Karlsruhe Institute of Technology

Division III – Mechanical and Electrical Engineering

Institute of Neutron Physics and Reactor Technology (INR)

The Tritium Breeding Blanket

Looking into the Heart of a Nuclear Fusion Reactor

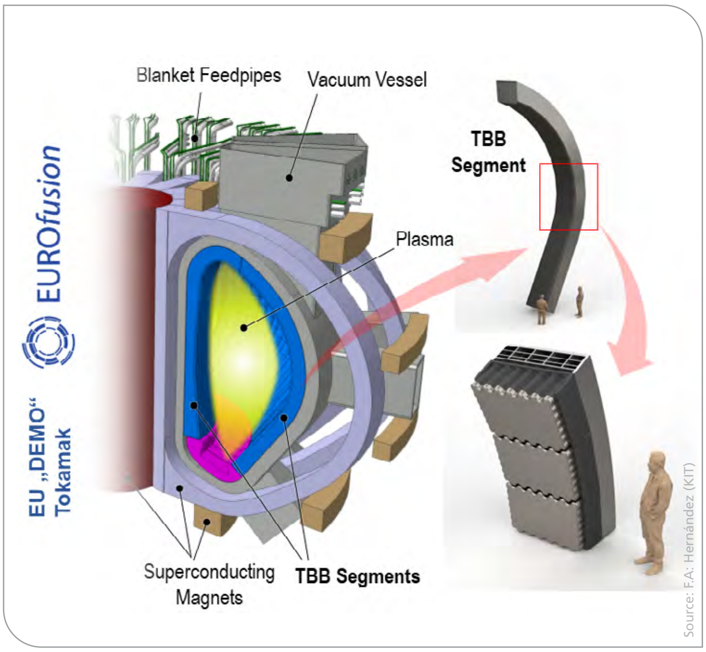
The tritium breeding blanket (TBB) constitutes the heart of any deuterium- and tritium-fueled nuclear fusion reactor. It is located between the plasma having a temperature of 150 million °C and the near-zero superconducting magnets confining the plasma. All these components are arranged within a few meters distance, representing one of the biggest challenges in fusion technology. At this central position in the reactor, the TBB fulfills several essential functions. While deuterium is abundant in nature, reaching a concentration of about 150 ppm in water sources, tritium is virtually non-existent. Consequently, any reactor working with both fusion fuels has to generate own tritium. This is one of the key functions of the TBB. Nuclear fusion of deuterium and tritium produces high-energy helium ions and fast neutrons.

Using the Fusion Neutrons

The helium ions are confined in the plasma thanks to the magnetic fields produced by the superconducting magnets. The neutrons that are not influenced by the magnetic fields escape this confinement. The first - and ideally last - element hit by the neutrons is the TBB.

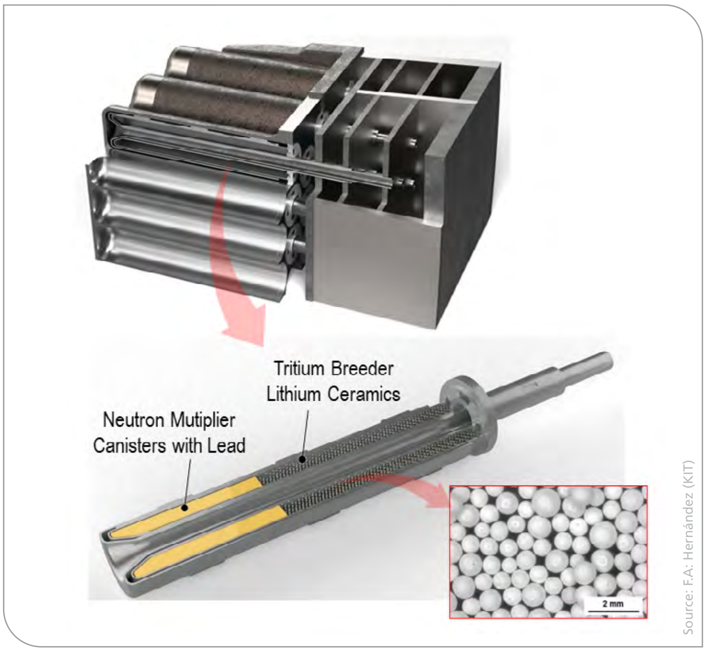
The TBB components or so-called segments are prismatic structures of about 10 m length and about 1 m² cross section that are made of a reduced-activation steel (EUROFER97). Deep holes pointing towards the plasma are drilled into these monoblock segments and filled with so-called fuel breeding pins. These pins contain a combination of lithium oxide ceramic pebbles and canisters filled with lead. The incoming neutrons trigger transmutation of the lithium atoms contained in the ceramic pebbles into tritium as well as neutron multiplication reactions in the lead, which may give rise to additional tritium breeding reactions.

All nuclear reactions taking place in the TBB produce a vast amount of heat. Hence, the energy of the fast neutrons in the TBB is not only used for generating the tritium fuel, but also for the production of high-grade heat. This heat is dissipated by a coolant flowing through the fuel breeding pins. Helium gas is used for cooling, because it ensures an optimum operation temperature not only for efficient tritium extraction, but also for maximizing the thermal efficiency of the plant and optimizing the lifetime of the steel.



Source: F.A: Hernández (KIT)

Representation of the planned EU nuclear fusion reactor DEMO, a TBB segment, and the central part of the TBB.



Source: F.A: Hernández (KIT)

Section of the HCPB-TBB and fuel breeding pin with its components

At the Interface of Natural Sciences and Engineering

KIT's Institute for Neutron Physics and Reactor Technology (INR) leads the German and European TBB development work in the European Atomic Energy Community (Euratom). Within the EUROfusion consortium, several TBB concepts are being pursued. Of these, the so-called helium-cooled pebble bed (HCPB) described here is considered a reference for a future fusion power plant. R&D work is of integrated character and based on the cooperation of researchers from different physics and engineering disciplines. Power plant integration and manufacturing aspects are taken into account to ensure industrialization and cost minimization of this component.

The key components of the TBB are the pin monoblock and the fuel breeding pins containing the lithium oxide ceramic pebbles and lead-filled canisters. In cooperation with the voestalpine Foundry Group in Traisen (Austria), the pin monoblock was cast using EUROFER97 steel with an innovative technology based on 3D-printed sand molds to produce the semi-finished part with deep holes. Future steps will focus on forging a massive EUROFER97 block to produce highest-quality RAFM steel with the required properties.

On the Way towards a Fusion Power Plant

KIT also is in charge of materials development and demonstrating the manufacture of the lithium oxide ceramic pebbles and lead-filled canisters. This includes the entire range of characterization analyses for the qualification of materials at a number of KIT institutes. Engineering at KIT ends with the construction of mid-size integral prototypes that are then tested under relevant thermohydraulic and structural conditions in INR's high-pressure and high-temperature helium loop HELOKA. Such tests give rise to high-quality validation data that are fundamental to the qualification and licensing of the components needed to make the plans for a future pilot power plant or power plant come true.


Picture: Laila Tkotz

Pin monoblock prototype of the HCPB-TBB

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