Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

Fission blankets for tritium production in hybrid reactors

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FUNFI-IT workshop, Deember 11, 2024, Centro Ricerche Enrico Fermi (Roma)

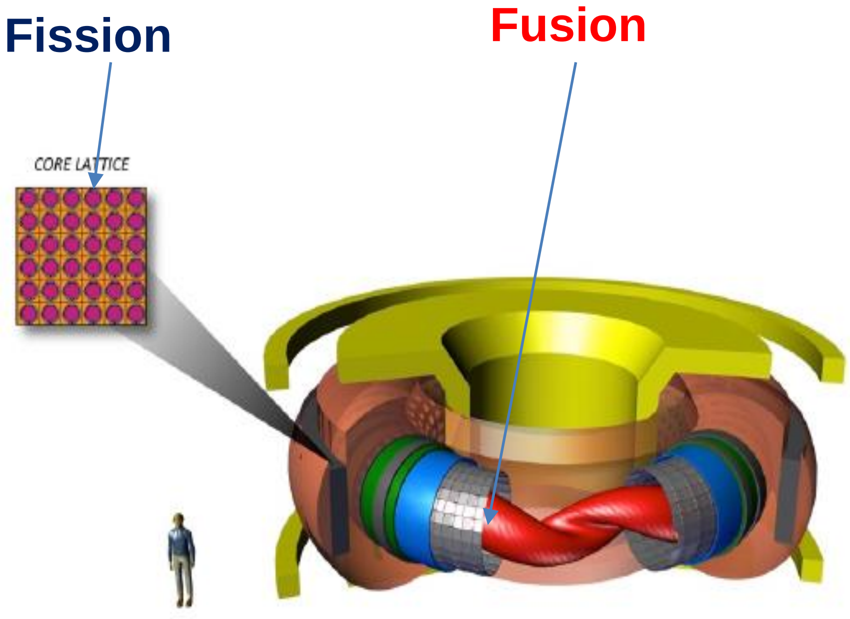
Fusion-fission hybrid systems

In a hybrid reactor, the neutron flux emerging from **nuclear fusion reactor** is used to induce fissions (or transmutations) in a **fission blanket** in subcritical mode (k<1).

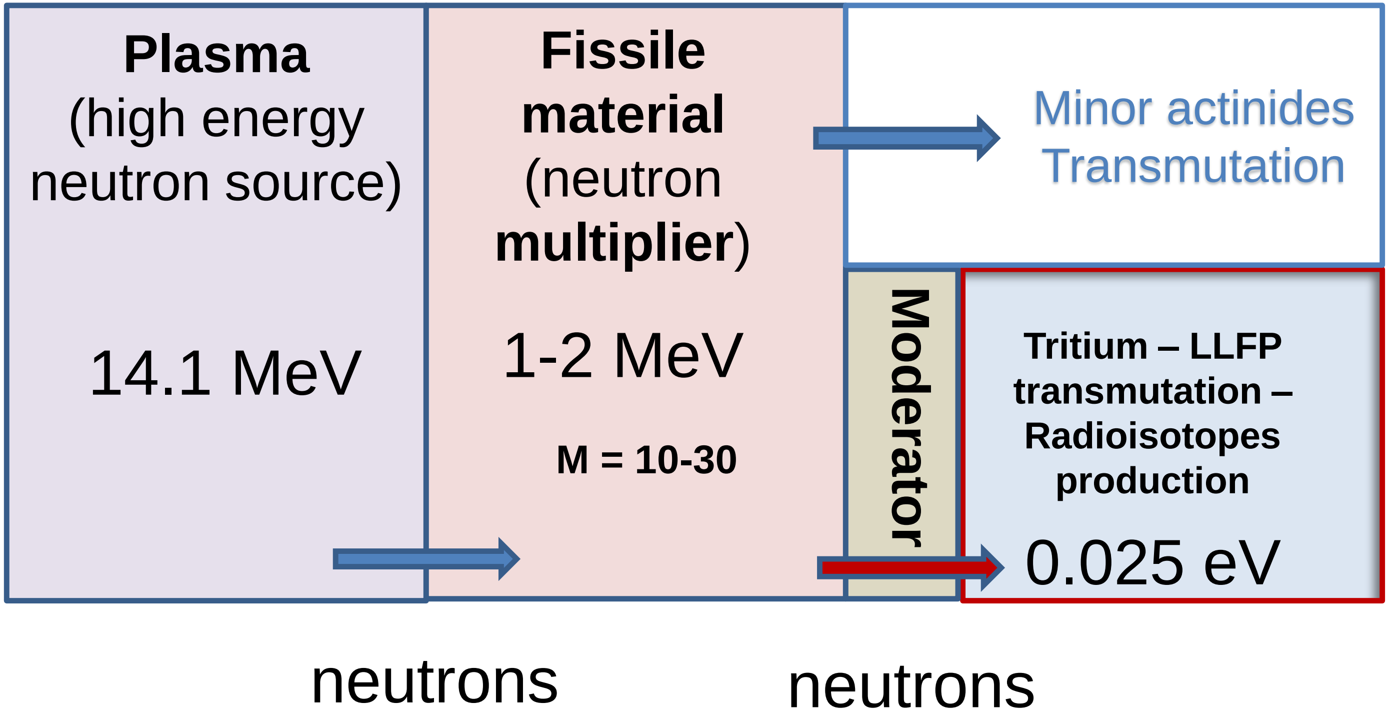
FFHS can contain a blanket forr:

- Energy generation
- Radioactive waste transmutation
- Nuclear fuel production (fertilization)
- **Tritium breeding (currently produced by CANDU reactors)**

These systems could represent an intermediate step towards the industrializatio of nuclear fusion



Fission blanket design



Tritium production reactions

$$D + T \longrightarrow {}^{4}He + n + 17.6\ MeV$$

Plasma

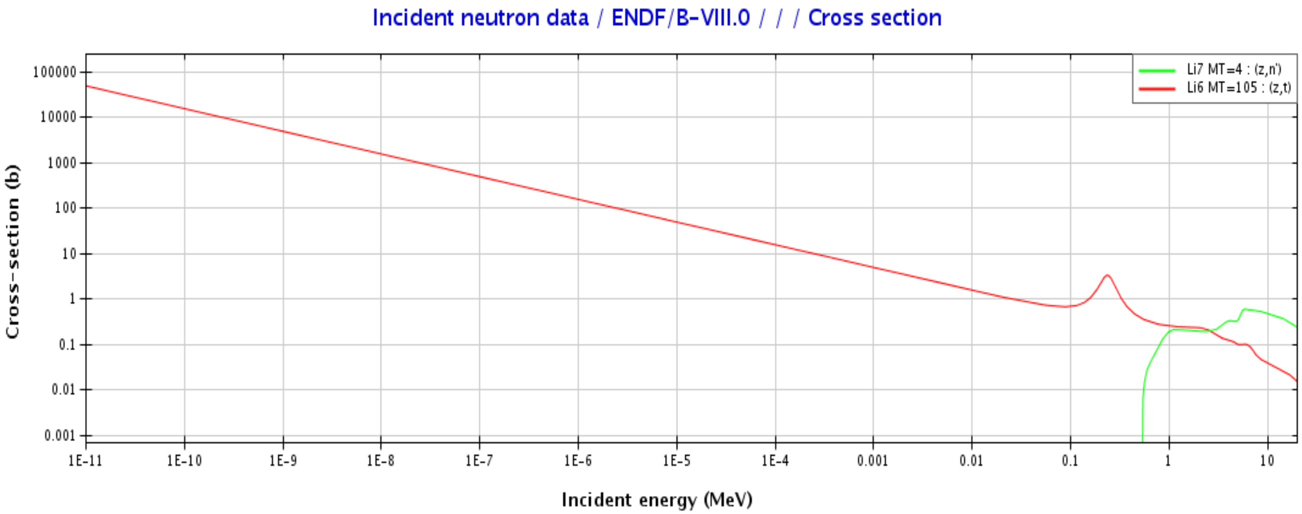
$${}^{6}Li + n \longrightarrow {}^{4}He + T + 4.8\ MeV$$

$${}^{7}Li + n \longrightarrow {}^{4}He + T + n - 2.5\ MeV$$

Breeding blanket

Li6 natural abundance ≈ 7%
It is also possible to use Li6 enriched materials up to 90%

Tritium production reactions XS



Tritium production is an important issue for future fusion systems.
Future systems should produce tritium by Lithium irradiation.

Li(n,T)α cross section is far higher (up to 3 order of magnitude) for thermal neutrons

RFP fusion core

Machine section and performances

R = 6 m

a = 0.8 m

Plasma current = 11.6 MA

T_e = 11.3 keV

$P_{ohmic\_heating}$ = 70 MW

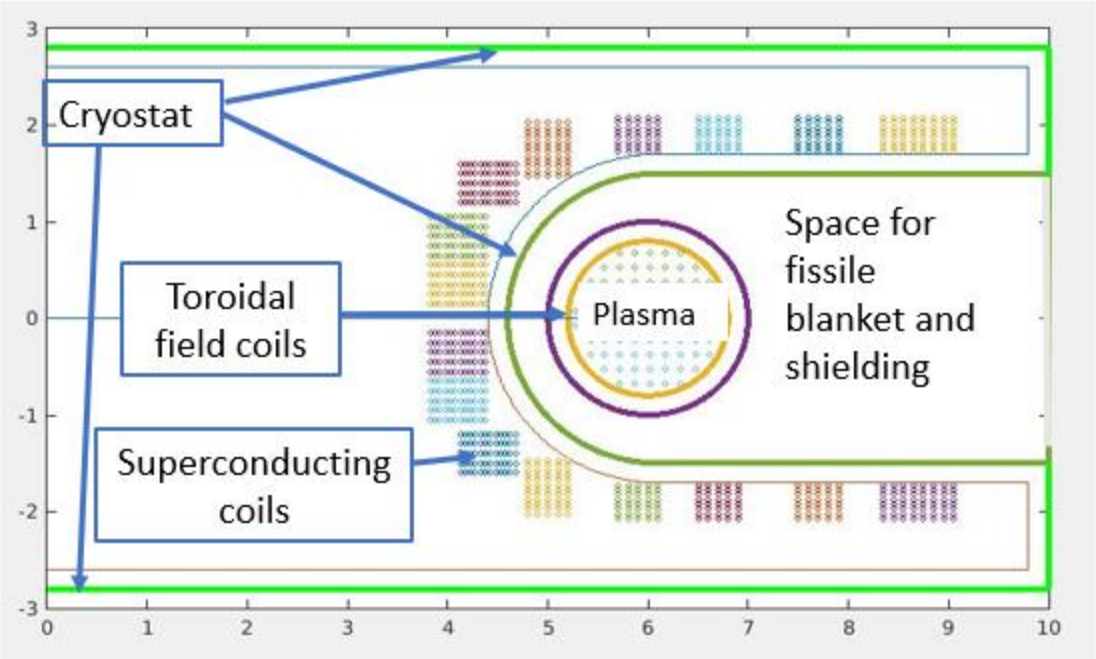
P_{fusion} = 108 MW

P_{alfa} = 21.6 MW

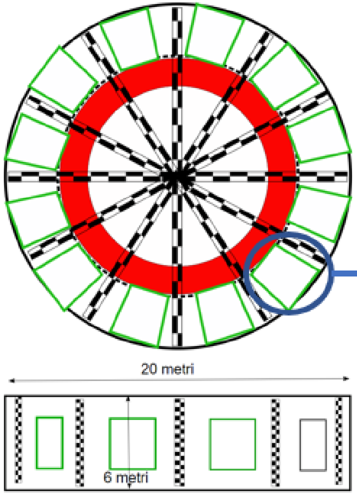
$P_{neutron}$ = 86.4 MW

n = 3.8×10^{19} neutron/s

$n_{flux} = 2 \times 10^{13}$ n/(cm²· s)

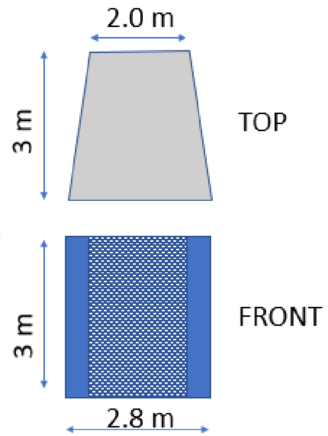


RFP based FFHR



Machine top and side views

Layout and fissile blanket



Top and front views of the fissile module

- 12 fissile modules arranged around the torus
- Fissile modules completely detached from the fusion plant, easily accessible
- Toroidal field coils external to the cryostat at room temperature

RFP confinement properties **adequate for low Q operation** (Q ≈ 1)

- Machine with **high accessibility** and relatively low complexity
- **Inductive operation** only

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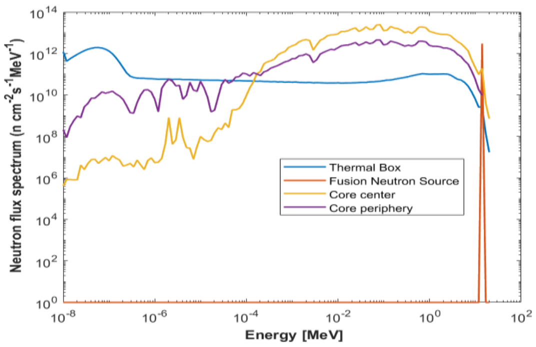
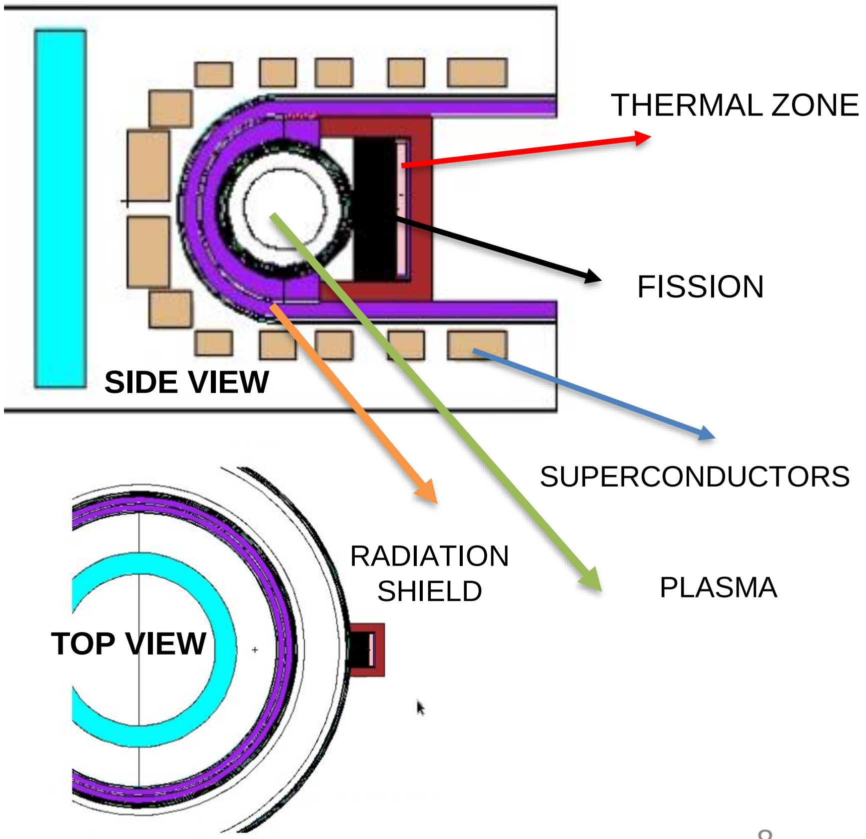
Fission blanket

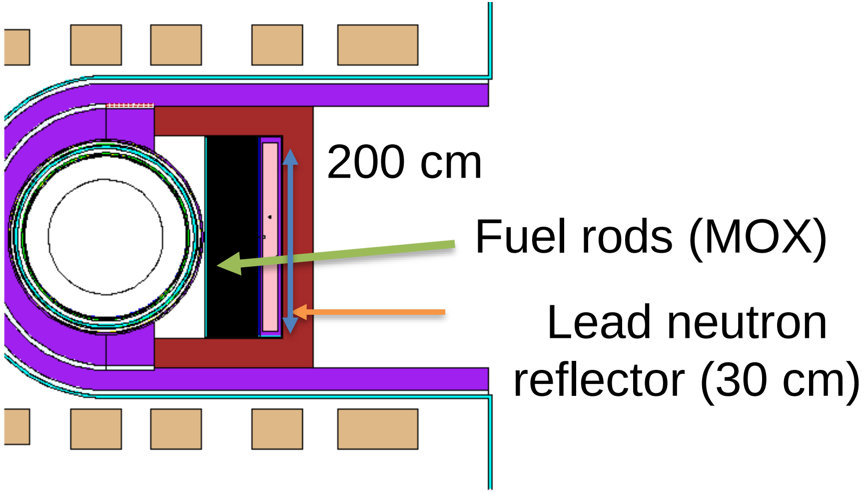
An RFP-based hybrid system concept has been studied (R=6 m, a=0.8 m). The fission blanket proposed is characterized by a multi-zone design:

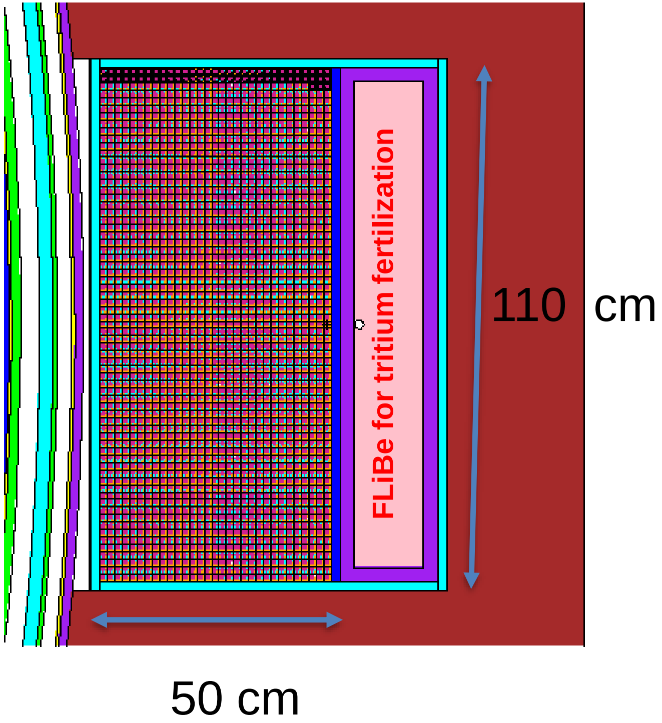
- A **fast core** (fuel MOX- cooling fluid Molten salt)
- A **thermal neutron spectrum zone** for **tritium breeding** (FLiBe)





Fission core design



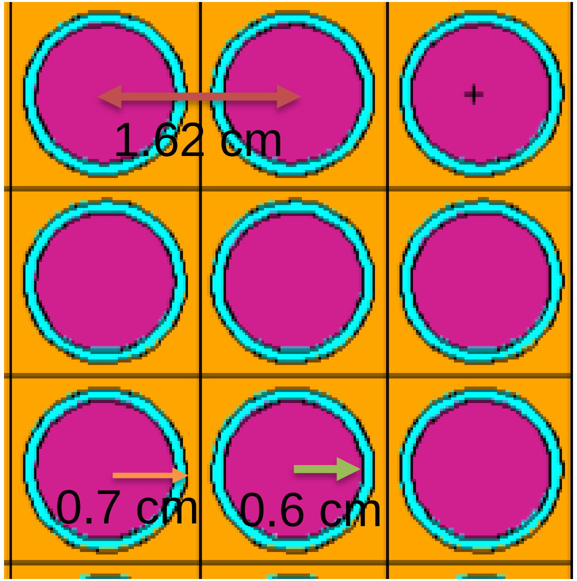


Core dimensions: 50 x 110 x 200 cm^3

Molten salt cooling system: NaF – ZrF_4

Fission core lattice

- 2553 rods
- R_{MOX}= 0.6 cm
- R_{clad}= 0.7 cm
- h_{rod}=197.52 cm
- AISI 316 steel cladding thickness: 0.1 cm
- $d_{rod\text{-}rod}$=1.62 cm



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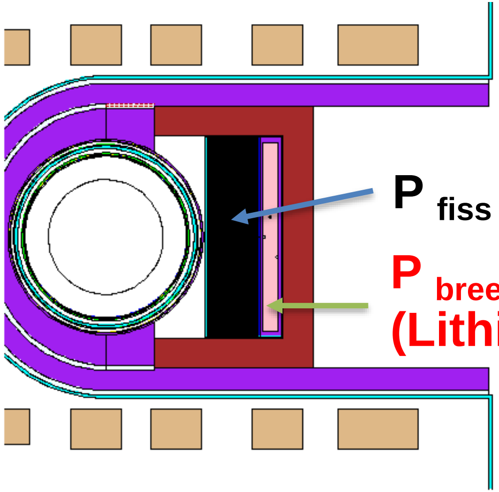
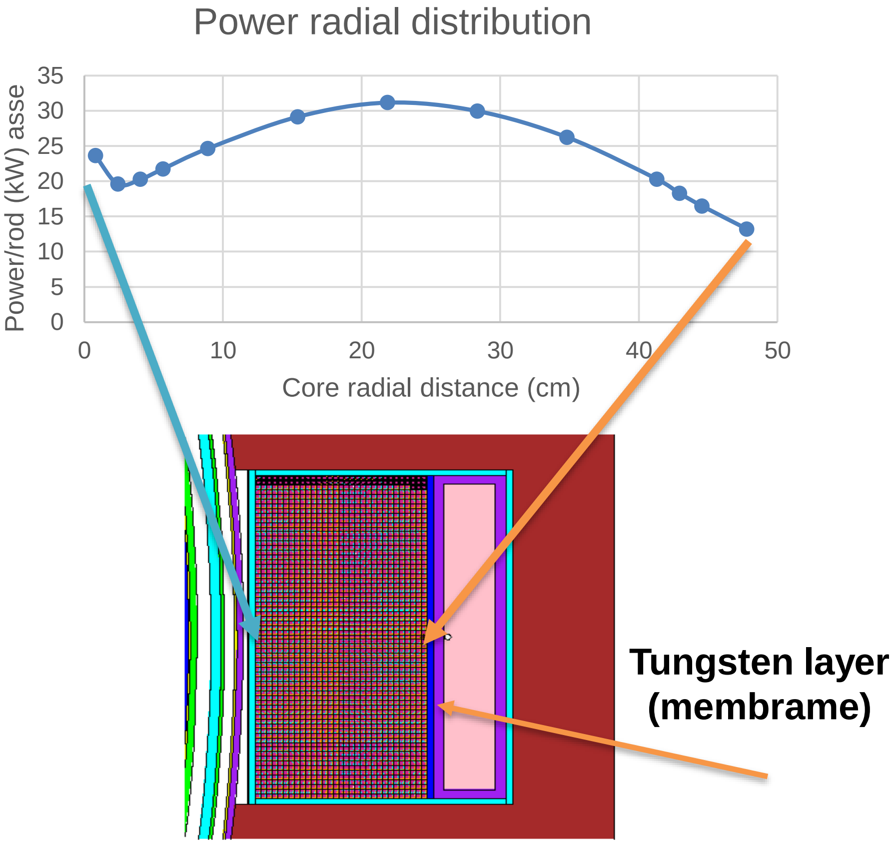
Radial power distribution



P_{fiss} = 42 MW

P_{breed} = 10 MW (Lithium reactions)



Obtainable Tritium and synergy with the Fusion Power Plants

Fusion core of the FFHR - Total Tritium in the torus: 50 mg
- Tritium consumption: 0.19 mg/s
- Fusion power: 108 MW

Fission blanket – Fission power in the fast core: 600 MW
- Power in the Lithium box: 120 MW
- **Net Tritium production: 140 kg/year**

Tritium extraction efficiency from production is difficult to estimate; if it is assumed 50%, **the net available Tritium is 65 kg/year**. This amount could:

- supply a 1.1 GW fusion power plant without a breeding blanket;
- contribute to supply a fusion power plant with TBR < 1;
- provide the reserve of Tritium for a fusion machine start-up or to supply pulsed machines (ITER, CFETR,…)

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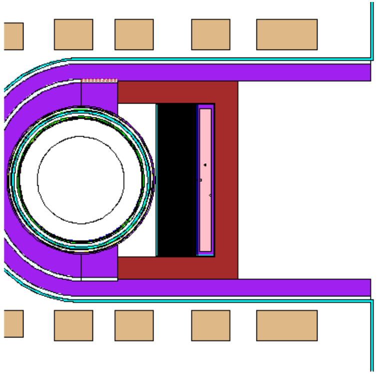
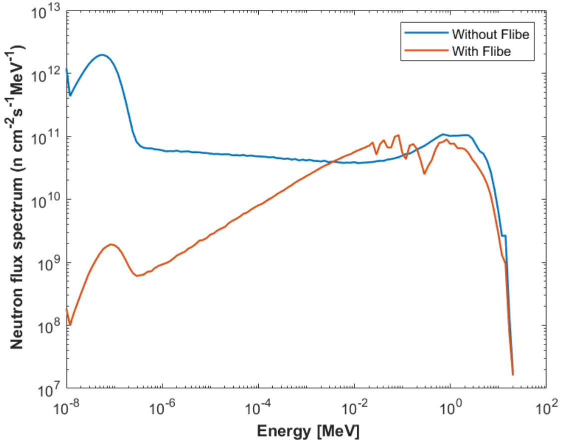
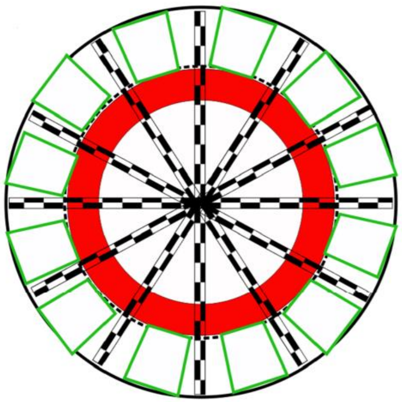
Tritium breeding blanket

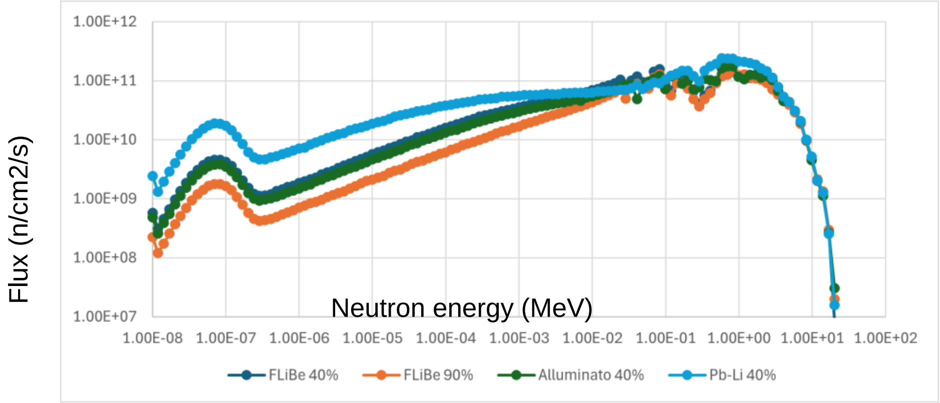
- K_{eff} =0.97; P_{core}=42 MW; P_{box} = 10 MW
- Tritium breeding zone dimensions = 197*110*15 cm^3
- FLiBe mass (^6Li enrichment: 40%) = 645 kg
- Estimated tritium production for the entire machine (12 modules) = 5.56 mg/s (TBR = 29)
- No tritium extraction efficiency has been considered (the presented results take only into account the tritium production process). An optimistic efficiency evaluation can be considered about 50%.
- **A similar FFHS can in principle produce the fuel (ε=50%) for a 1/1.5-GW pure fusion device**







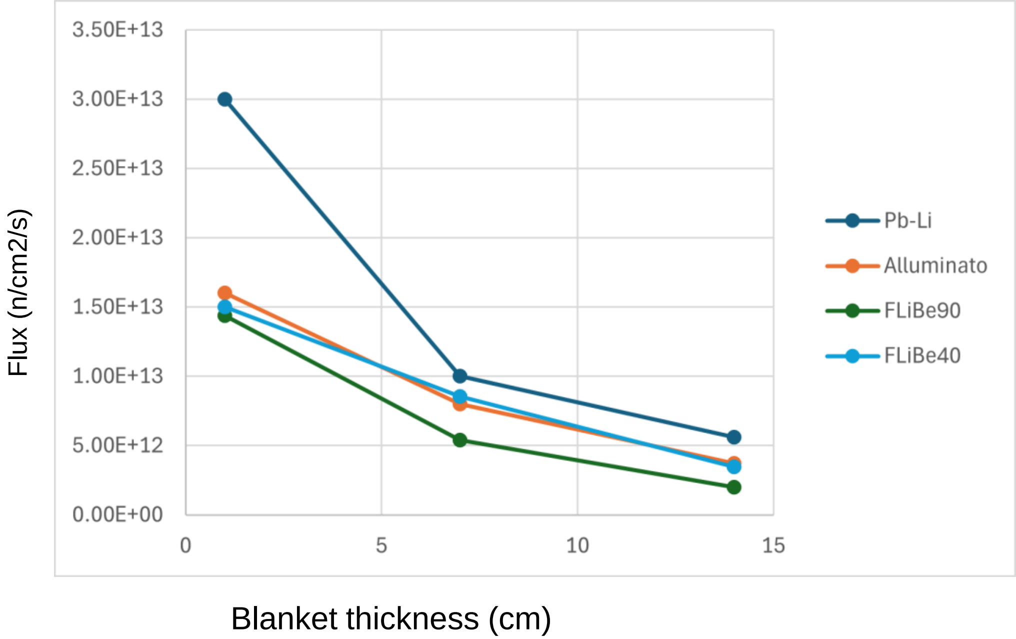
Alternative brreding materials



Materiale	TBR
FLiBe (40% Li-6)	29
FLiBe (90% Li-6)	65
Alluminate (40% Li-6)	**27**
Pb-Li (40% Li-6)	6.22

- **FLiBe, Pb-Li** can be useful for a pure fusion blanket (Be and Pb can be used as neutrons moultiplicators)
- **Be** caould be avoided for its toxicity
- For **thermal neutrons** the presence of a multipicator is not necessary and can give the possibility to have a higher Li concentration inside the blanket
- A **solid blanket** (alluminate or silicate) seems to be a good choice also for the extraction method (helium or water)
- A **low Li-6 enrichment** (or natural concentration) are suggested

Neutron penetration inside breeding blanket



A good thickness choice can bring as uniform as possible the neutron flux intensity inside the blanket

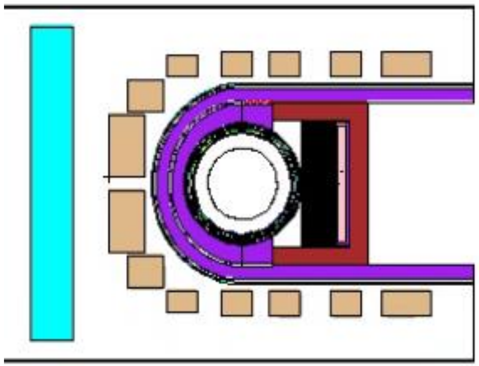
Superconductor magnets shielding

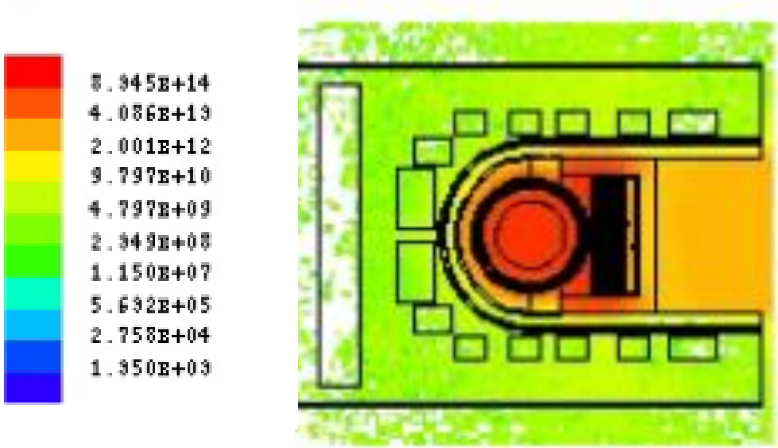
Limits to be respected for superconductors:

- Fast neutron flux (E>0.1 MeV) on the magnet = 10^11 n/cm^2s
- Neutron fluence (E>0.1 MeV) on the magnet = 10^19 n/cm^2
- Total heating for each TFC = 14 kW

Shielding design:
Mixed graphite+tungsten in layers (20 cm g + 5 cm t + 20 cm g + 5 cm t) + steel structure. Graphite slows down neutrons, Tungsten plays the roles of photon screen and neutron absorber

Power and neutron flux limits are respected





Conclusions

- A conceptual design of a RFP-based hybrid reactor for triutium breeding has been presented
- The neutronic design consists of a 2-neutron-spectrum zones: a fast core and a thermal zone for tritium breeding purposes
- The tritium breeding analysis estimates a tritium net production of 5.5 mg/s for this configuration (12 blankets)
- Results show that flux and power requirements for superconductors are respected

Future activities:

- Machine engineering
- Termomechanics analysis (in particular for the breeding blanket)
- Biological shielding