

# Romanian participation at EUROfusion WPBB and complementary research

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## Objectives:

### 1. Definition and optimisation of process requirements for the TER WLCB system

The first major objective is the preliminary definition and optimisation of the **Tritium Extraction and Recovery (TER)** process requirements for the Water-Cooled Lead Ceramic Breeder (WLCB), using the TER HCPB configuration as a technical reference.

This work focuses on identifying operating conditions that enable efficient tritium extraction while reducing system complexity and energy demand. The analyses include:

- Evaluation of purge gas throughput as a function of hydrogen isotope content
- Assessment of the impact of reduced flow rates on isotope partial pressures
- Analysis of superficial velocity and pressure drop in the Reactive Molecular Sieve Beds (RMSB), using packed-bed correlations
- Evaluation of energy consumption for different operating pressures and volumetric flow rates

The results demonstrate that lowering purge gas flow rates increases hydrogen isotope partial pressures while significantly reducing gas velocities and pressure losses. In parallel, reduced operating pressure lowers compression power requirements and relaxes mechanical design constraints. Together, these findings support a more hydraulically efficient and energetically favourable TER concept for WLCB.

### 2. Experimental validation and performance optimisation of RMSB and getter bed technologies

A second major objective is the experimental validation and optimisation of the trapping technologies forming the core of the TER system.

#### RMSB – Isotopic exchange optimisation

A 1:10 scale RMSB mock-up was used to consolidate and extend isotopic exchange tests between hydrogen and deuterated water adsorbed on platinized zeolite.

The test campaign investigated:

- Platinum loadings of 0.3, 0.5 and 0.7 wt%
- Operating temperatures between 25 °C and 120 °C
- Deuterium extraction efficiency over a 10-hour exchange period

The results confirm that both increasing temperature and increasing Pt content enhance isotopic exchange efficiency. Above 80 °C, the system approaches quasi-steady behaviour, indicating reduced kinetic limitations. From a combined performance–cost perspective, a platinum content of approximately 0.5 wt% was identified as a balanced solution.

### **Getter Bed – Structural integrity and endurance behaviour**

In parallel, a ZAO-based getter bed mock-up was integrated into an upgraded experimental loop to assess hydrogen absorption–desorption behaviour under controlled conditions.

Six absorption–desorption cycles were performed, with hydrogen loading limited below the embrittlement threshold. Desorption was conducted at elevated temperatures (650–750 °C). While hydrogen uptake and release were successfully demonstrated, the tests revealed irregular behaviour and mechanical degradation of the ZAO discs after dismantling.

These results provide valuable insight into material durability, flow distribution effects, and thermal cycling constraints relevant for long-term operation.

### **3. Development of experimental infrastructure for hydrogen isotope permeation studies**

The third major objective is the development of a dedicated experimental capability to investigate hydrogen isotope permeation from gas to water — a phenomenon of direct relevance for water-cooled blanket concepts.

This activity included:

- Design and manufacturing of two permeation cells (SS316 and P92)
- Construction of a high-temperature (up to 300 °C) and high-pressure experimental rig
- Implementation of pressure control and overpressure protection logic
- Calibration of gas-phase isotope measurements using QMS
- Isotopic analysis of water samples using mass spectrometry

Preliminary permeation tests at 300 °C demonstrated measurable deuterium transfer from the gas phase into water, with approximately 37.7% of the deuterium lost from the gas being detected in the aqueous phase.

This infrastructure establishes the experimental basis for future systematic studies on material selection, permeation modelling, and safety assessment in WLCB-type systems.

### **Details on key results 2024 - 2025:**

#### **1. Results on process optimisation of the TER WLCB system**

##### **Increase in hydrogen isotope partial pressures at reduced flow rates**

When the total purge gas flow rate is decreased, the dilution of hydrogen isotopes in helium is reduced. As a result, the partial pressure of HT increases from values close to 1 Pa to several Pa under reduced-flow conditions. This behaviour improves the driving force for downstream trapping processes, while maintaining constant tritium release assumptions from the breeder.

##### **Significant reduction in superficial velocity in RMSB**

Lower purge gas flow rates reduce the superficial velocity in the Reactive Molecular Sieve Beds from values on the order of ~20 m/s (HCPB reference) to below ~4 m/s in optimised WLCB conditions. This leads to:

- Lower mechanical stress on the packed bed
- Reduced risk of erosion
- Lower pressure drop across the bed

- More favourable adsorption conditions  
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### **Reduced pressure drop and compression power**

Packed-bed calculations (Ergun-based analysis) and system-level energy estimates show that:

- Pressure losses increase strongly with superficial velocity and operating pressure
- Operating at lower pressure significantly reduces compression power demand
- At constant volumetric flow rate, high-pressure operation requires substantially higher energy input

Together, these results confirm that operating the TER system at reduced pressure and reduced flow rate provides a dual benefit: improved hydraulic behaviour and lower energy consumption.

## **2. Results on RMSB and Getter Bed performance validation**

### **2.1 RMSB – Isotopic Exchange Efficiency**

The consolidated isotopic exchange campaign on the 1:10 RMSB mock-up provided quantitative performance data for platinized zeolite materials.

#### **Influence of temperature**

Deuterium extraction efficiency increases consistently with temperature. The most pronounced improvement occurs between 25 °C and 80 °C. Above ~80 °C, the exchange process approaches a quasi-steady regime, indicating reduced kinetic and mass-transfer limitations.

#### **Influence of platinum loading**

Increasing Pt content from 0.3 wt% to 0.5 wt% and 0.7 wt% systematically enhances isotopic exchange efficiency. Higher loadings reduce the time required to reach effective exchange and improve the overall deuterium recovery fraction.

#### **Optimised compromise**

From a combined efficiency–cost perspective, ~0.5 wt% Pt was identified as a balanced solution, providing high recovery performance without excessive catalyst cost.

### **2.2 Getter Bed – Absorption–Desorption behaviour and structural integrity**

The integration of the ZAO getter mock-up into the experimental loop enabled controlled hydrogen absorption–desorption testing.

#### **Successful hydrogen loading below embrittlement limit**

Hydrogen absorption was limited to ~25% of the embrittlement threshold to avoid catastrophic failure. Controlled hydrogen feeding and QMS monitoring allowed quantification of absorbed and desorbed hydrogen.

#### **Thermal desorption performance**

Desorption at 650–750 °C confirmed hydrogen release capability, but behaviour was not fully reproducible between cycles.

#### **Observed degradation after cycling**

Post-test dismantling revealed:

- Loose particles inside the vessel
- Partial fracture of ZAO discs
- Signs of mechanical degradation

This degradation likely explains the irregular absorption/desorption behaviour and suggests that thermal cycling and/or local hydrogen concentration peaks may contribute to structural damage. These results provide essential input for future design refinements, particularly regarding temperature control, flow distribution, and mechanical robustness.

### **3. Results on hydrogen isotope permeation (gas → water)**

The development of the permeation test facility enabled preliminary quantification of deuterium transfer from gas to water at high temperature.

#### **Successful operation at 300 °C and high pressure**

The permeation cell and rig were operated at temperatures up to 300 °C and pressures up to ~85 bar(g), confirming structural integrity and functional control of the installation.

#### **Quantification of deuterium loss from gas phase**

By comparing initial and final gas compositions using QMS, the number of deuterium atoms lost from the gas phase was determined.

#### **Detection of deuterium in water phase**

Water sample analysis showed a measurable increase in deuterium concentration. Approximately 37.7% of the deuterium lost from the gas phase was detected in the water as bound deuterium.

These results demonstrate:

- The feasibility of high-temperature gas-to-water permeation testing
- The capability of the measurement chain (QMS + isotopic water analysis)
- The presence of significant isotope transfer under representative conditions

The established experimental platform now enables systematic studies on material comparison (SS316 vs P92), permeability modelling, and long-term permeation assessment.

#### **Conferences:**

- George Bulubasa, George Ana, Ovidiu Balteanu, Radu Ana, Maria Craciun, Alina Niculescu, *Tritium extraction from helium purge gas in fusion reactors*, "23rd International Balkan Workshop on Applied Physics and Materials Science"
- Maria Craciun, George Bulubasa, George Ana, Alina Niculescu, Ciprian Bucur, Iulia Stefan, Robert Daramus, *Characterization of reactive zeolites for tritium extraction from fusion reactor purge gas*, "23rd International Balkan Workshop on Applied Physics and Materials Science"
- George Ana, Ovidiu Balteanu, Ciprian Bucur, Radu Ana, *Non-evaporable getter materials for tritium capture in fusion reactor purge systems: a preliminary study*, "23rd International Balkan Workshop on Applied Physics and Materials Science"

#### **Papers:**

- George Ana, George Bulubasa, Alina Niculescu, Maria Craciun, Ciprian Bucur, Iuliana Stefan, *Characterization of water adsorption capacity at high pressure of the molecular sieve proposed to be used in TER RMSB*, Fusion Engineering and Design 215 (2025) 115039;
- Alina Niculescu, Maria Craciun, George Ana, Gheorghe Bulubasa, *ICSI contributions regarding barriers against hydrogen isotope permeation through stainless steel and EUROFER97 in DEMO*

*applications*, Journal of Fusion Energy (2026) 45:16, <https://doi.org/10.1007/s10894-026-00560-4>.