telescope, a total of over 120 kilometers of beam-pipe is needed.

TNO will investigate the technical feasibility of using plasma techniques to remove water and other contaminates from the inner surface of the beam tube. For this study, a dedicated setup has been designed and built to assess whether plasma assisted cleaning can achieve the low partial pressure requirements as are needed for the Einstein Telescope.

During the presentation, we will discuss the realization of the experimental setup, as well as the outcome of the first half year of experiments.

8:45am **VT-ThM-4 in-Situ Bakeout of Beam Line Assemblies Under Project Constraints: A Measurement-Driven Approach Validated on the LCLS-II He Installation Campaign*, Pierre Ribault,*** *Giulia Lanza, TC Chen, Dale Gill, Dentell Reed, Robert Coy,* SLAC National Accelerator Laboratory

The LCLS-II High Energy upgrade installation at SLAC uses a specific bake procedure for its beam line assemblies (BLAs): in-situ heating at 50 °C for eight hours, with an additional in-situ heating step on the BLA ceramic. The reason is practical. We want to desorb more water during the in-situ pumping phase, so that the total pump-down time of the full line stays within the project budget. This abstract describes how the bake parameters were chosen, the measurements that supported them, and the fleet-scale validation we are running on the HE installation.

Water dominates the outgassing budget at room temperature on stainless steel and ceramic surfaces, and it sets the in-situ pump-down time. Heating the BLA accelerates water release from the metal surfaces. The ceramic is harder to bake through bulk heating because of the thermal coupling in the integrated assembly, so we added a dedicated heating step for it. Both steps were sized so that the per-BLA outgassing fits within the budget for the full line.

We measured the outgassing of representative HE BLAs before installation rather than relying on extrapolated values. These measurements were used to refine the predictive model and to set the duration and temperature of the in-situ ceramic heating step. The 24-hour per-BLA pumping target was derived from the assembly time and the post-bake pumping requirement, set against the line-level pump-down budget defined by the project.

About twenty-three identical BLAs will be installed and baked over the course of one year. Each is monitored continuously by a SLAC particle-free turbo cart, which provides residual gas analysis with networked acquisition and a common time base across stations. The campaign gives us a chance to compare nominally identical units baked under the same procedure, and to look at the spread between them.

The presentation will cover four points. The engineering reasoning behind the bake parameters and the ceramic heating step. The outgassing measurement campaign and how it fed into the model. The first comparisons between predicted and observed bake trajectories on the BLAs installed by the time of the symposium, including the disagreements. And what the fleet data tells us about the spread between BLAs that should, on paper, behave the same way.

We submit this work as a documented case of a project-driven bake procedure: how it was designed, what data supported the design choices, and how the campaign is being monitored. The intent is to share the approach and the dataset with the community.

9:00am **VT-ThM-5 ESS Vacuum System Commissioning for Beam on Target*, Marcelo Juni Ferreira,*** European Spallation Source ERIC, Sweden*; Artur Gevorgyan, Laurence Page, Adrien Besson, Hilko Spoelstra,* European Spallation Source, Sweden

The European Spallation Source (ESS) is a multidisciplinary research infrastructure and neutron source facility based on a 2 GeV, 5 MW proton linear accelerator (LINAC). The facility uses superconducting radio-frequency (SRF) cavities assembled under particle-free conditions to accelerate the proton beam, which produces neutrons through spallation on a helium-cooled tungsten wheel. The facility can host up to 42 neutron instruments.

The ESS Vacuum Group is responsible for all technical vacuum systems across the Accelerator, Target, and Neutron Scattering Instruments (NSS).

This presentation will provide an overview of the installed vacuum systems for the commissioning phase of the proton accelerator and monolith target systems for Beam-On-Target in Q1 2027. It will cover the vacuum hardware, the EPICS-based vacuum control interface, and the system's early performance, including the first beam to the tuning beam dump. The presentation will also describe the Target monolith vacuum system and comment on the installation of neutron instruments.

9:15am **VT-ThM-6 Engineering and Validating Vacuum Systems for the Spallation Neutron Source Second Target Station*, Austin Chaires,*** Oak Ridge National Laboratory

The Second Target Station (STS) project at the Spallation Neutron Source (SNS) requires specialized vacuum systems to support particle transfer, inert experiment environments and safety requirements. This work outlines the engineering responsibilities and validation methodologies used to design vacuum environments across the STS target and instrument systems. Various vacuum systems must fulfill diverse functional needs, including clearing proton and neutron flight paths, isolating the inert environments of instruments, managing hazardous hydrogen gas concentrations under National Fire Protection Association (NFPA) safety standards, and providing thermal insulation for liquid hydrogen target cooling. Additionally, vacuum is used to safely remove water from highly active, radioactive components destined for disposal. To mitigate radiation exposure and ensure system robustness, the engineering approach leverages twenty-five years of SNS operational lessons learned to integrate As Low As Reasonably Achievable (ALARA) principles, modular common pump stations, and redundant pumping pathways. Design validation is achieved through a multi-faceted analytical approach combining empirical formulas, vendor consultation, and software modeling via ANSYS APDL and VacTran. For novel configurations, multiple parallel analytical methods are cross validated to guarantee compliance. This comprehensive design and validation framework ensures system readiness as the STS target and instrument vacuum systems approach final design reviews this year in anticipation for the Department of Energy (DOE) project milestone critical decision (CD) 2/3 approval to proceed to procurement.

9:30am **VT-ThM-7 Gas Dynamic Modeling of an Upgraded Titanium Arc-Gettering Neutral Beam Pumping System*, Alan Van Drie,*** TAE Technologies

Fusion Neutral Beam Injection (NBI) systems impose demanding vacuum pumping requirements due to the need to maintain gas pressures in the 2–3 mTorr range within the beam neutralizer section while simultaneously reducing downstream pressures to the 10^{-5} Torr range to minimize beam re-ionization losses and cold gas bleed into the main fusion vessel.

This work presents modeling and prototype testing of an upgraded multi-scale finned titanium arc-gettering pumping system developed in support of higher-voltage and longer-duration upgrades to the NORMU neutral beams. The objective of the pumping upgrade is to increase effective pumping speed and gas capacity within the restricted geometric envelope of the neutral beam vessel. Gas modeling across both transitional and molecular flow regimes was used to evaluate pressure and density distributions, gas transport, and pumping effectiveness within complex neutral beam geometries. The distributed finned geometry was developed to improve hydrogen isotope pumping performance while addressing engineering integration and conductance constraints associated with upgraded neutral beam architectures.

Vacuum Technology
Room 321 - Session VT-ThA

Vacuum Technology Flow and Pumps

Moderators: Dr. Marcello Juni Ferreira, ESS, **Marcy Stutzman**, Jefferson Lab

2:15pm **VT-ThA-1 Vacuum Technology in Cork Science: From Permeability to TCA Desorption***, Orlando Teodoro,* Nova School of Science and Technology, Portugal **INVITED**

Natural cork has been used for centuries as a high–performance sealing material for wine bottling due to its elasticity, durability, tightness to liquids, and naturally low gas transmission. In addition to being a renewable and recyclable material, cork combines mechanical resilience with a unique cellular structure that enables long-term sealing performance. However, the cork industry has historically faced important challenges related to the variability of sealing performance at the cork–bottle interface and to the presence of trace contaminants responsible for wine defects, particularly 2,4,6–trichloroanisole (TCA), the main compound associated with cork taint. TCA is of particular concern because it can migrate from cork to wine, producing sensory defects at concentrations as low as 2–3 ng/L.

This work presents several applications of vacuum technology developed and introduced for cork science and industrial processing over the last two decades. The first topic addresses the characterization of gas and vapor permeation through cork using vacuum-based methods. Permeability measurements performed under controlled pressure conditions enabled the study of transport mechanisms in natural cork and supported the development of transport models accounting for the permeation of gases and vapors through the cellular cork structure.

The second topic focuses on the sealing performance of cork stoppers in bottlenecks and on the role of surface treatments and lubricants. Vacuum-based leak testing methods were used to characterize sealing performance at the cork–glass interface, revealing leak rates ranging from below 10^{-7} mbar·L/s for well-sealed stoppers to above 10^{-5} mbar·L/s for poor sealing conditions.

The third topic concerns the interaction of TCA with cork and the development of large-scale vacuum-based thermal desorption processes for contaminant removal. Experimental studies combining controlled heating, vacuum exposure, and gas analysis provided insight into the desorption behavior of TCA and its interaction with the cork structure. These studies contributed to the development of industrial processes capable of efficiently reducing TCA contamination while preserving the physical integrity and performance of the cork.

The work illustrates how vacuum technology evolved from a laboratory research tool into an enabling industrial technology in the cork sector. These developments contributed to substantial improvements in cork quality control, contaminant removal, and sealing consistency, playing a significant role in the modernization of the cork industry over the last decades.

2:45pm **VT-ThA-3 Gas Transport in 3D-Printed Polymers: Linking Microstructure to Outgassing and Permeation Behavior***, Sefer Avdiaj,* University of Prishtina, Kosovo*; Zgjim Rrustemi,* University of Prishtina. Department of Physics, Kosovo*; Ramiz Hoti,* University of Prishtina. Department of Chemistry, Kosovo*; Partizan Malkaj,* Polytechnic University of Tirana. Department of Physics, Albania*; Zeqe Tolaj,* University of Prishtina. Department of Physics, Kosovo*; Makfire Sadiku,* University of Prishtina. Department of Chemistry, Kosovo

Additive manufacturing is opening new possibilities for producing polymer components with complex and customized geometries. However, their use in vacuum environments is still limited by gas transport effects such as diffusion, permeation, and outgassing. In this study, we investigate how the microstructure created during 3D printing influences gas transport behavior in commonly used polymers.

Samples are being fabricated using fused deposition modeling (FDM), with systematic variation of key printing parameters such as infill density, layer thickness, and raster orientation. These parameters are expected to significantly affect the internal structure of the materials, including porosity, interlayer bonding, and anisotropy. Gas diffusion and permeation are being measured using steady-state and time-lag methods, while outgassing behavior is evaluated under controlled vacuum conditions.

Preliminary results indicate that gas transport properties are strongly influenced by printing-induced microstructure. Early observations suggest that increased porosity and weaker interlayer bonding lead to higher permeation and outgassing, while optimized processing conditions reduce gas release. Ongoing work is focused on obtaining quantitative relationships between processing parameters, microstructure, and transport properties.

The expected outcomes of this study will provide a deeper understanding of gas transport mechanisms in 3D-printed polymers and establish guidelines for improving their performance in vacuum and low-pressure applications. This work aims to support the development of additively manufactured components suitable for vacuum technology.

3:00pm **VT-ThA-4 Study on the Influence of Different Combinations of Roots Pump Sets on Flow Characteristics***, Shengquan Yang, Kun Liu,* Northeastern University, China

Abstract: The multi-stage series Roots pump set has broad application prospects in fields such as nuclear fusion vacuum systems, semiconductor manufacturing, aerospace environment simulation, and large-scale scientific devices due to its advantages of high pumping speed, high compression ratio, no oil pollution, and suitability for high flow gas transportation. By operating in series with multi-stage pump bodies, the working pressure range of the pump group can be significantly expanded, the ability to extract light gases can be improved, and the demand for efficient pumping under complex working conditions can be met. However, the internal flow process of multi-stage Roots pump sets is complex, and phenomena such as gas transport, pressure distribution, and reflux leakage between stages are coupled with each other. The matching relationship between different stages has a significant impact on the pumping speed, compression ratio, and operational stability of the pump set. Especially under conditions of high speed, large pressure difference, and light gas, significant issues such as increased flow loss, uneven inter stage flow field, and local temperature rise are prone to occur within the pump unit, which in turn affects the overall pumping performance and long-term operational reliability. This study is based on computational fluid dynamics methods to establish a transient flow model for multi-stage Roots pump sets. Numerical simulations were conducted on the inter stage flow field, pressure distribution, and gas transport process of the pump sets, and the flow characteristics and pressure distribution laws of different combinations of pump sets under different operating conditions were analyzed. The research results indicate that as the compression ratio increases from 10 to 1000, the inter stage pressure difference significantly increases, and the clearance reflux velocity and reflux rate significantly increase; The heat generation effect of gas compression is enhanced, and the inter stage temperature at a compression ratio of 1000 is significantly higher than that at a compression ratio of 10; And the highest temperature occurs in the stage before the exhaust stage, not in the final exhaust stage, indicating that this stage has undergone the strongest gas compression and thermal accumulation; The gap between Roots rotors decreases, resulting in a decrease in leakage, but the reflux velocity increases, leading to an increase in inter stage pressure. This study provides a theoretical basis

3:15pm **VT-ThA-5 NAVAC Vacuum Technology: Old Problems. New Architecture. NAVAC HelixDrive Screw Pumps and NAVAC ShieldDrive Mag-Coupled Rotary Vane Pumps***, Evan Sawyer,* NAVAC

Part One: HelixDrive Series — Dry Screw Technology Reimagined

Dry screw vacuum technology has existed for decades. Two intermeshing rotors trap and compress gas without contact — no oil, no sealing fluid. The concept is sound. The execution has historically been the problem. Traditional dry screw pumps are large, thermally complex machines with gearboxes and couplings that demand as much management attention as the processes they serve.

The HelixDrive series starts differently. Its coaxial design integrates motor and pump along a shared axis, eliminating mechanical interfaces and achieving the smallest dry screw form factor at this performance level.

The HD series reaches an ultimate pressure of 7.5×10^{-4} torr — challenging oil-sealed rotary vane pumps and exceeding most dry screw designs. A proprietary internal coating provides chemical resistance in corrosive, moisture-laden environments, sustaining performance over time. Thermal management is integrated: smaller models use onboard air cooling; the HD100 uses water cooling limiting surface temperature rise to under 50°F, keeping performance predictable.

Maintenance is largely eliminated. No tip seals means no wear, no particulate, no contamination risk. No oil means no changes, no mist filters, no backstreaming.

Part Two: ShieldDrive SDi Series — Rotary Vane Done Right

Oil-sealed rotary vane technology is proven but carries known liabilities: shaft seal leakage, oil mist in the workspace, messy maintenance, and degradation in chemically aggressive environments.

The SDi series engineers those problems away. A magnetic drive coupling replaces the dynamic shaft seal entirely, creating a hermetic boundary with no leakage path. An integrated oil mist filter — built into the pump body — captures exhaust droplets and doubles as an exhaust muffler, with tool-free quick-change access. An integrated drip tray handles maintenance mess. A detachable oil reservoir replaces drain plugs with a clean swap. Due to the magnetically coupled seals, there is no need for the "Cookie sheets" underneath the rotary pump. Additionally, the simple addition of the oil reservoir allows for a quick oil change without having to move the pump or use a separate container to trap the oil.

Gas ballast is adjustable for condensable vapor processes. The variable-frequency drive enables Eco Mode, reducing speed, energy draw, and noise during lower-demand operation. Another innovation that allows for lower energy consumption when the pump doesn't need to run at full capacity.

3:30pm **VT-ThA-6 From Experiment to Grid: A Systems Engineering Approach to Vacuum Pumping Systems in Stellarators***, **Danah Garcia**,* Type One Energy Group, Inc.

The fusion industry sits at a pivotal point in its trajectory from experimental reactors to power plant devices. The Infinity Two Stellarator is currently in design by Type One Energy. Part of the risk mitigation platform on Infinity Two will be conducted with the Infinity One device, a smaller scale stellarator that will help reduce physics and engineering uncertainties in fusion power plant design. Employing systems engineering fundamentals is crucial for mobilization of the industry, and special attention should be paid to systems that are integral to the power output of the device, namely the vacuum pumping system (VPS). The VPS interfaces with the plasma chamber and the tritium plant, linking the fuel processing system with the main reaction chamber of the device. As this link, the VPS is responsible for continuous exhaust of deuterium, tritium, helium and other plasma impurities, and helps maintain a burning plasma in the reactor, which is necessary for net energy out of the power plant. Type One Energy's VPS on the Infinity One fusion device will serve as an integrated design verification testbed for the Infinity Two stellarator, with demonstration of plasma particle exhaust as a key objective. The Wendelstein 7-X (W7-X) stellarator is the largest, most technologically advanced stellarator in the world, however its design is best suited for exploration of magnetic configurations, rather than particle exhaust. Demonstration of enhanced particle exhaust in Infinity One over W7-X will help solidify Infinity One's purpose of risk reduction, with emphasis on increased particle flux out of the plasma chamber and achieving target subdivertor pressures. With respect to the VPS, advancing the technology readiness level of high throughput vacuum pumping systems with fusion fuel present is critical. This work will demonstrate the scalability of the VPS from the Infinity One device to a reactor-scale device, exemplifying the need for risk mitigation in the transition of the fusion industry from the laboratory to the grid.

3:45pm **VT-ThA-7 Measuring Rf Surface Resistance of Non-Evaporable Getter Coatings***, **Eleni Marshall**, Oleg Malyshev, Daniel Seal, Reza Valizadeh,* STFC Daresbury Laboratory, UK

A new method for measuring the RF surface resistance of non-evaporable getter (NEG) coatings on tubular samples has been developed at Daresbury laboratory.

NEG coatings are vital for achieving good pressures in vacuum systems with limited conductivity but will reduce the RF surface conductivity of the vacuum chamber when compared with the substrate material. For purposes such as particle accelerator chambers, this is important as the increased surface resistance can cause a loss in beam energyand increase in beam energy spread.

With this method, both the surface resistance and the NEG pumping properties can be measured from the same sample, allowing a full quantification of NEG properties.

This study compares samples of TiZrV of different thickness and microstructure, to see the relationship between NEG surface resistance and pumping properties.

4:00pm **VT-ThA-8 Feasibility of Turbomolecular Deceleration as an Intrinsic Measurement of System Pressure***, **Andrew Chew**, Paul Smith, Sam Lodge,* Edwards Ltd, UK*; James Healy,* University of Bristol, UK

When the drive power to a turbomolecular pump (TMP) is halted the TMP decelerates at a rate dependent upon various parameters/variables. These include TMP impeller mass, original rotational speed, suspension type, inlet and exhaust pressure and pumped gas type. Also and crucially, the TMP pumping configuration in terms of number of turbomolecular blade rows and drag stage numbers and types. We will report measurements of dependency of different TMPs on these variables and the feasibility of indicative pressure readings.

Patent Application: GB1902564.2

4:15pm **VT-ThA-9 Single-Stage Vacuum Pump Performance Measuring Method***, **Xiaoyu Chi**, Kun Liu, Dechun Ba, Yuanhua Xie,* Northeastern University, China

Traditional dry pump measurement devices usually focus on the entire vacuum pump performance parameters other than vacuum pump interior flow situation .This paper propose a performance test method for testing a single stage of a vacuum pump, concentrating on four basic physical quantities ; flow, vacuum degree ,temperature and rotating speed. For a better description of the measurement method , this test method is divided into six modules: the pump inlet test doom module, the pump outlet test doom module, the pressure measurement module, the temperature measurement module,the flow measurement module and the rotating speed measurement module. This method ensures the normal operation and parameter measurement of the single-stage vacuum pump by adjusting the pressure range of the front and rear vacuum dooms so that we can measure the flow field inside the single rotor and the specific measurement parameters to fit pumping speed - pressure curve and other parameter curves. The pressure, flow, temperature and rotating speed measurement ranges of the test method are 10^{-3}~10^{5} Pa，20 SCCM~5000 SLM , 20℃~300℃and 100 rad/s~3000 rad/s. Compared with the traditional vacuum pump measurement method, the measurement method of the single-stage vacuum pump proposes a performance parameter to measure the internal flow field of the first-stage rotor of the multi-stage vacuum pump and the related parameters to provide design reference and experimental data support and rotor profile design for the rotor combination of the multi-stage vacuum pump.

Vacuum Technology
Room Ballroom A - Session VT-ThP
Vacuum Technology Poster Session

VT-ThP-1 Maintenance, Upgrade, and Vacuum System Optimization of the LCLS Superconducting Injector During 2026 Long Downtime*, **TC Chen**,* SLAC National Accelerator Laboratory

The LCLS-II superconducting (SC) photoinjector at SLAC National Accelerator Laboratory is designed to produce high-brightness electron beams at repetition rates up to 1 MHz. The injector system integrates a Cs_2Te photocathode, RF gun, buncher, cryomodule, and extensive vacuum infrastructure to maintain ultra-high vacuum (UHV) conditions critical for cathode lifetime and beam quality. Following extended operation, component aging, vacuum degradation risks, and reliability concerns necessitate a comprehensive maintenance and upgrade campaign during the scheduled 2026 long downtime (LDT).

The maintenance strategy involves coordinated interventions across three major subsystems: the photocathode loadlock system, RF gun, and low-energy beamline (LEB). Key activities include removal of auxiliary hardware, such as cables, waveguides, tuners, cooling water hoses, and the 1.3 GHz cryomodule (CM) endcap support to provide access of parts being replaced , followed by replacement of failed and aging components including vacuum pumps, pneumatic gate valves, residual gas analyzers (RGAs), and RF waveguide windows.

VT-ThP-2 Design and Construction of a Calibration Chamber and Pressure Control System for Automated Calibration of Capacitance Diaphragm Gauges and Other Vacuum Standards*, **Jacob Ricker**, Jay Hendricks, Kevin Douglass, Ifenna Anakor, Thomas Howard,* NIST

The calibration of vacuum gauges from 13 mPa to 130 kPa has been done for the last 40 years using liquid column manometers. NIST new Fixed Length Optical Cavity (FLOC) pressure standards will be replacing these standards, however because they are based on gas refractivity, they require high purity gas. The current manifold is contaminated with mercury and oil from the manometers, so NIST has been designing and constructing a new manifold capable of automatically adjusting pressures and calibrating customer gauges against the standard. The automated system must be able to precisely control flow to set pressures in the chamber to within mPa accuracy at low pressure, however it must have capability for fast flow when filling pressures near atmospheric pressure. This presentation will describe the design, assembly, and testing of a low-cost calibration system capable of calibrating vacuum gauges over the range of 13 mPa to 130 kPa.

VT-ThP-3 Vacuum Considerations for the Next Generation of DC High Voltage Polarized Electron Gun at Jefferson Lab*, **Marcy Stutzman**,* Thomas Jefferson National Accelerator Facility, United States Minor Outlying Islands (the)

The polarized electron source at Thomas Jefferson National Accelerator Facility (JLab) has delivered highly polarized electron beams for the nuclear physics program for over 20 years using a series of custom DC high voltage electron guns. We achieve pressure approaching 10^{-12} Torr in the electron gun by applying NEG coatings to heat treated stainless steel chambers, installing a large array of NEG modules and an ion pump, and baking the system for several days prior to use. The operational lifetime of the system is strongly affected by the vacuum level, as residual gasses ionized by the electron beam can damage the photocathode. Recent research on the electron guns has focused on improving high voltage performance by iterating the cathode electrode and insulator designs necessary for operation at a DC bias of -200 kV, with only minimal changes to the vacuum systems. However, the next generation polarized electron gun is now being designed to deliver at least 10x higher current to generate a polarized positron beam. The design for the high voltage, vacuum, and electrostatic beam optics must all be optimized, and some of the design choices that improve one aspect adversely affect other aspects. Vacuum system options will be discussed, such as chamber material, cathode electrode material, and pumping optimization, as well as the status of balancing the optimal design for both the high voltage and vacuum systems.

VT-ThP-4 Microreactor for Quantitative Reactivity Measurements and In Situ Infrared Spectroscopy on Single-Crystal Model Catalysts*, Adam Lagin, Johannes Filzmoser, Ulrike Diebold, Michael Schmid, Gareth Parkinson, **Jiri Pavelec**,* TU Wien, Austria

Single-crystal model catalysts provide an ideal platform for elucidating reaction mechanisms and benchmarking computational models. Yet, accurately determining intrinsic reaction kinetics on low-surface-area single crystals at realistic pressures remains challenging [1]. Direct comparability with theory therefore requires tight control of gas-flow dynamics and exceptionally low background signals. Here, we present the design of a dedicated high-pressure reaction cell that addresses key limitations of conventional “pressure-gap” approaches through rigorous vacuum engineering and flow optimisation.

A defining feature of the microreactor design is operation in the molecular-flow regime within the narrow cell gap at pressures around 1 mbar. In this regime, quantitative turnover frequency (TOF) measurements can be obtained without the complex fluid-dynamic modelling or diffusion corrections typically required at higher pressures. The system retains the capability for operation up to atmospheric pressure (~1 bar). Trace product formation is detected by coupling the exhaust to a high-sensitivity mass spectrometer equipped with liquid-helium cryogenic pumping. In parallel, molecules on the catalyst surface are monitored using a home-built in situ IRAS setup optimised for the low reflectivity of metal oxides [2].

O-ring-free sealing is achieved by mating two optically flat surfaces [3]: the single-crystal sample and an IR-transparent diamond window. This “hard-seal” concept suppresses background contamination during high-pressure experiments. The design is prepared for full integration with standard UHV surface-science infrastructure. This enables controlled surface preparation and post-reaction characterisation by X-ray photoelectron spectroscopy, low-energy ion scattering, and scanning tunnelling microscopy facilitating direct correlation of atomic-scale structure with quantitative reactivity.

Essential aspects of the design have been supported by modelling, mainly in COMSOL Multiphysics, including vacuum-flow studies, heat transport, mechanical and optical simulations, as well as coupled multiphysics calculations. These studies guided critical design choices and will be showcased in this contribution.

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VT-ThP-5 New Developments in the Use of Fixed Length Optical Cavities as a Photonic Pressure Standard*, **Thomas Howard**, Thinh Bui, Jacob Ricker, Kevin Douglass, Jay Hendricks,* NIST-Gaithersburg

The Fixed Length Optical Cavity (FLOC) is an optical pressure standard based on gas refractometry. Three different FLOC technologiesare being developed at NIST to cover a wide pressure range from micropascal to megapascal. Typical FLOC instruments determine pressure by measuring the shift in the beat note frequency between two separate lasers coupled to a dual cavity system. Recent advances allow the use of only a single laser source, reducing cost and complexity while maintaining the high (part-per-million level) precision and accuracy of the typical two laser system. Results and comparisons to previous FLOC pressure measurements will be discussed here.

VT-ThP-6 The Vacuum System Design for the Extreme Photonics Applications Centre (EPAC)*, **Keith Middleman**,* Science & Technology Facilities Council - STFC, UK

The EPAC facility currently under construction at the STFC Rutherford Appleton Laboratory is a new UK national facility that provides a unique opportunity to develop laser driven accelerator research, enabling a plasma wakefield accelerator facility with multi-GeV electron beams and spatially coherent x-ray and gamma-ray beams for cutting-edge experiments in plasma physics, laboratory astrophysics and condensed matter and material science.

This paper describes the design of the vacuum systems for Experimental Area 1 of the EPAC facility where high intensity lasers interact with a high density of gas molecules to ignite a plasma. The EPAC facility will run in the High Vacuum (HV) range with a typical operating pressure of 10^{-6} – 10^{-7} mbar. However, at the interaction point where the plasma is ignited there will be a gas injection nozzle that will provide the required gas density. It is anticipated that the expected gas pressure at the interaction point could be in the range of 10^0 – 10^2 mbar.

The vacuum design is presented showing what has been done to minimise the spread of the localised high-pressure gas from the target location into the laser delivery beamline. This is essential to avoid laser breakdown and non-linear effects occurring before the laser reaches its peak intensity at the focus. The differential pumping configuration will be explained and there will be an overview of the gas dynamics work done across the pressure regimes from transitional flow to molecular flow.

The outcome of this work is a vacuum system capable of the demands put upon it from localised gas densities to the performance of the laser optics in delivering the required laser intensities. It is anticipated that this new UK user facility will open in late 2026.

Vacuum Technology
Room 315 - Session VT-FrM

Vacuum Technology Pressure Measurement

Moderators: Dr. Julia Scherschligt, National Institute of Standards and Technology, **Mr. Charles Smith**, Oak Ridge National Laboratory

10:30am **VT-FrM-10 High Vacuum MEMS Devices – Advances in Vacuum Technology in Microscale***, **Michał Krysztof**, Tomasz Grzebyk, Piotr Szyszka, Paweł Urbański, Marcin Białas, Jakub Jendryka, Jan Sobków, Paweł Knapkiewicz, Jan Dziuban,* Wroclaw University of Science and Technology, Poland **INVITED**

High and ultra-high vacuum technologies have long been a cornerstone of advanced scientific instrumentation, including electron microscopes, mass spectrometers, and X-ray sources. Traditionally, such systems rely on large vacuum chambers and complex, multistage pumping infrastructures, which inherently limit their miniaturization, portability, and widespread deployment. Despite continuous optimization, the fundamental architecture of vacuum technology has remained largely unchanged for decades.

Recent advances in microelectromechanical systems (MEMS) enable a fundamentally different approach, in which vacuum is generated, maintained, and utilized directly at the microscale. A key breakthrough was achieved at Wroclaw University of Science and Technology with the development of a MEMS-compatible high-vacuum micropump [1]. Fabricated using standard silicon–glass MEMS processes, this integrated pump allows stable vacuum levels on the order of 10^{-7} mbar to be generated in millimeter-scale volumes, eliminating the need for external pumping systems.

This invited talk presents how the availability of such a miniature vacuum pump enabled the development of a family of fully integrated, ultra-compact vacuum devices (Fig. 1). Selected examples include MEMS-based field-emission X-ray sources [2], miniaturized gas analyzers [3] and quadrupole mass spectrometers [4], as well as other electron- and ion-based vacuum microsystems [5]. The technological aspects of integrating vacuum, electron-optical, and nanoelectronics components into sealed MEMS structures are discussed, together with their functional capabilities.

The presented results demonstrate that MEMS technology enables a paradigm shift in vacuum engineering—from large, centralized vacuum installations toward autonomous, application-specific microscale vacuum instruments. This approach opens new opportunities for vacuum technology in space science, materials research, environmental diagnostics, and distributed sensing systems.

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11:00am **VT-FrM-12 Cassini - A MEMS Pirani with Range of 9 Order of Magnitude***, **Klaus Bergner**, Kristian Kirsch, Lukas Reger, Andreas Truetzschler,* VACOM, Germany

Many key applications of vacuum technology—such as coating and thin-film processes, surface analysis, and semiconductor manufacturing processes—operate continuously between atmospheric pressure and approximately 10^{-6} mbar. To cover this range completely and with metrological reliability, three measurement principles are combined in practice: capacitive diaphragm sensors (CDG) for high pressure to low vacuum, thermal conductivity measurement (Pirani) for a broad medium vacuum range, and Bayard–Alpert ionization gauges (BAG) for high and ultra-high vacuum. However, the multisensor solution comes with engineering drawbacks: additional connection ports and dead volume, increased maintenance and calibration requirements, risks of errors in the overlap ranges, and higher system costs.

The Pirani sensor traditionally covers the largest single measurement range. Since Marcello Pirani, the principle has been based on the pressure-dependent heat transfer from a heated element to the gas. Classic wire Pirani sensors limit the expansion of the measurement range primarily due to control-related restrictions: To generate sufficient temperature differences at atmospheric pressure, high power levels would be required, which would thermally and mechanically overload the wire; at very low pressures, conservative control often results in a pressure-dependent signal excursion that is too small. Added to this are aging and drift, as well as long thermal time constants.

We present a new MEMS-based approach (Cassini) that specifically addresses these limitations. Central to this approach is pressure-adaptive control: different heating powers and temperatures are used depending on the pressure regime to consistently achieve a large pressure-dependent signal range. A combined control and evaluation method seamlessly links different modes across the various pressure regimes.

With Cassini, we demonstrate that a single, compact MEMS Pirani sensor can continuously cover nine orders of magnitude of pressure, from atmospheric pressure down to 1xE-6 mbar. Measurements in reference gases are calibrated against CDG and BAG standards and demonstrate consistent signal range, low hysteresis, and robust reproducibility.

11:15am **VT-FrM-13 AVS History Committee-Sponsored Talk: From Mercury Columns to Quantum-Based Standards: The Evolution of Vacuum and Pressure Metrology at NIST***, **Jay Hendricks**, Jacob Ricker, Kevin Douglass, Thinh Bui,* NIST

The pursuit of precision in measuring pressure and vacuum has been a cornerstone of scientific and industrial progress for over a century. This presentation provides a brief overview of the trajectory of pressure metrology, tracing its evolution from the early foundations at the National Bureau of Standards (NBS)—now the National Institute of Standards and Technology (NIST)—to the cutting-edge quantum-based innovations of the modern era.

The journey began in the early 20th century, shortly after the founding of the NBS in 1901. Initial efforts focused on establishing primary standards for atmospheric pressure, evolving through the 1920s and 1930s with the establishment of dedicated laboratories for vacuum research. Key historical milestones include the 1948 establishment of the Pressure Section, which formalized the development of primary standards and calibration services for government and industry. From the early use of mercury columns and the development of the McLeod gauge to the creation of altitude chambers for testing Liberty engines, NIST has consistently pushed the boundaries of how we measure the "extremes" of physical quantities.

Today, the Pressure and Vacuum Group at NIST remains a world leader, but the paradigm of measurement is shifting. The redefinition of the International System of Units (SI) has catalyzed a transition toward quantum-based metrology, enabling the realization of fundamental units through the laws of physics rather than physical artifacts. This talk will explore the technical breakthroughs driving this transition, specifically highlighting the Fixed Length Optical Cavity (FLOC) for pressure measurement and the Cold Atom Vacuum Standard (CAVS) for vacuum metrology. By leveraging quantum mechanics and photonics, these methods achieve unprecedented levels of accuracy and precision.

A theme of the presentation will be the intersection of vacuum science and miniaturization. The "NIST on a Chip" program exemplifies this trend, aiming to shrink complex metrology systems into field-deployable formats. This shift from laboratory-bound primary standards to compact, portable devices represents a fundamental change in the metrology ecosystem, allowing high-precision measurements to be conducted in real-world environments.

Finally, the talk will situate these advancements within the broader mission of the International Union for Vacuum Science, Technique and Application (IUVSTA), emphasizing how science transforms our ability to measure and understand the physical world.

11:30am **VT-FrM-14 Fast, Optimal Readout of a Tethered Optomechanical Pressure Sensor***, **Daniel Barker**, Stephen Chen, Yiliang Bao, John Lawall, Jason Gorman,* National Institute of Standards and Technology

We demonstrate a fast readout method for tethered optomechanical pressure sensors. The fast readout method allows mechanical ring-down measurement rates that exceed the total mechanical damping rate. We model the uncertainty of our ring-down measurements with the Cramér-Rao bound, including the effect of thermomechanical noise. Both our data and the Cramér-Rao bound indicate that measurement rates on the order of the mechanical damping rate produce the lowest uncertainty. At low pressures, using the optimal measurement rate allows 10× faster measurements or 3× lower uncertainty compared to allowing our sensor to ring down to the thermomechanical noise floor. Our results allow tethered optomechanical pressure sensors to operate at rates comparable to commercially available pressure gauges, removing an obstacle to adoption of optomechanical pressure sensors in industrial settings.

11:45am **VT-FrM-15 Recent Updates to the NIST Helium Leak Calibration Service***, **Stephen Eckel**, Daniel Barker, James Fedchak, Julia Scherschligt,* National Institute of Standards and Technology (NIST)

The NIST leak rate calibration service is responsible for calibrating helium leaks from roughly 10^{-13} mol/s to 10^{-6} mol/s. Traceability is established through NIST's primary vacuum flowmeters. These constant pressure flowmeters both generate and measure a flow rate of known gas and are traceable to measurements of pressure, temperature, volume displacement, and time. Over the last several years, major upgrades have been completed. In 2024, the vacuum leak system (VALES) — a system designed to hold the NIST working standards under vacuum and in a temperature-controlled environment— was completed. In late 2025, a fully automated flowmeter has been added to the system to allow all leaks to be calibrated against a flowmeter. In this talk, we will present the updated calibration service, discuss the associated uncertainties, and show initial results on the stability of the NIST leaks in the VALES.

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