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FUNCTIONAL MATERIALS STRUCTURE AND PROPERTIES CHANGES IN TOKAMAK REACTORS INDUCED BY FUSION RADIATION

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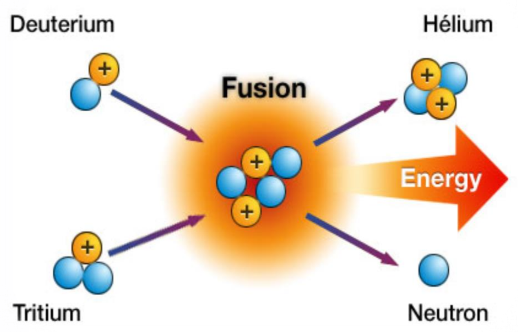
INTRODUCTION

Fusion energy

The world's growing demand for electricity makes the search for the new sources of alternative energy. As one of the most promising forms of energy production are thermonuclear fusion - the reaction between the elements of light nuclei to form a heavier element, releasing at the same time a large amount of energy.



Fusion reaction of hydrogen isotopes – **deuterium ^{2}H** and **tritium ^{3}H**, is considered to be the most convenient for energy production due to its high energy yield.

$$^2H + ^3H \rightarrow ^4He + n + 17.6\ MeV$$

Deuterium is stable isotope of hydrogen that can be extracted from the sea water.

Tritium is radioactive isotope with relatively short half-life (12.3 years) and has to be produced artificially by interaction of neutrons with **lithium**

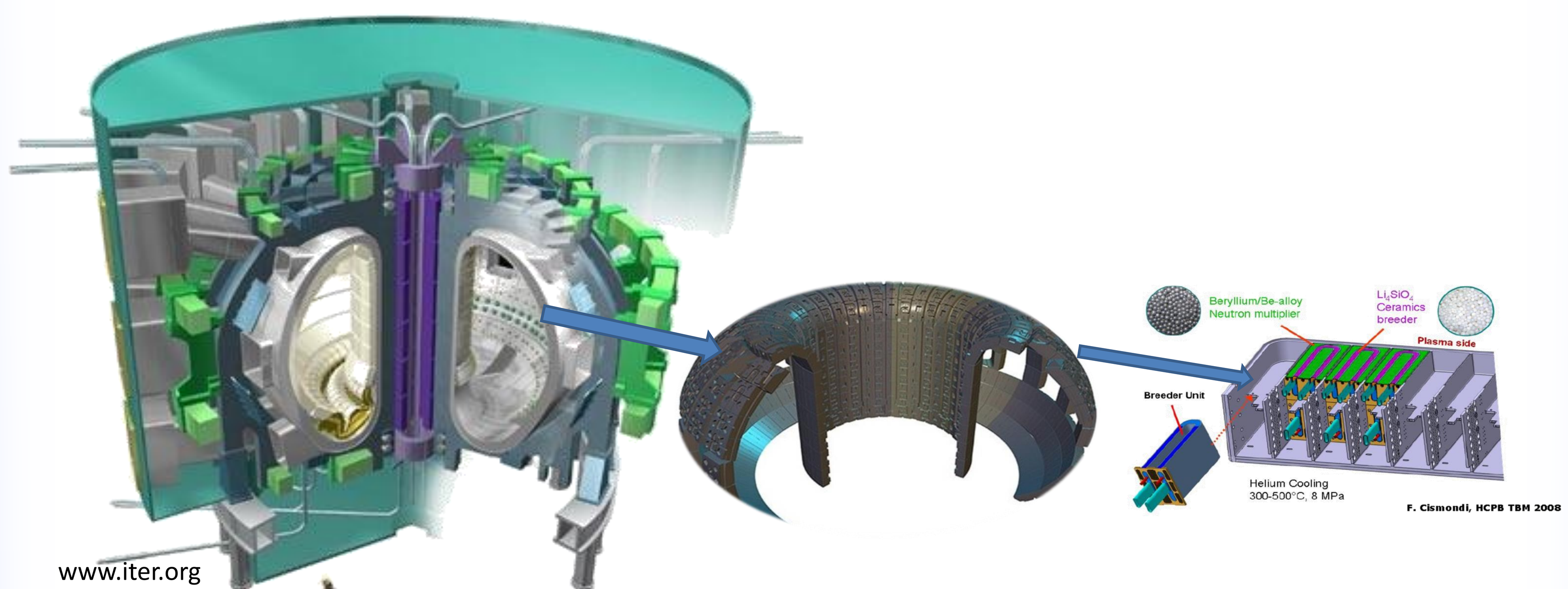
$$^6Li + n\ (thermal) \rightarrow ^4He + ^3H$$

Problem and scope of the work

Successful thermonuclear energy use in the power production is significantly dependent on the **development of materials**. In order to create both physically and commercially viable fusion reactor, the materials have to be able to conserve their functional properties. They must be able to withstand the extreme conditions of reactor plasma. Thermonuclear fusion reactions taking place in the reactor generated particles flow, including neutron radiation of functional materials induce certain features: **reduce the strength, increase brittleness, increase swelling and reduce structural integrity.**

The study aims to evaluate the reactor blanket area of functional and close contact plasma materials structures and properties of the changes caused by various external factors, such as temperature, ionizing radiation and magnetic field, which would allow to develop more efficient and more sustainable reactor material.

Fusion reactor and tritium breeding



ITER reactor cross section — Breeding blanket — Tritium breeding module

The dominating fraction (about 80%) of the power generated by fusion will be captured by neutron moderation in the breeding blanket surrounding the plasma where tritium production and energy extraction take place.

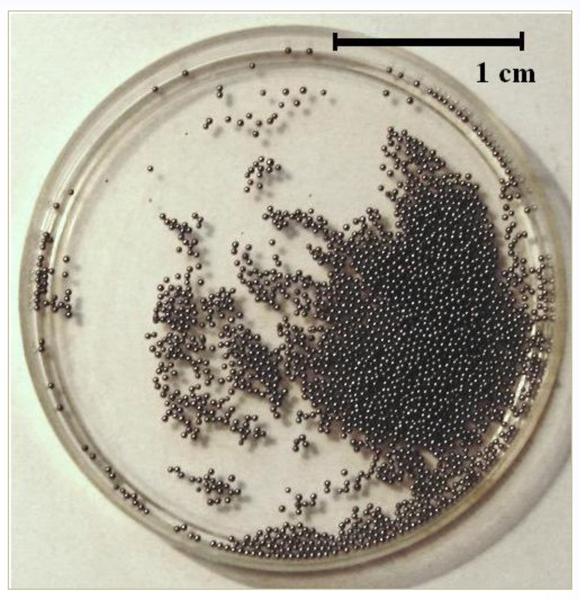
Tokamak (a Russian: тороидальная камера с магнитными катушками) type reactor thermonuclear plasma reaction shall be held with a strong magnetic field. Tokamak Experimental Reactor type - international experimental fusion reactor (International Thermonuclear Experimental Reactor - ITER) with DEMO (demonstration Power Plant) constraction principles is currently under construction in France, at Cadarache.

EXPERIMENTAL

SAMPLES

Candidate materials are mainly screened by their mechanical properties, physical chemical characteristics (fusion fuel component tritium and deuterium retention degree, He build-up, swelling) and corrosion characteristics. In the study is planned to use:

- beryllium and beryllium compounds exposed to high neutron radiation
- lithium containing materials exposed to high neutron radiation
- tungsten depressed in plasma
- carbon



Non-irradiated berylllium pebbles

METHODS

Research methods: non-destructive materials physico-chemical spectroscopy, electron and optical microscopy, hydrogen isotope detection by gas ionization, liquid scintillator and mass spectrometry.

Beryllium pebbles chemical scavenger and dissolution method

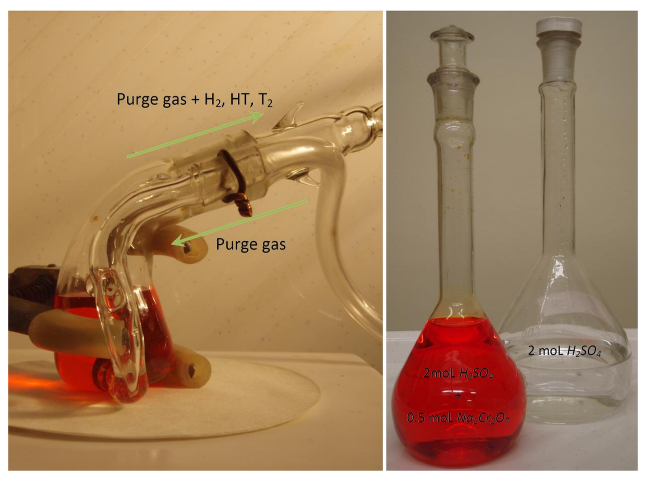
Beryllium pebbles are foreseen as a neutron multiplier to the reference concept of the helium-cooled pebble-bed breeding blanket (HCPB) in the European Breeding Blanket Programme for the DEMO design [1].

Tritium inventory in the beryllium as a result of neutron-induced transmutations is a significant safety and technological issue for the operation of the breeding blanket.

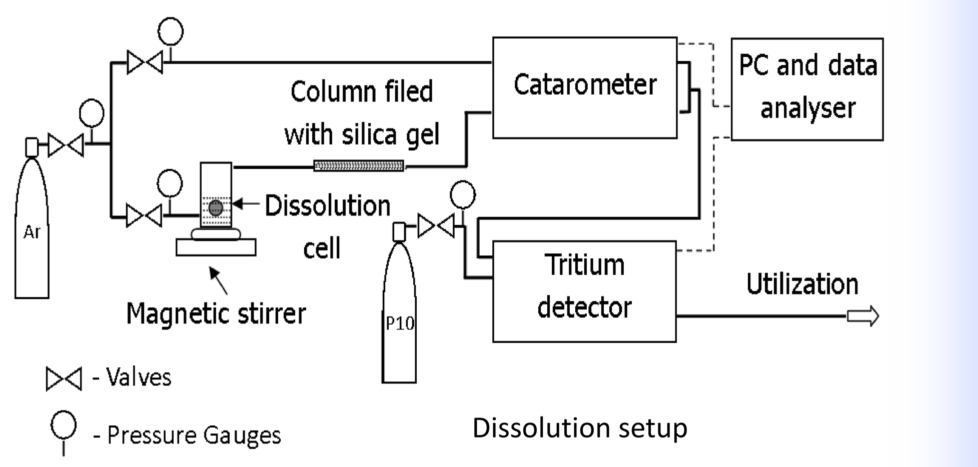
Detritiation based on the thermo-annealing might be considered as one of the solutions.

- Total tritium activity
- Tritium bulk distribution
- Abundance ratios of chemical forms (T_2,T^0,T^+)

Method based on dissolution of beryllium pebbles in the solutions of 2 moL H_2SO_4 and 2moL H_2SO_4 + 0.5 moL $Na_2Cr_2O_7$ in a special setup.



Dissolution cell (on the left) and solutions (on the right) used in the experiments



Dissolution setup

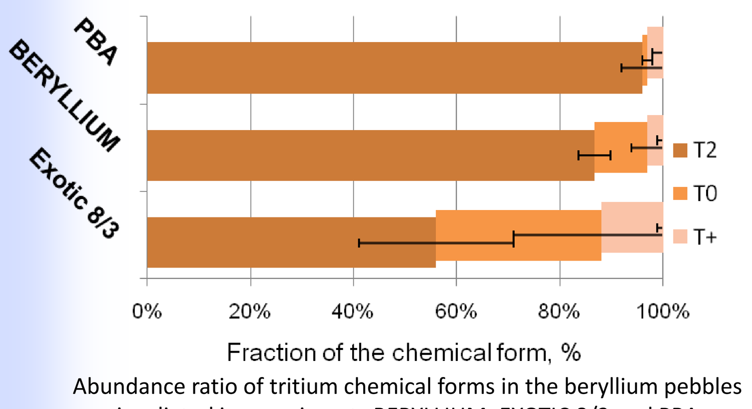
RESULTS

Tritium chemical state and distribution in beryllium pebbles

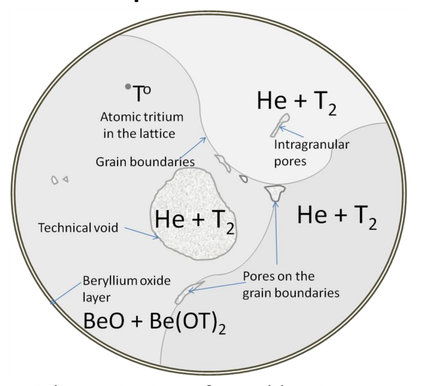
Tritium produced in the neutron induced transmutation of beryllium can diffuse into the lattice or can be trapped by structure traps (such as intragranular He bubbles, closed porosity, grain boundaries, etc.) or it may react with *BeO* to form *Be(OT)$_2$*. Therefore 3 chemical states are possible: T_2, T^0, T^+.

Abundance ratios of tritium chemical forms depend both on the irradiation conditions and properties of the beryllium sample.

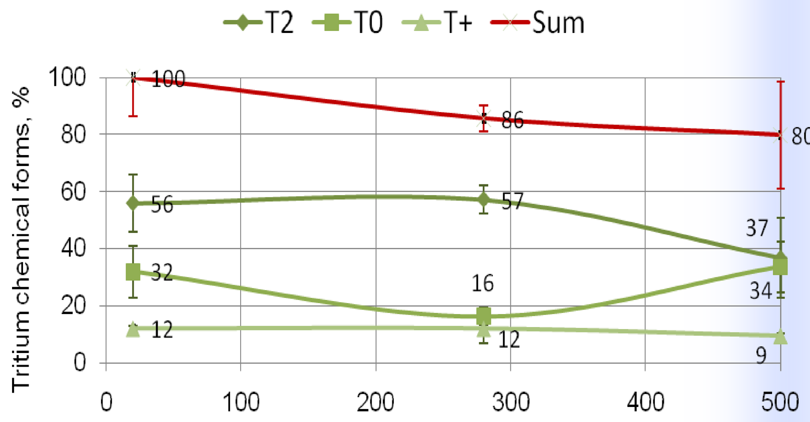
To demonstrate role of the chemical state on the desorption process measurements have been done after partial tritium desorption in different temperatures.



Abundance ratio of tritium chemical forms in the beryllium pebbles irradiated in experiments BERYLLIUM, EXOTIC 8/3 and PBA



Schematic view of possible tritium states in the neutron irradiated beryllium pebble

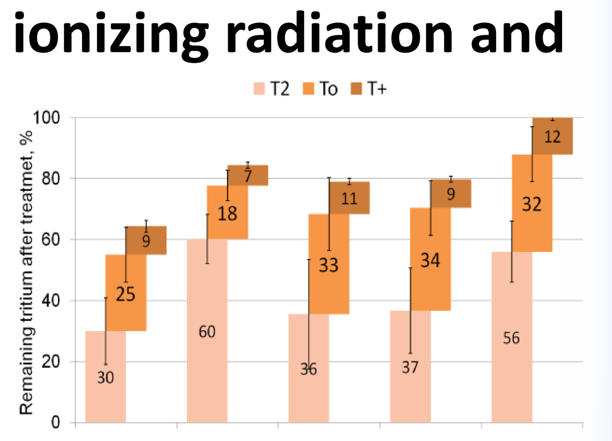


Tritium distributions in the bulk of pebbles irradiated in PBA (a) and BERYLLIUM (b) experiments

Tritium desorption under action magnetic field, ionizing radiation and temperature

Tritium desorption from samples has been studied in order to compare material reliability for fusion applications regarding the detritiation possibility.

Tritium desorption from different beryllium samples starts at different temperatures, moreover these differences reached several hundred degrees



Tritium release at different thermo-annealing conditions (T –temperature, 500°C, MF - magnetic field - 1,7 T,R- accelerated electrons - 5MeV. 14MGy·h^{-1})

Beryllium pebbles thermo-annealing

- tritium thermo - desorption curves
- Effects of magnetic field and ionizing radiation on tritium desorption

Tritium desorption studies under simultaneous or separate action of temperature, fast electron irradiation and high magnetic field are possible because of the original radiation thermo magnetic setup that has been developed in the laboratory. This equipment is based on the electron accelerator LINAC-4.

Experiments are based on heating the sample with and without action of fast electron irradiation (14MGy·h^{-1}, 5MeV) and high magnetic field (1.7T).

CONCLUSIONS

1. Chemical scavenger method and radiation thermo magnetic setup developed in Laboratory of Radiation Chemistry of Solids can be successfully applied for studies on tritium behaviour in materials for fusion application.
2. Facilitating effect of simultaneous action of temperature, ionizing irradiation and magnetic field is significant and must be taken into account in prediction of tritium behaviour in real reactor conditions
3. Detritiation methods based on thermo-annealing of materials could be improved by adding exposure to ionizing radiation and magnetic field.

ACKNOWLEDGMENTS

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REFEREECES

[1] Boccaccini, L.V., et al., *The EU TBM systems: Design and development programme.* Fusion Engineering and Design, 2009. **84**(2-6): p. 333-337.

FuseNet PhD Event 2015
Prague 15 – 18 November, 2015