HADES (High heAt loaD tESt) facility

The HADES (High heAt loaD tESt) facility, developed by CEA-IRFM, is an advanced testing platform for plasma-facing components (PFCs) in nuclear fusion reactors. Leveraging a high-power electron beam and sophisticated diagnostics, it simulates extreme thermal conditions to evaluate PFC performance. Originating from the FE200 platform, HADES supports fusion projects like ITER and WEST. Its precise control, robust cooling, and real-time monitoring offer significant advantages. Beyond fusion, HADES applies to aerospace, automotive, and materials science. Opportunities for industrial collaboration include testing, validation, and advanced material research.

Description of the technology

The HADES (High heAt loaD tESt) facility at CEA-IRFM in France is an advanced experimental platform specifically designed to test the performance and durability of plasma-facing components (PFCs) used in nuclear fusion reactors. This cutting-edge facility utilises a high-power electron beam to simulate the extreme thermal conditions that PFCs encounter in a fusion environment, allowing researchers to assess their heat removal capabilities and resistance to thermal shock.

Central to the HADES facility is its high-power electron beam gun, the EH300V from Von Ardenne. This sophisticated device is capable of delivering up to 150 kW of continuous power, with a maximum acceleration voltage of 45 kV. The electron beam produced is approximately 12 mm in diameter and features a Gaussian energy distribution, which ensures precise and controlled energy deposition on the target surface. The gun's programmable sweep system allows for various energy distribution patterns, such as line, spiral, raster, cycloid, and mesh, enabling researchers to tailor the thermal load to specific testing requirements. This flexibility is crucial for simulating both steady-state conditions and transient thermal events, with thermal fluxes reaching several tens of MW/m^2 in steady state and up to 1 GW/m^2 for short durations.

The electron beam is directed into a large vacuum chamber, a robust stainless steel vessel measuring 3.5 x 1.5 x 1.5 meters, with an internal volume of 8 cubic meters. This chamber can accommodate large test components up to 2 meters in length, making it ideal for testing full-scale PFCs. To maintain the necessary vacuum conditions, the chamber is equipped with a sophisticated pumping system comprising a diffusion pump, roots pump, and rough pumps, which together achieve a pressure of approximately 10^{-3} Pa. This low pressure is essential for preventing contamination and ensuring the purity of the experimental environment.

Cooling is a critical aspect of the HADES facility, given the intense heat loads involved. The primary cooling loop uses pressurised and overheated water, capable of operating at pressures up to 3.9 MPa and temperatures up to 230°C, with a maximum flow rate of 6 kg/s. This system effectively dissipates the heat generated during testing, ensuring that the PFCs do not exceed their thermal limits. A secondary cooling loop with decarbonated water cools the vacuum chamber's internal panels and the electron beam gun's electrical components, maintaining their operational integrity and preventing overheating.

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To monitor the thermal response of the PFCs during testing, the HADES facility is equipped with an array of advanced diagnostic tools. An infrared camera provides real-time thermal imaging, capturing detailed temperature profiles across the test surface. Visible CCD cameras offer optical observations, allowing researchers to visually inspect the components during and after testing. Additionally, monocolor and bicolor pyrometers measure specific temperature ranges, providing precise thermal data. Embedded thermocouples in the test components and cooling circuits deliver accurate temperature readings, essential for evaluating the thermal performance and endurance of the materials under test.
The HADES facility was conceived to replace and upgrade the former FE200 high heat flux testing platform. Initially developed in the 1990s through a collaboration between CEA and Framatome, the FE200 was located in Le Creusot, France, and served for 25 years before its decommissioning in 2017. The key components of the FE200 were relocated to Cadarache and integrated into the HADES facility, which underwent significant modernisation to meet current standards. This included the installation of a new high-power electron beam gun and the latest diagnostic equipment, enhancing its capabilities and ensuring it remains at the forefront of fusion research.
In practical applications, the HADES facility has been pivotal in testing and qualifying PFCs for fusion reactors such as ITER and the WEST tokamak. By simulating the intense thermal conditions these components will face in service, HADES enables researchers to identify potential issues and optimise material performance. This comprehensive testing is vital for ensuring the reliability and longevity of PFCs, which are critical to the safe and efficient operation of fusion reactors.

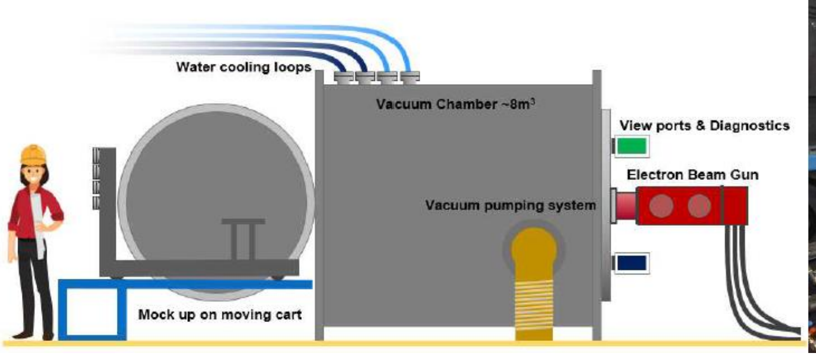

Figure 1: schematic representation of the HADES platform

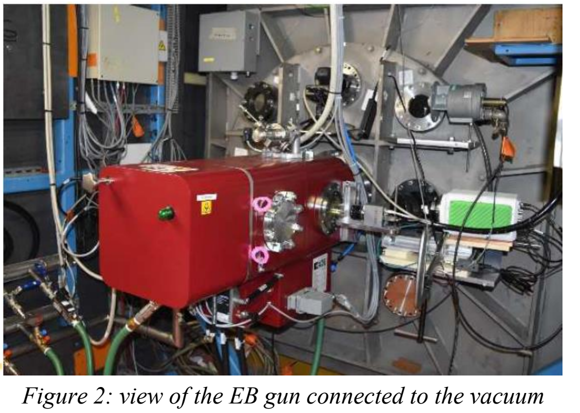

Figure 2: view of the EB gun connected to the vacuum chamber flange with all the main diagnostics dispatched around

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Innovation and advantages of the offer

The HADES facility excels in testing plasma-facing components (PFCs) for nuclear fusion reactors with unmatched precision and flexibility. Its high-power electron beam gun allows for precise control of energy distribution, simulating both steady-state and transient thermal conditions accurately.
Advanced diagnostics, including infrared and visible cameras and pyrometers, provide real-time, detailed thermal imaging. Embedded thermocouples ensure precise temperature measurements, enhancing the reliability of data.
Robust cooling systems manage extreme thermal loads effectively, ensuring components are tested safely under high-pressure, high-temperature conditions. The large vacuum chamber, equipped with safety features like lead shielding, supports full-scale PFC testing.

Non-fusion Applications

The HADES facility's technology and expertise extend beyond nuclear fusion and have significant potential in other industries. These include aerospace for testing thermal protection systems, the automotive sector for evaluating engine and exhaust components, materials science for researching thermal properties of new materials, and the energy sector for testing components in high-temperature environments such as those found in concentrated solar power plants.

EUROfusion Heritage

The development and success of the HADES facility are rooted in several key EUROfusion projects. Initially, the high heat flux platform FE200 was developed through a collaboration between CEA and Framatome under the European Fusion Programme. HADES has been crucial in testing and qualifying plasma-facing units for the WEST tokamak, supporting the broader goals of EUROfusion. Additionally, by providing a testing ground for ITER-like components, HADES plays a vital role in preparing for ITER, a cornerstone of the EUROfusion programme. These contributions highlight the facility’s importance in advancing fusion technology and its significant impact within the EUROfusion consortium.

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