

Neutronics analysis of the functional materials within the IFMIF-DONES Test Modules

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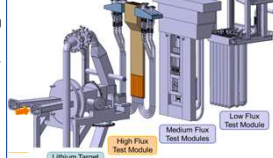
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Objectives and scope of the neutronics analysis:

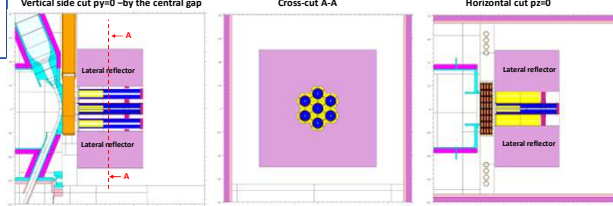
- To provide neutronics analyses in support of the materials qualification of (among others) the EU DEMO Helium-Cooled Pebble Bed (HCPB) Breeding Blanket (BB) by designing the neutron irradiation experiments in the IFMIF-DONES (International Fusion Materials Irradiation Facility – DEMO Oriented NEutron Source).
- The dedicated module for irradiation of the DEMO structural materials is the High Flux Test Module (HFTM). Behind HFTM, in the middle flux position, we can install one of two modules:
- (1) **ICBIM** (In-situ Ceramic Breeder Irradiation Module), designed to irradiate and study the EU DEMO HCPB BB functional material “Advanced Ceramic Breeder” (ACB) at well-defined radiation, temperature and purge gas conditions with the ability to apply transients of the DEMO HCPB BB parameters and measure time-resolved responses of the tritium release, (2) **BLUME** - **B**lanket **U**nfunctional **M**aterials **M**odule – to study the functional design of the HCPB BB under neutron irradiation in DEMO, taking into account the physical effects from HCPB design heterogeneity of temperature and irradiation conditions. This work is focused on BLUME.

Positions of Test Modules:



BLUME neutron lateral reflectors made of graphite (C) and lead (Pb)

Graphite and lead reflectors have been installed in the MCNP model with HFTM, removed: N-Spec, Shifter, W-armor, FW



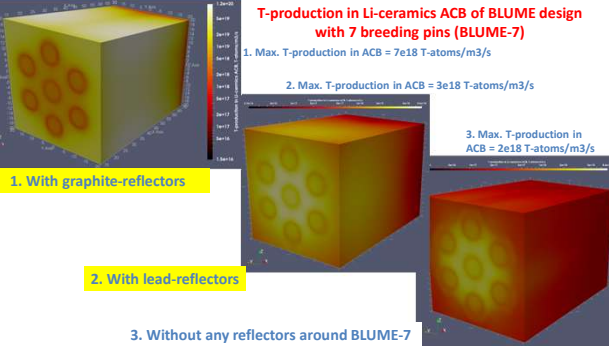
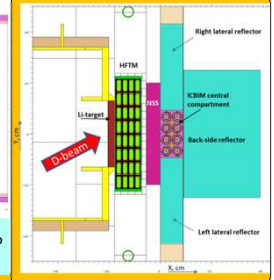
Calculated and compared in BLUME and ICBIM Breeding Blanket test modules:

- Neutron fluxes
- Nuclear heat for 3 materials: Li-ceramics, TiBe12, EUROFER
- T-production in Li-ceramics ACB
- Neutron damage (DPA/FPV)

A Monte Carlo CAD-based neutronics methodology developed at KIT with codes such as McDeLicious-17, OTF-GVR, McCad can model the d-Li neutron & photon source at the Li target and perform effective deep-penetration radiation transport calculations.

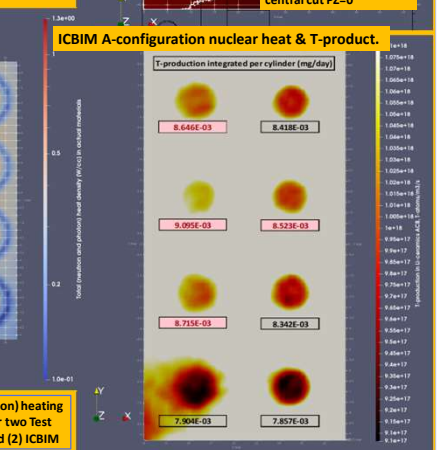
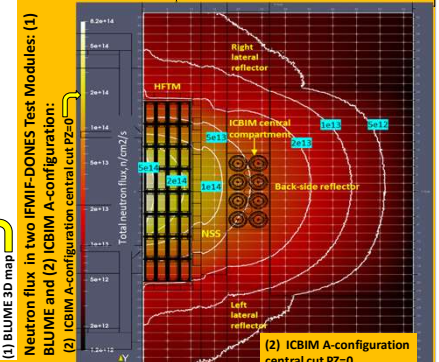
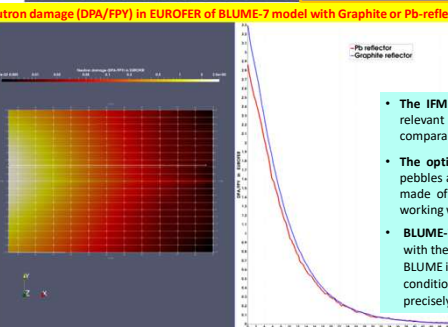
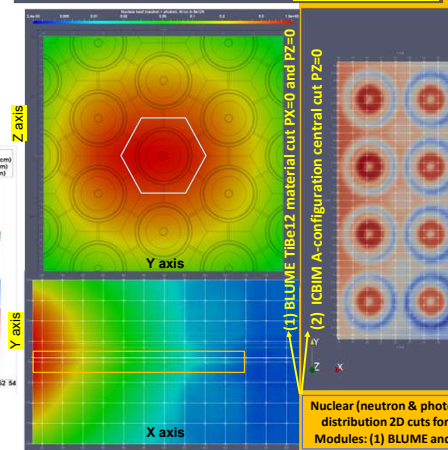
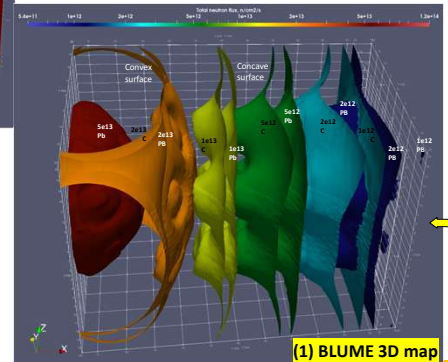
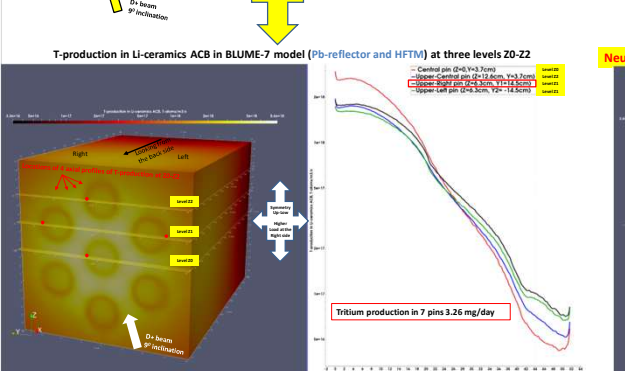
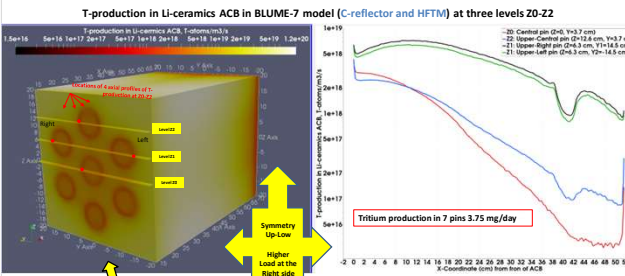
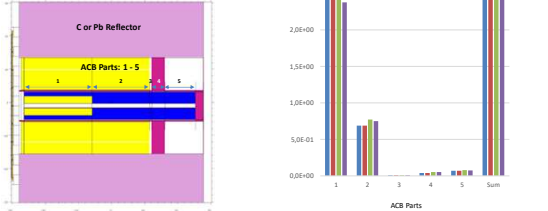
- The neutronics computations have been performed on Marconi-Fusion, Leonardo, and Pitagora HPC Cineca, Italy. Neutron and photon fluxes, neutron damage, T-production, and nuclear heating have been analyzed for the structural and functional materials.
- The beam of deuteron (d) ions is accelerated to 40 MeV with a current of 125 mA to impinge on the target of liquid lithium (Li) jet, producing by nuclear stripping reaction $\text{Li}(d, xn)$ neutron flux of $5e14 \text{ n/cm}^2/\text{s}$ peaking at the energy of 14-15 MeV.

ICBIM A-configuration of two lateral (Right and Left) and Back reflector



Integral tritium production (mg/day) in 5 ACB parts of all 7 pins of 4 BLUME material configurations: variation of reflector material and Li6 enrichment

ACB Parts	C-Reflector, 90 at% Li6	C-Reflector, 60 at% Li6	Pb-Reflector, 90 at% Li6	Pb-Reflector, 60 at% Li6
1	2.9507E+00	2.7378E+00	2.4800E+00	3.3788E+00
2	6.8809E-01	6.9937E-01	7.7101E-01	7.5076E-01
3	8.3099E-03	8.3337E-03	1.0584E-02	1.0206E-02
4	3.7283E-02	3.7482E-02	5.4313E-02	5.1609E-02
5	4.9351E-01	4.9446E-01	5.2724E-01	5.0614E-01
Sum	3.7534E+00	3.5418E+00	3.5203E+00	3.9623E+00



Type of the HCPB Breeding Blanket Test Module mockup	Integral T-production in the whole ACB material, (mg/day)
BLUME-7 with C-Reflector, 60% at% of Li6	3.54 mg/day
ICBIM A-configuration	6.7520E-02 mg/day
BLUME-7 / ICBIM ratio	Ratio = 5.2455E+01

Conclusions:

- The IFMIF-DONES facility represents the unique neutron source to irradiate fusion-relevant structural and functional materials with neutrons of high energy and fluences, comparable with the radiation loads to be reached at the EU DEMO fusion reactor.
- The optimum BLUME-7 design has seven pins of the ACB tritium breeder ceramic pebbles and the titanium beryllide neutron multiplier, surrounded by neutron reflectors made of graphite. BLUME-7 can produce 3.75 mg of tritium daily in its seven pins working with DONES's single 40 MeV accelerator at a deuteron current of 125 mA.
- BLUME-7 with 7 pins generates 52 times more tritium than all the ICBIM 8 cylinders with the same breeder materials of Advanced Ceramic Breeder (ACB). The downside of BLUME is that ACB is irradiated under heterogeneous temperature and irradiation conditions, making studying the time-resolved responses of tritium released by the ACB precisely almost impossible. ICBIM avoids this downside of BLUME.