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

Report sulla conferenza FEC 2023 (reattori ibridi)

Frascati – 06/11/2023

F. Panza/ F: P. Orsitto

IAEA FEC 2023 London Notes

In the opening session few important remarks were given

- ITER is planning a new baselining activity including tungsten wall and ECRH heating installation . ITER-Timeline is not known at the moment: it will be officially known in june 2024 . A guess of the start of the active phase is yr2040.

- .The activity on the realization of fusion reactor is now carried out also by private (or mixed public/private) companies with the aim of realizing PILOT power plants. The realization of the fusion DEMO(s) implies a strong involvement of Fusion Industries in R&D and engineering of subsystems .

- The target ignition in the context of inertial confinement NIF (LLNL-USA) experiment is now conceived as a basis for an extensive programme aimed at the optimization of efficiency of laser driver , in the improvement of direct drive concept .

TRITIUM PRODUCTION IN A FUSION-FISSION HYBRID REACTOR BASED ON A SPHERICAL TOKAMAK NEUTRON SOURCE

F.P. ORSITTO, N. BURGIO, M CIOTTI,F. PANZA, A SANTAGATA (ENEA)

MOTIVATIONS

1. The Fusion reactor concept implies self-sufficiency in terms of the tritium production. On the other side the tritium inventory available on earth (about 20Kg see Kovari NF 2018) will be consumed by ITER operation (and CFETR).
2. So it is important-, for the development of fusion technology, to build systems for increasing tritium production.
3. In this paper, a fusion-fission hybrid reactor (FFHR) model-devoted mainly to tritium production is presented.

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Summary of the IAEA paper

The paper presents a complete conceptual design of a FFHR (Fusion-Fission hybrid reactorfor the Tritium producion

The paper has three sections

A.Project of the ST neutron source based on the non-thermal /Hot ion scenario

B.The calibration on experimental data of the neutronics codes for the evaluation of the tritium production

C. Evaluation of tritium production using a fusion-fission blanket designed for the Tritium porduction.

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Spherical Tokamak neutron source parameter design

This part is based on a new confinement scalng law for the hot ion mode derived from Supershot TFTR database, and from the L-mode confinement scaling .

- The scaling law is the following :

$$\tau_{TFTR} \propto Ip^{0.22}\, Bt\ Wbeam^{-0.56}\, R^{1.83}\ A^{0.06}\ k^{0.64} \left(\frac{n}{\langle n \rangle} \right)^{1.5} n^{0.4}$$

The hot ion mode (studied intensively at TFTR and JET DTE1 and DTE2
is chosen because it is considered ideal for a low Q device because it maximizes the
Neutron production and low values of tHe product n τE

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SCALING LAW FOR SPHERICAL TOKAMAK FUSION REACTORS IN SUPERSHOT-LIKE SCENARIO

We start with the working conditions useful for defining the plasma state of a fusion reactor:

i) the reactor is working at a value of Q_0=ni τE Ti , where ni is the ion density, Ti the ion temperature and τE is the energy confinement time given by the eq.1;

ii) the alpha particle slowing down time (τSD) must be less than the energy confinement time : i.e. τSD = ΛSD τE, where ΛSD>>1 is a number.

$$R \propto n^{-0.76} Bt^{-0.54} f_E^{-0.54} Q_0^{0.33} \left(\frac{\Lambda SD}{ASD} \right)^{-0.22}$$

$$\text{where } f_E^{-0.54} = Ip^{-0.12} W_B^{0.3} A^{-0.03} k^{-0.35} \left(\frac{n}{\langle n \rangle} \right)^{-0.82}$$

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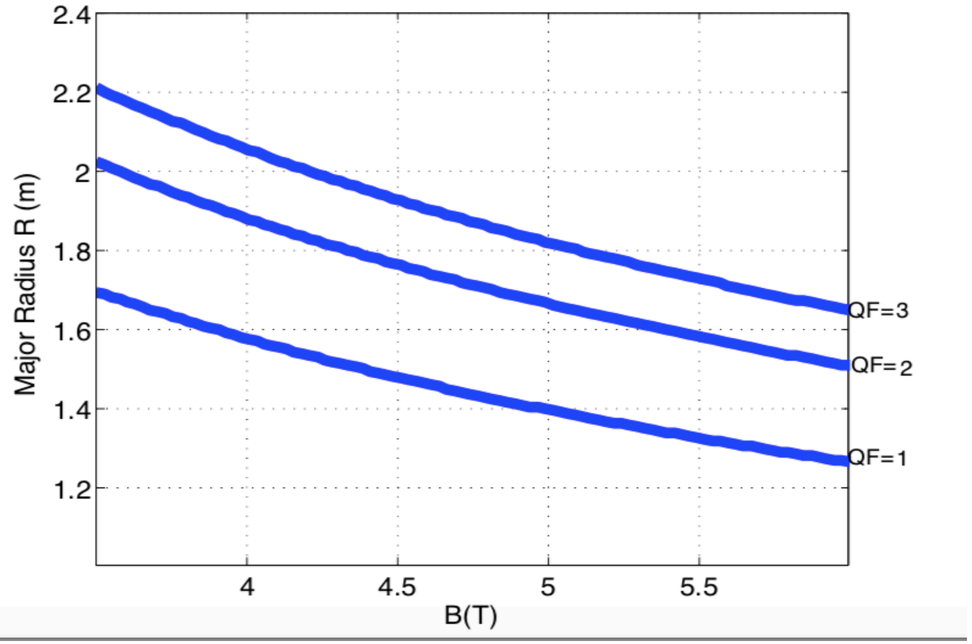
Design of the ST neutron source: ST180



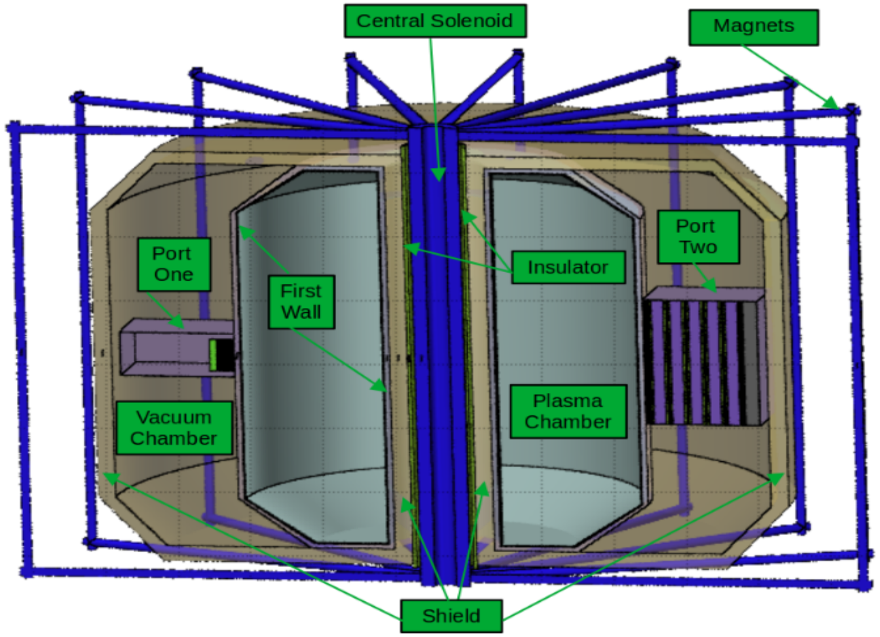


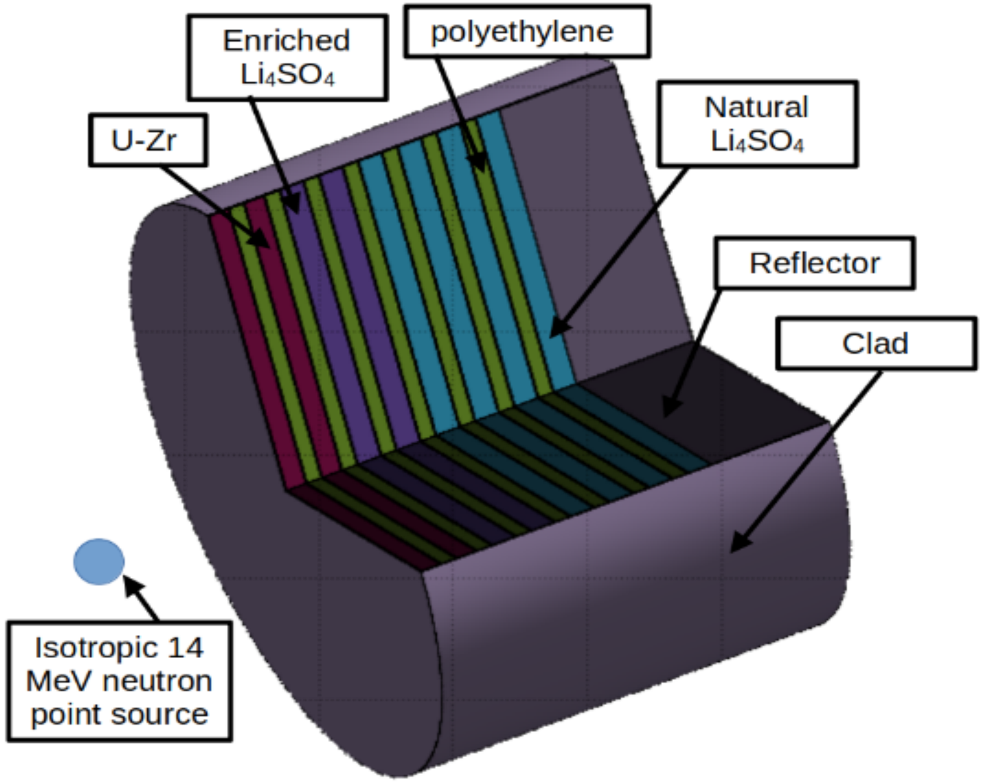
Fig.1 Major radius R vs magnetic field B at Q_F=1,2,3,
For a Fusion reactor Ip=6MA, A=1.8, k=2.9, n/<n>=3.5

From the fig.1 the following plasma parameters for a Q_{Fus}=2 spherical tokamak, named ST180, can be derived:
R=1.8m, A=1.8 , Ip=6MA, B=4.3T, n=8 10^{19}m-3 , (n/<n>)=3.5, elongation k=2.9, beam energy W_B=40keV.

MCNP AND FLUKA MC codes VALIDATION OF THE CFETR TRITIUM PRODUCTION

The validation is done using the experimentally measured fission rate and production of tritium in a test blanket

- The measurements are in Jimin Ma et al. “Neutronic experiment and analyses of a hybrid tritium breeding blanket mockup for CFETR”, Annals of Nuclear Energy 161 (2021) 108431.



Experimental validation of MC Codes : Results

MCNP and FLUKA evaluation of fission rate in the fission two layers

	Fissions in Fuel 1[atom^{-1} n^{-1}]	Fission in Fuel 2 [atom^{-1} n^{-1}]
FLUKA estimate	2.22E-28	1.68E-28
MCNP estimate of	1.93E-28	1.47E-28
*Mean Experimental fission rate	2.57E-28	1.53E-28

IN general regarding the tritium production , Both MCNP and FLUKA show that the fissionable fuel increases the tritium production of a factor ranging from 3.9 to 1.3 in the three first layers.

The agreement within one order of magnitude between simulations and experimental data encourages us to proceed further in the simulations.

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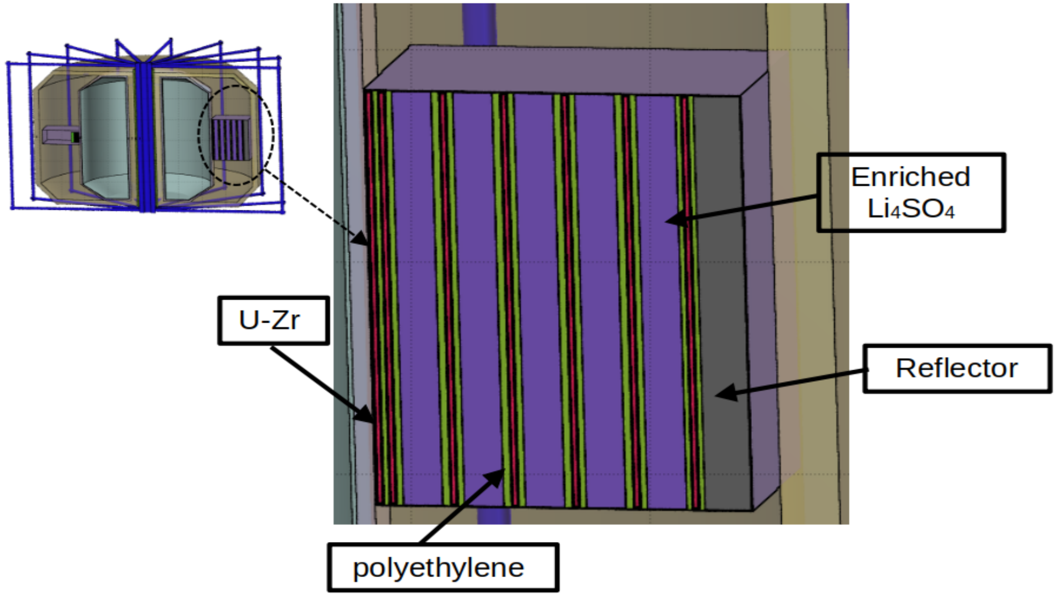
THE TRITIUM PRODUCTION IN THE ST180 PORT



five breeding regions containing ^{6}Li-enriched Li4SO4 with 7 Fuel boxes (U-Zr, 16 at% in 235U).

The annual net tritium production(Tp) is Tp=5.4 g/y, for isotropic neutron emission But taking into account that the neutron emission spatial distribution is peaked in the equatorial Plane the annual porduction could be estimated in Tp=23 g/y .

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DEVELOPMENT OF BASIC THERMONUCLEAR TECHNOLOGIES OF THE FUSION-FISSION HYBRID FACILITY FOR TESTING MATERIALS AND COMPONENT

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- State Research Program of Russia in the field of nuclear energy
- Is devoted to the realization of two devices :

- i) a Fusion Hybrid Facility(FHF) fusion power 40MW , consists in Tokamak with superconducting magnets R0=3.2m A=3.2 , B/Ip=5T/5MA, Qfus=20 Pfus=700MW

- Ii) a low power spherical tokamak FNS-C R0=0.5 , A=1.67 , Pfus=3MW, Qfus=0.5

FNS-C – Plasma Scenario is beam-plasma hot ion mode: NBI 10MW deuterium Beam Eb=100keV

General view of FNS-C facility is presented in Fig.1

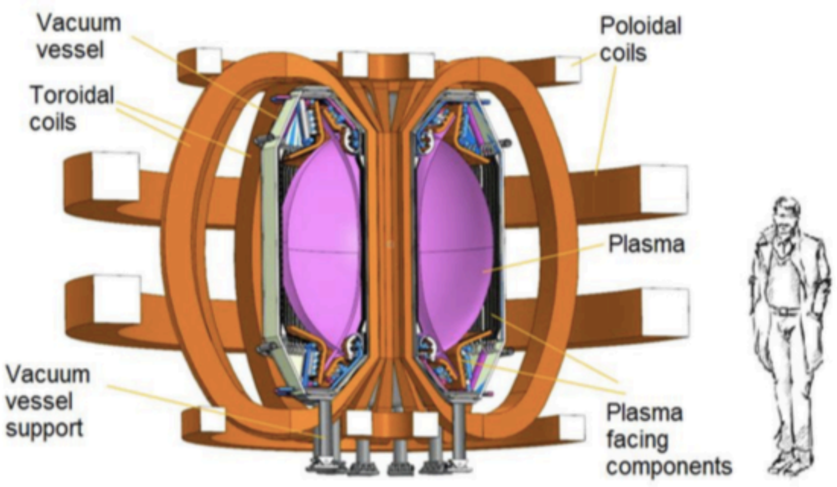

FIG. 1. FNS-C cut-view.

- the main purpose of the installation is to obtain of a significant number of thermonuclear neutrons (~1018 n/s) with an energy of 14 MeV for experimental testing of various aspects of nuclear technologies of controlled thermonuclear fusion;
- — the thermonuclear power of the facility is 3 MW when using 7.5 MW of additional plasma heating power;
- — the average neutron load on the walls is 0.2 MW/m2.

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FNS-C plasma wall and divertor design

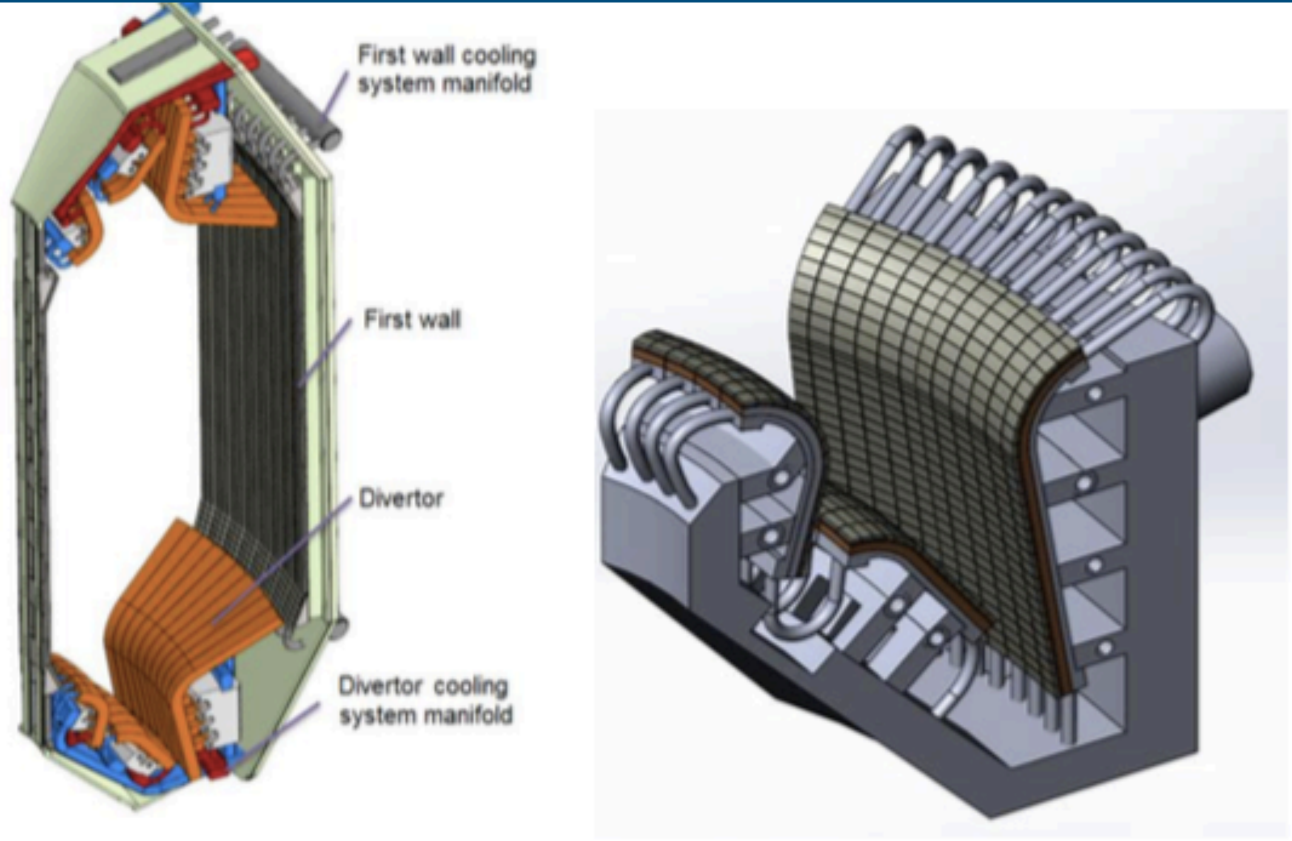
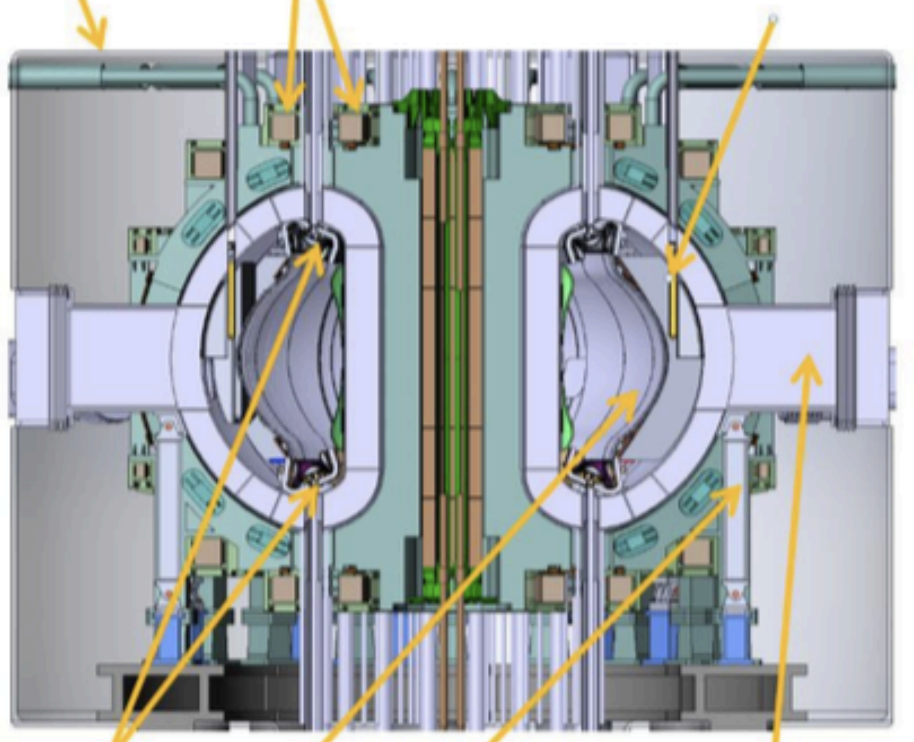


FIG. 2. FNS-C vacuum vessel segment with first wall and divertor.

- First wall material not clear , tungsten is likely to be chosen .

FHF nuclear Hybrid Facility (yr2045)

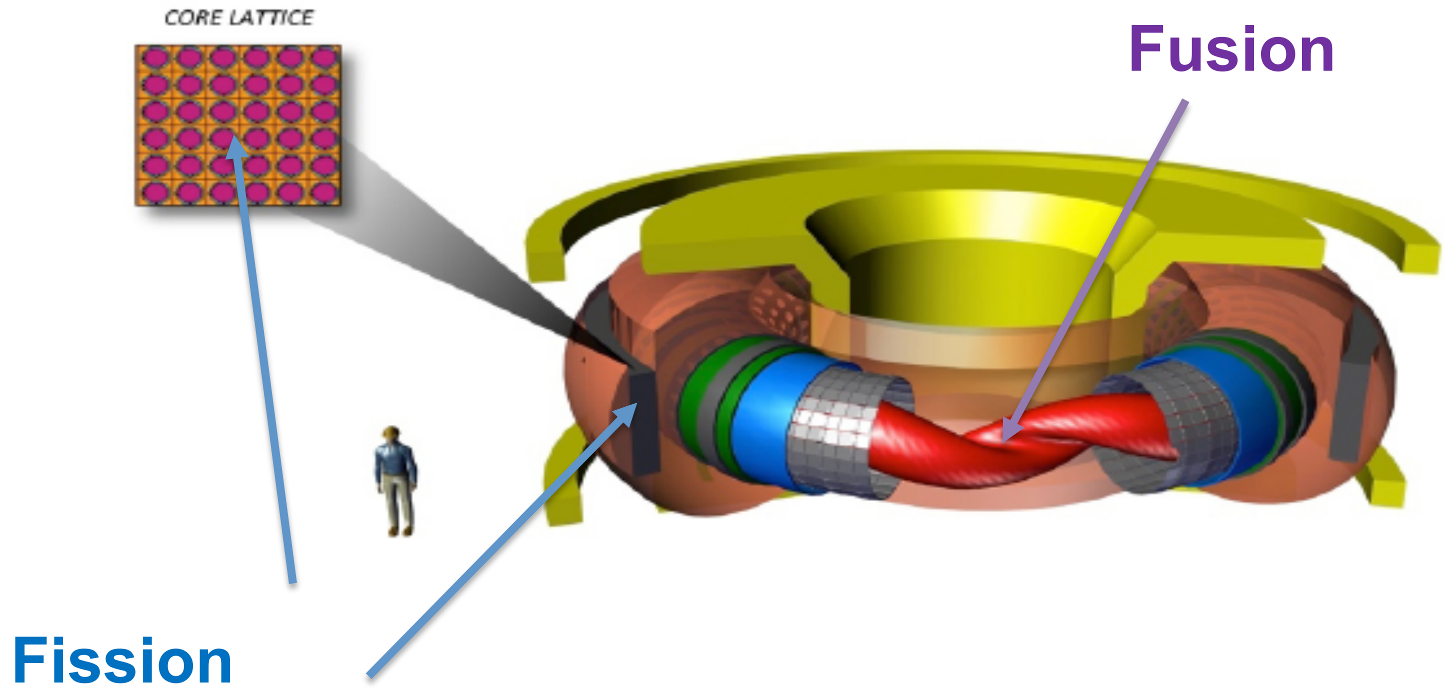


Major radius,	m	3.2
Minor radius,	m	1.0
Toroidal field,	T	5.0
Plasma current,	MA	5
NBI power,	MW	30
ECRH power,	MW	6
Electron/ion temperature,	keV	11.5/10.7
β_N		2.1
β_p		0.96
Neutron yield	n/s	$>10^{19}$
Consumed/generated Electric power,	MW	up to 200
Thermal power	MW	up to 700
Discharge time,	h	up to 5000
Duty factor		0.3
Life time, years		30

Fig.5 Hybrid facility cut section and design parameters

FFHR concept

Fusion-fission hybrid system represents the coupling between a fusion reactor, mainly acting as a neutron source (and not as a primary power source), and a sub-critical fission reactor with different purposes (energy production, waste transmutation, tritium breeding etc..



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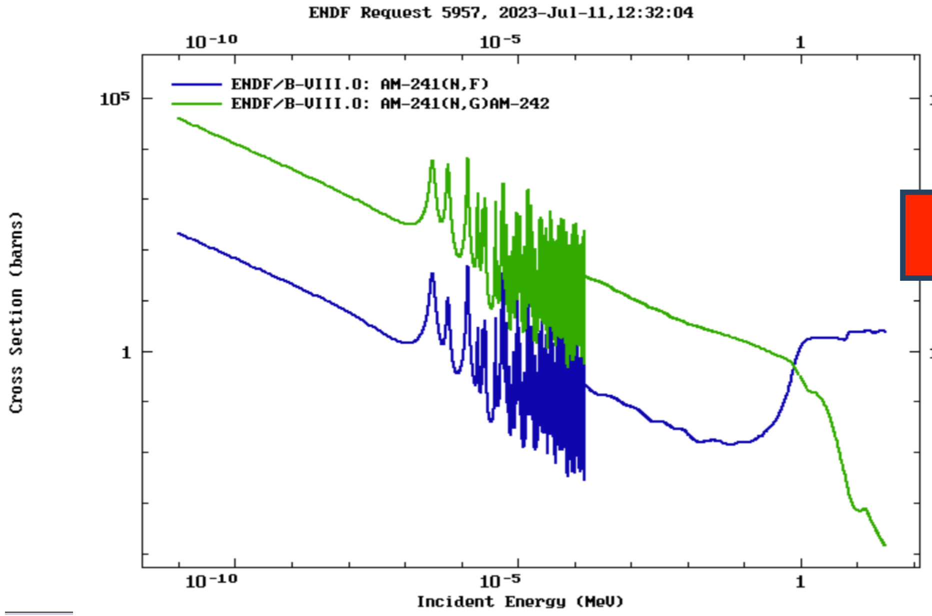
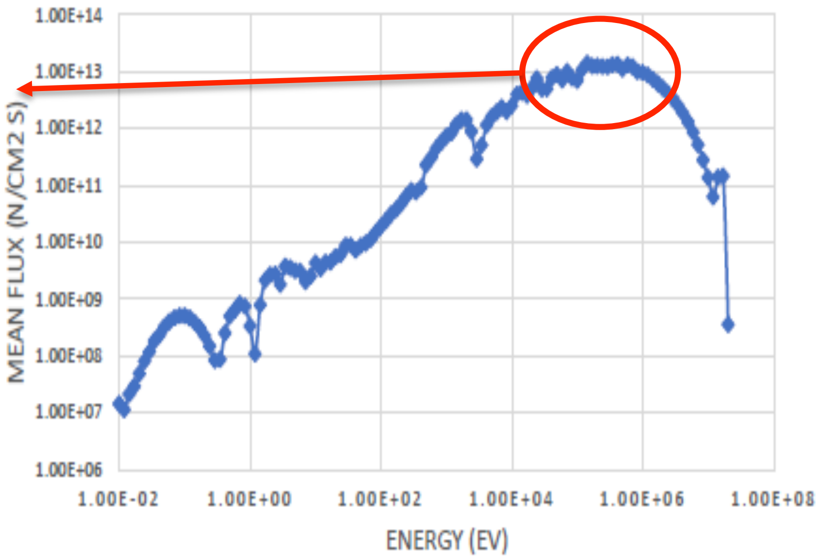
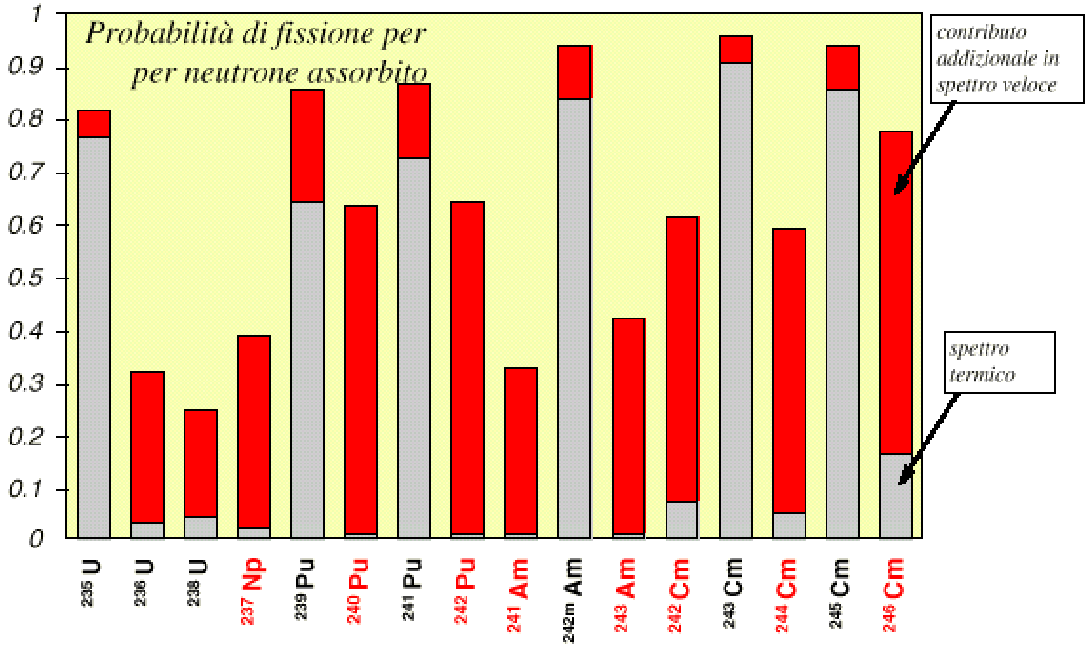
Nuclear waste transmutation



Fission vs capture ratio is greater than 1 for En>1MeV

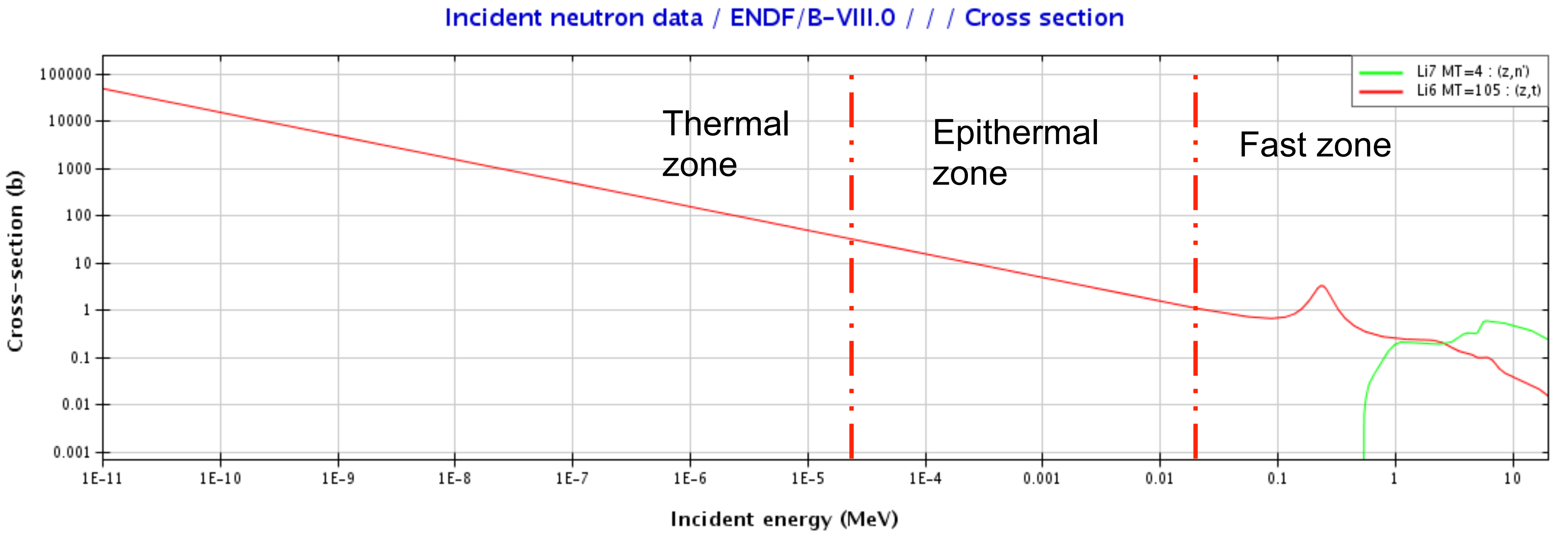
Mean neutron flux obtained in designed FFHR

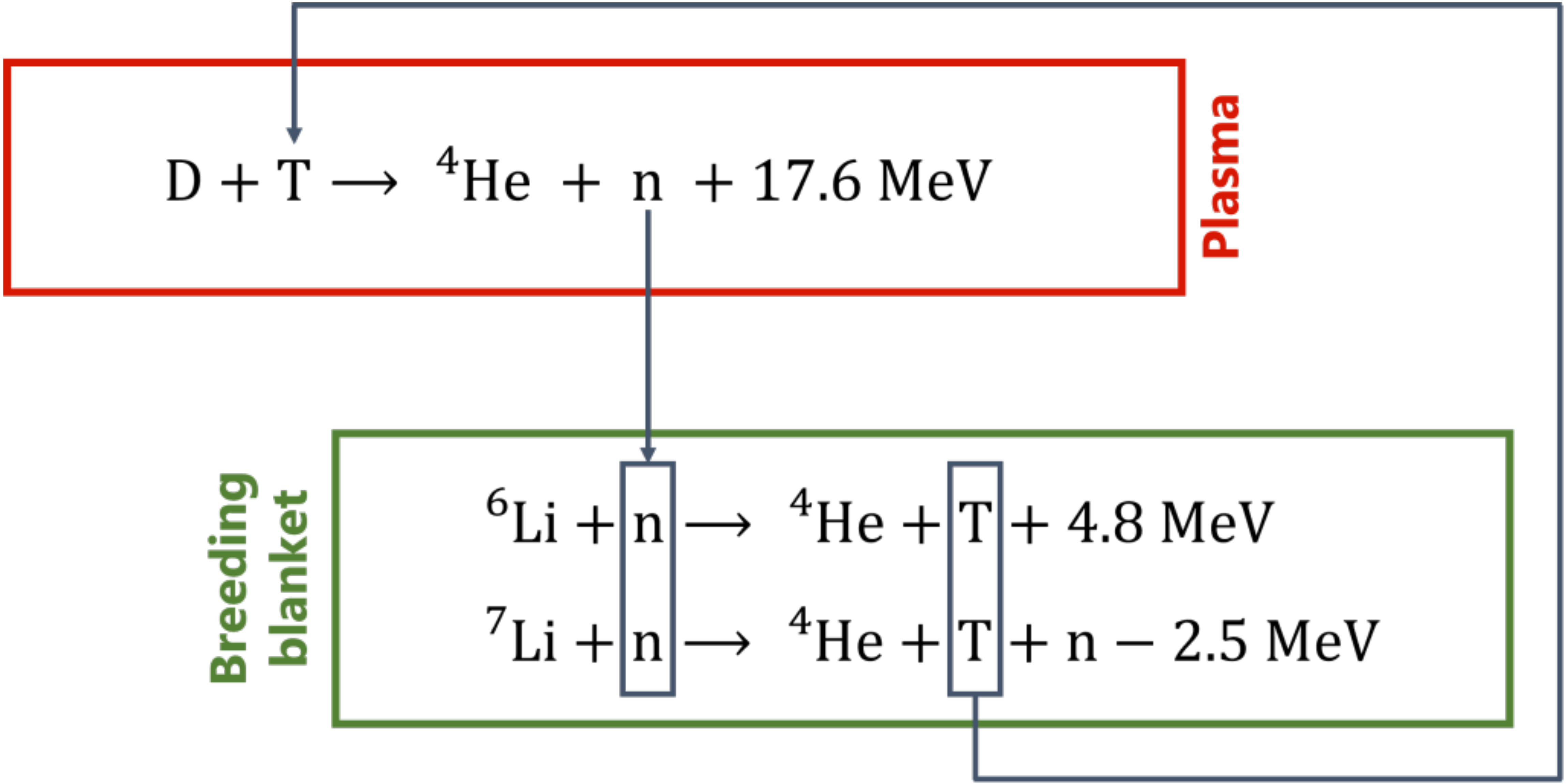




Tritium breeding

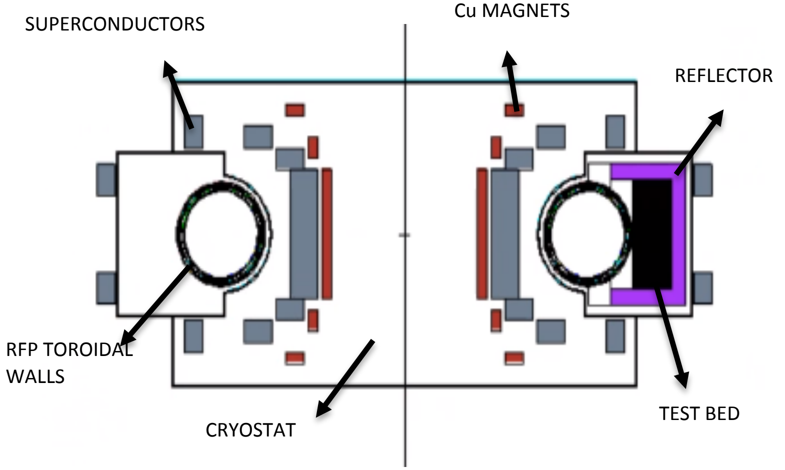
Li(n,T)α cross section is far higher (up to 3 order of magnitude) for thermal neutrons

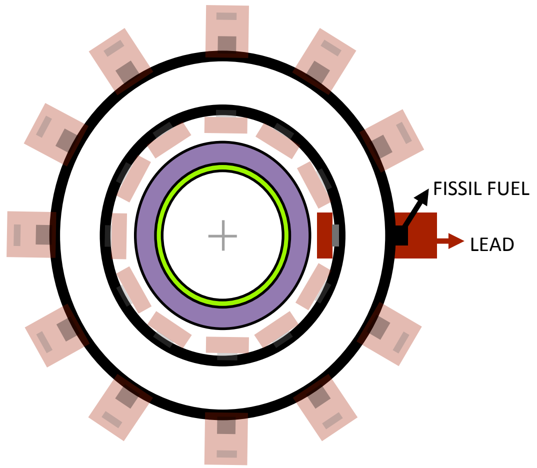



D + T ⟶ ⁴He + n + 17.6 MeV
Plasma
Breeding blanket
⁶Li + n ⟶ ⁴He + T + 4.8 MeV
⁷Li + n ⟶ ⁴He + T + n – 2.5 MeV

RFP-SSR Hybrid Reactor Model For Actinides Transmutation And Tritium Breeding Studies

S. Murgo, C. Bustreo, M. Ciotti, G. Lomonaco, F. Panza, R. Piovan, N. Pompeo, G. Ricco, M. Ripani





RFP parameters

Major plasma radius [m]	4
Minor plasma radius [m]	0.8
Max plasma current [MA]	12
Input ohmic power [MW]	60
Fusion power [MW]	55
Neutron Yield [$10^{19} s^{-1}$]	1.89
Continuous duty cycle [s]	11 ON/19 OFF

INFN Istituto Nazionale di Fisica Nucleare
CONSORZIO RFX Ricerca Formazione Innovazione
CETMA
ROMA TRE UNIVERSITÀ DEGLI STUDI
UNIVERSITÀ DEGLI STUDI DI GENOVA
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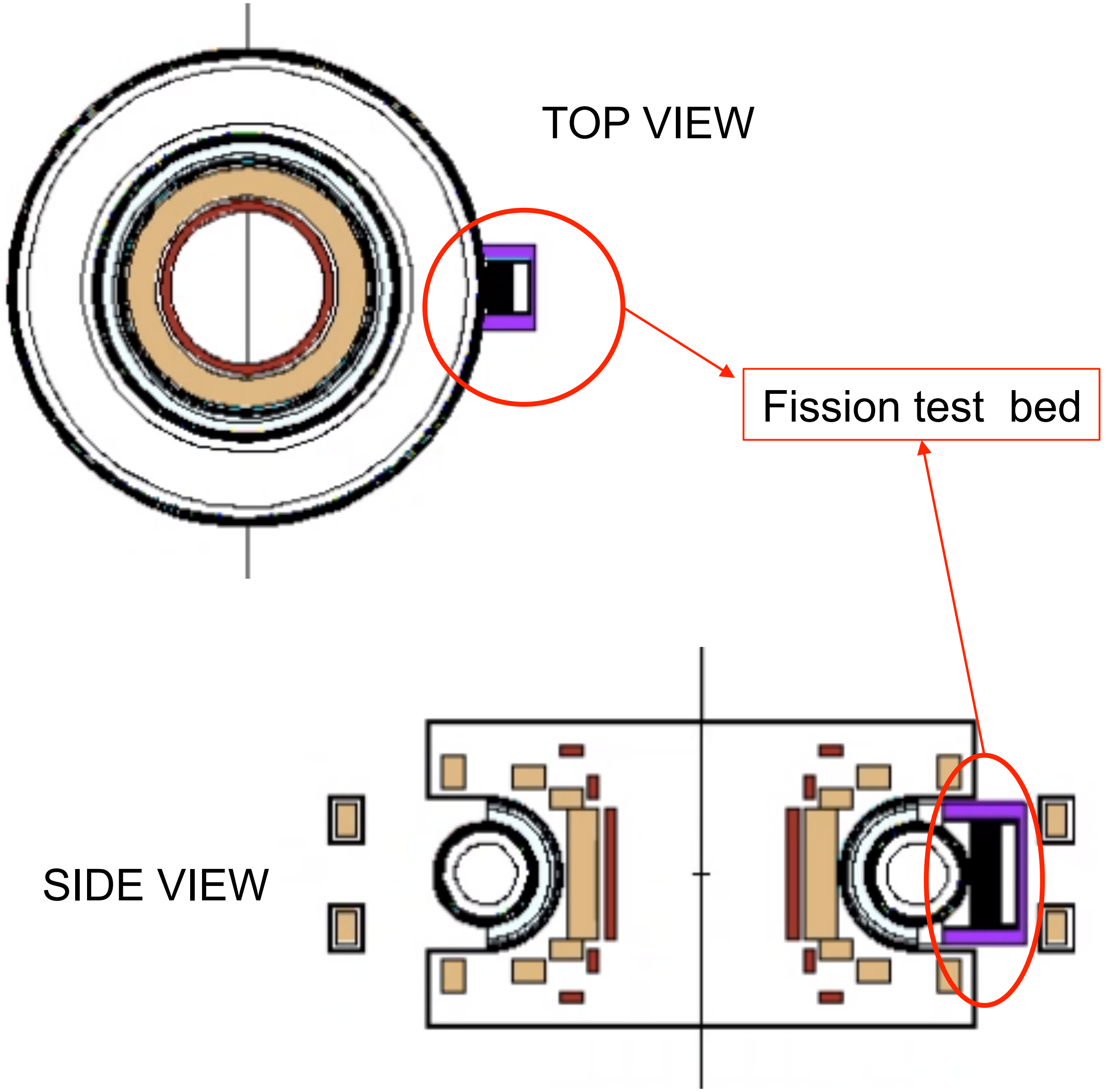

R [m]	4
r [m]	0.8
L_{core} [m]	1.10
S_{core} [m]	0.45
H_{core} [m]	1.97
S_{rif} (laterale) [m]	0.3
S_{rif} (retro) [m]	0.1

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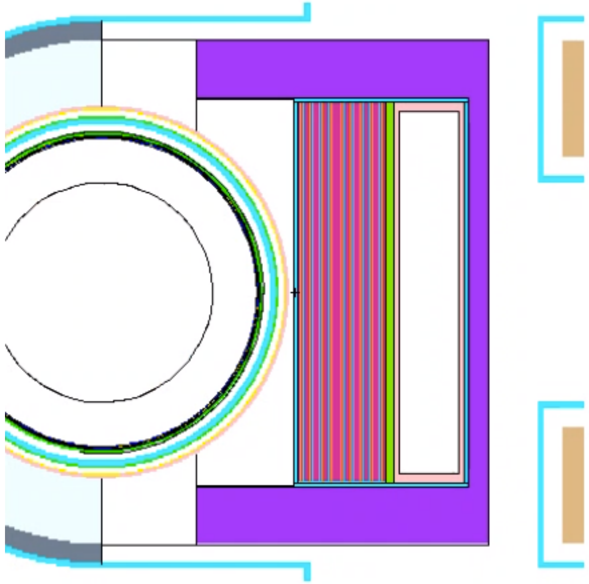
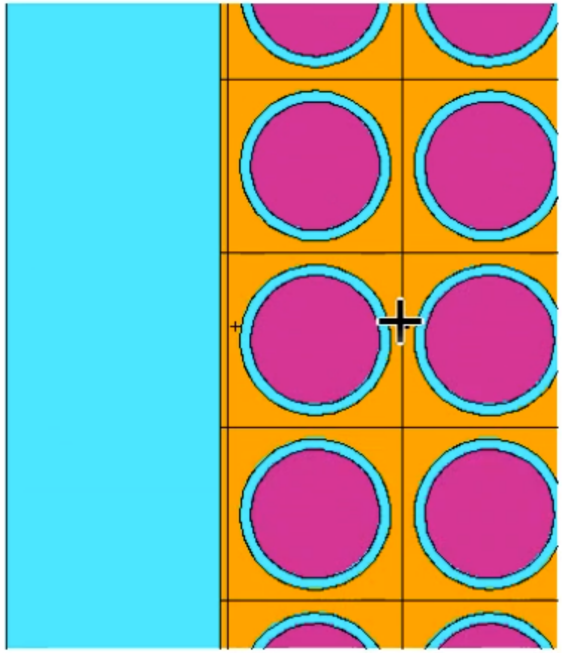
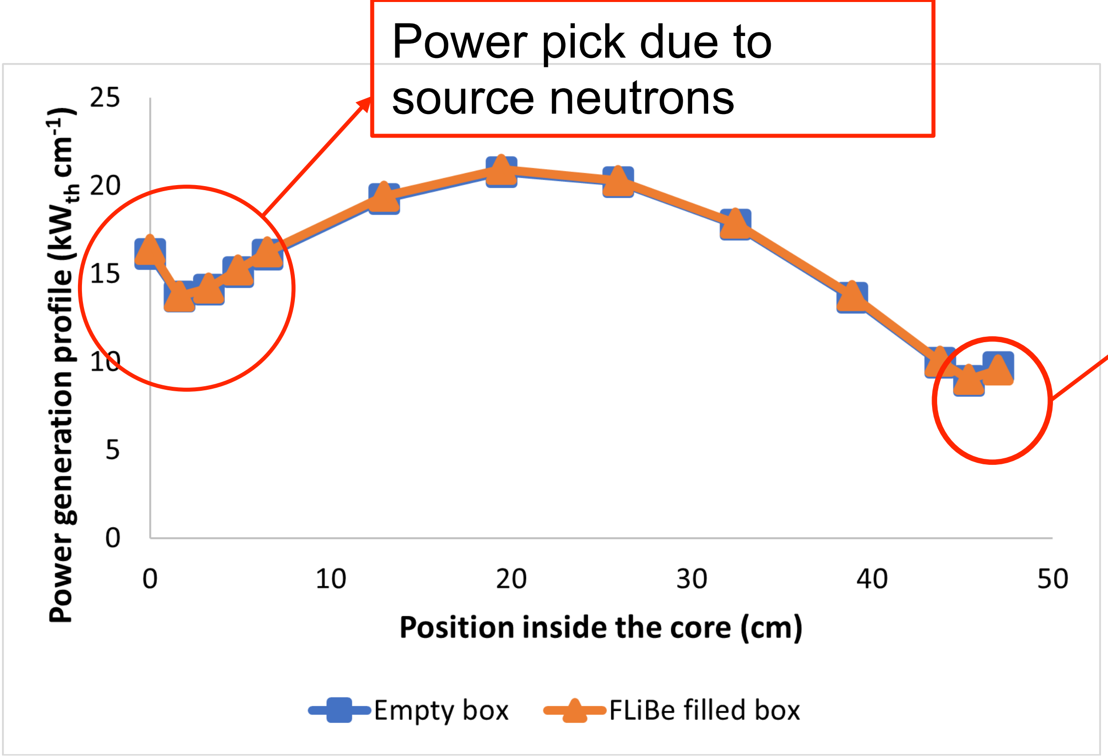
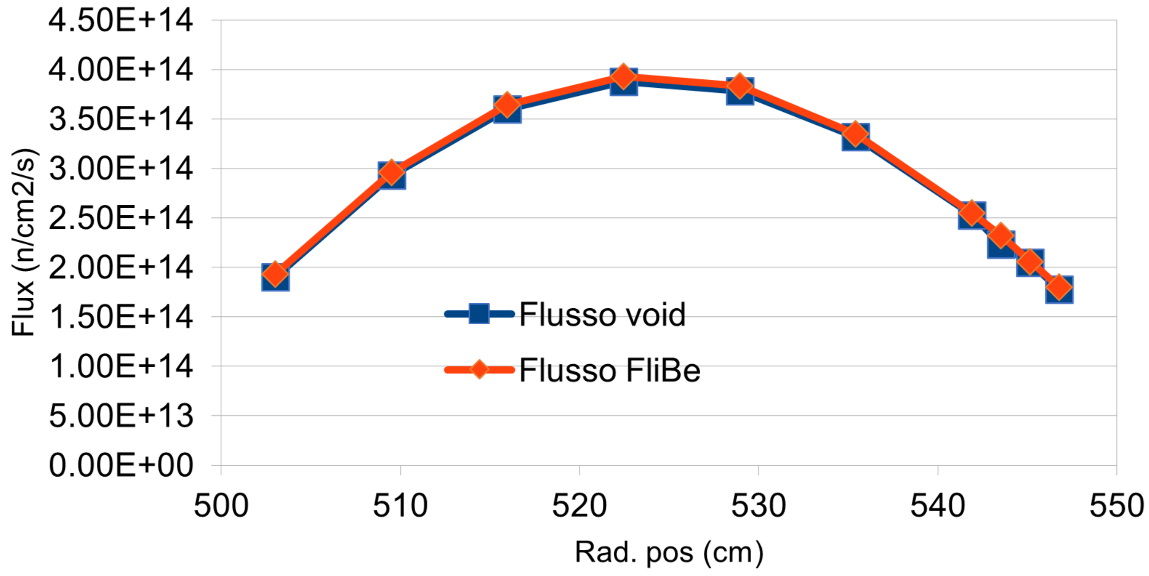
R_{in} [cm]	0.6
R_{out} [cm]	0.7
d [cm]	1.62
Fuel	MOX (22% Pu)
Refrigerante	NaF – ZrF4
Sale Box	FLiBe (40% Li6)
Sorgente [n/s]	1.9e+19
qmax [kW/l]	≈105
P [MW]	≈30
k	≈0.97





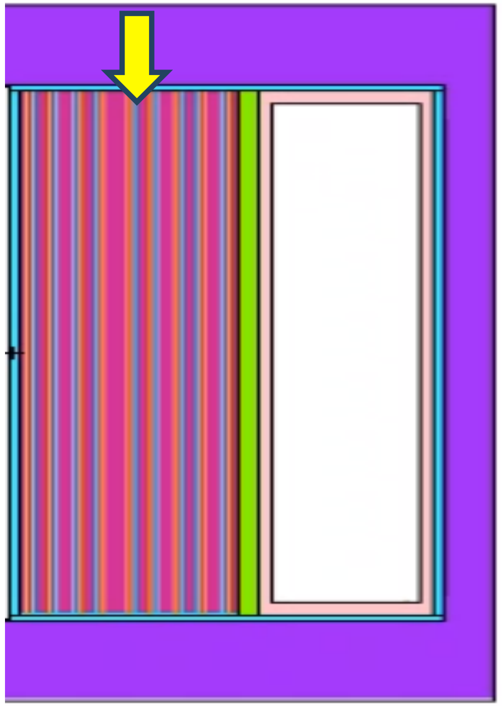


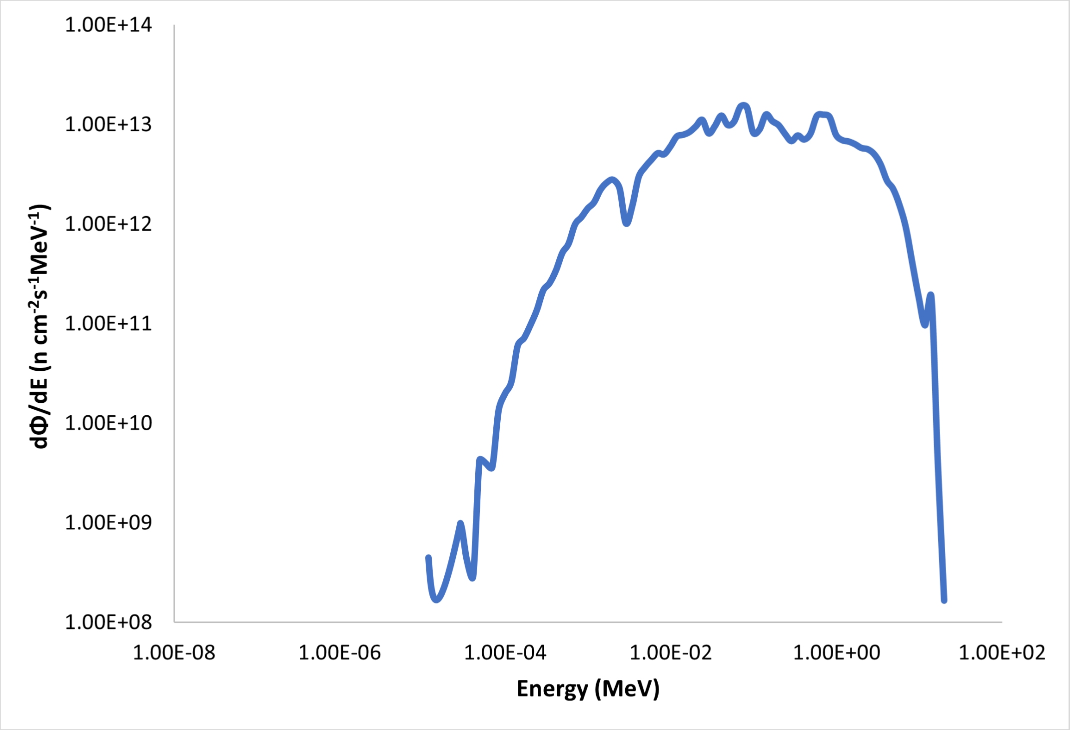
Power pick due to remaining thermal tail in the neutron flux spectrum



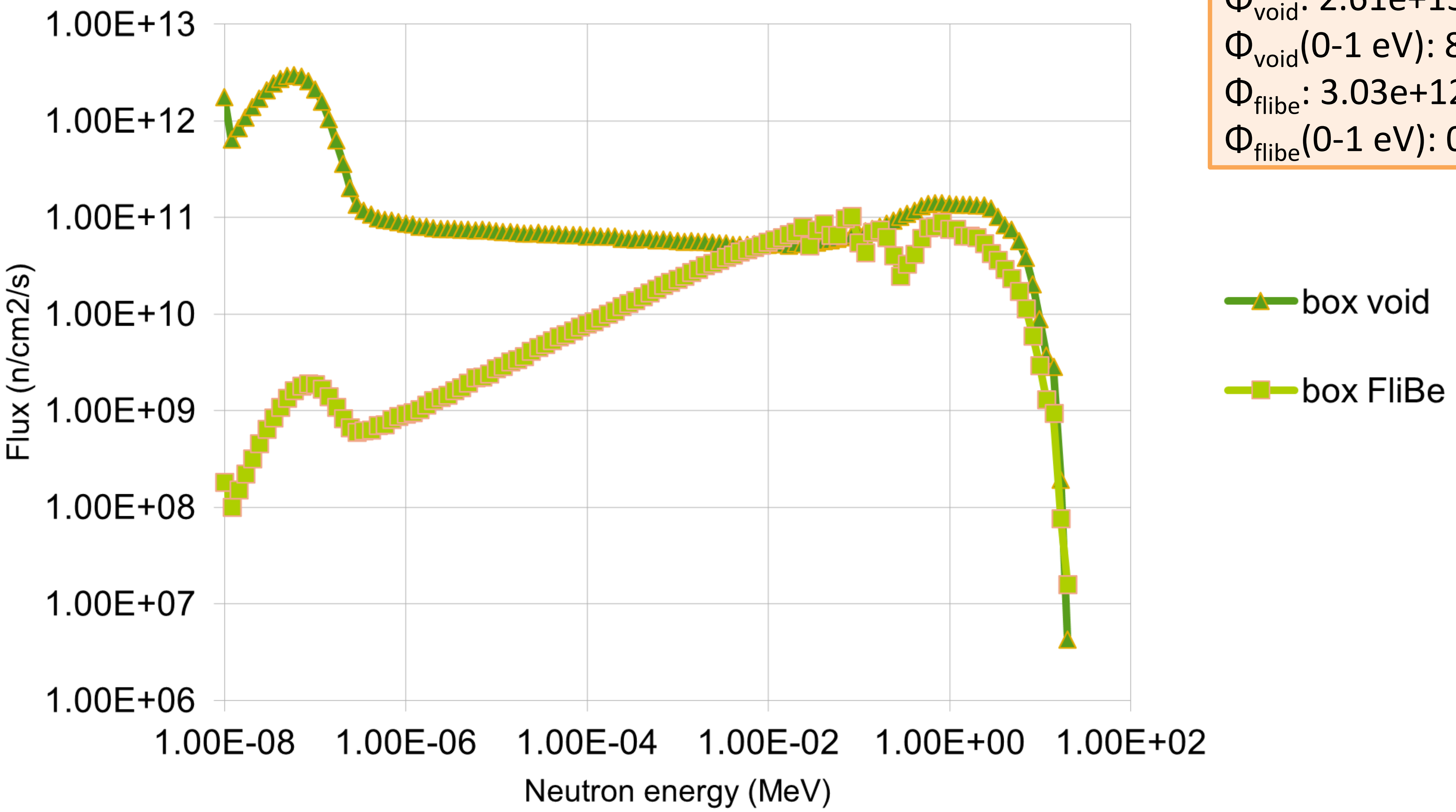
The graphite box is isolated from the core

Neutrons spectra inside the fission core

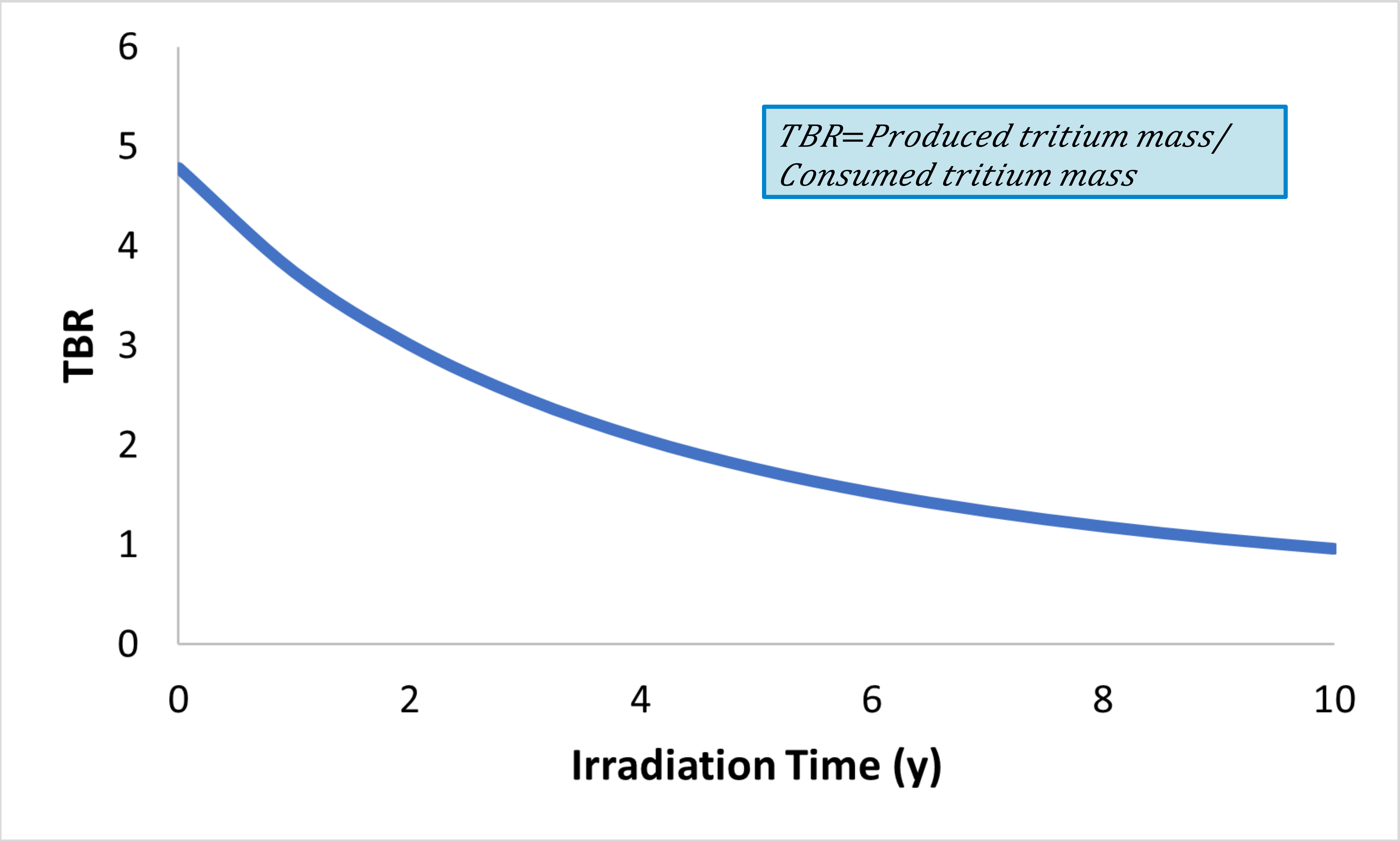




Tritium breeding



Φ_{void}: 2.61e+13 n/cm2s
Φ_{void}(0-1 eV): 83 %
Φ_{flibe}: 3.03e+12 n/cm2s
Φ_{flibe}(0-1 eV): 0.8 %


TBR=Produced tritium mass/
Consumed tritium mass
TBR
6
5
4
3
2
1
0
0
2
4
6
8
10
Irradiation Time (y)

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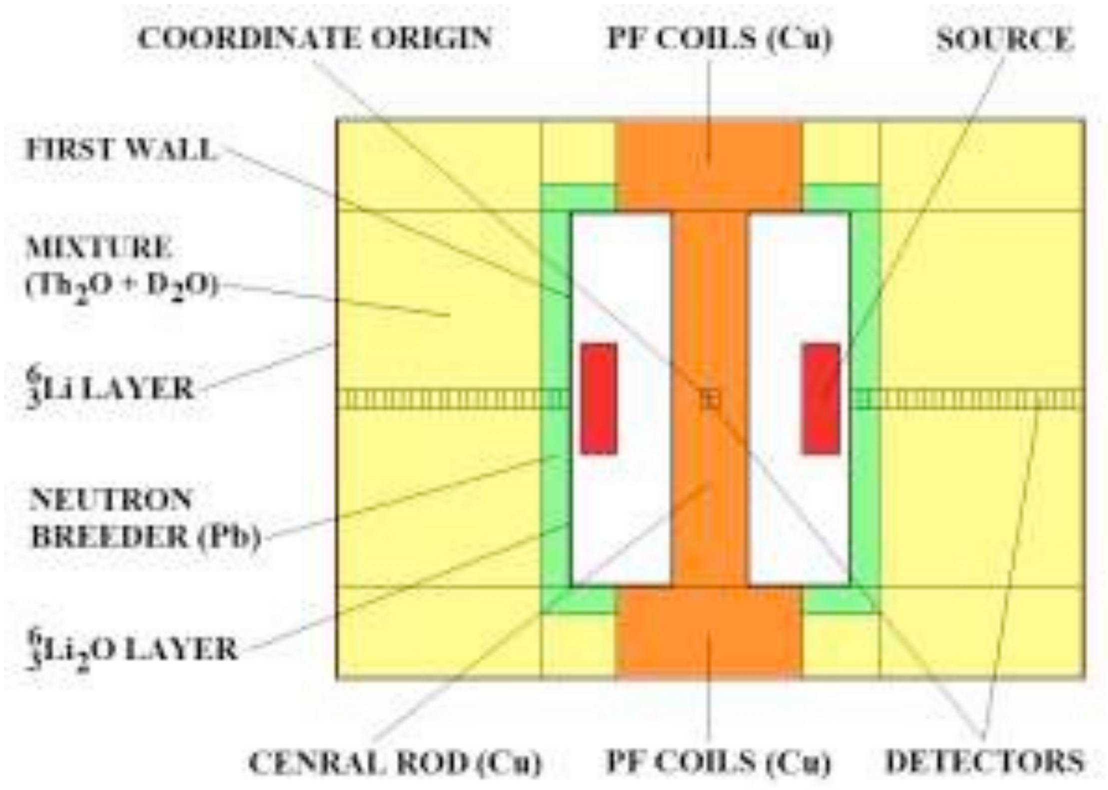
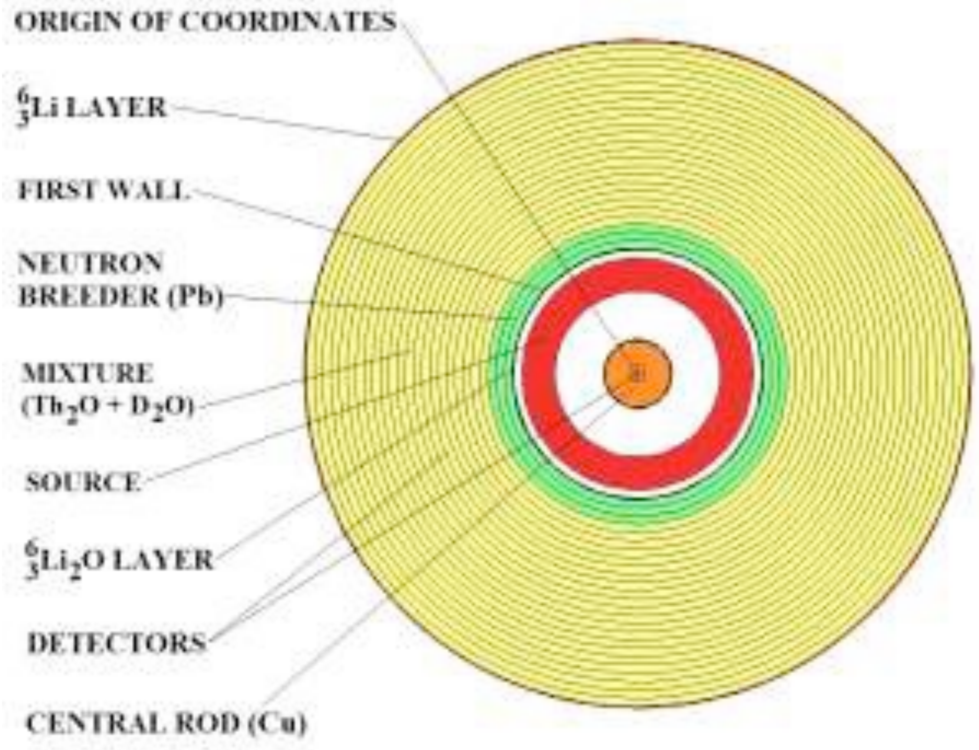
NEUTRON RADIATION DAMAGE IN THE MATERIALS OF A COMPACT HYBRID FUSION NEUTRON SOURCE WITH A HOMOGENEOUS HEAVY-WATER BLANKET (A.V. ZHIRKIN)

A.V. ZHIRKIN, B.V. KUTEEV, A.R. MUKARAMSHOEVA (National Research Center Kurchatov Institute)

FNS-C (tokamak) producing 1.775×1018 n/s. from DT reactons

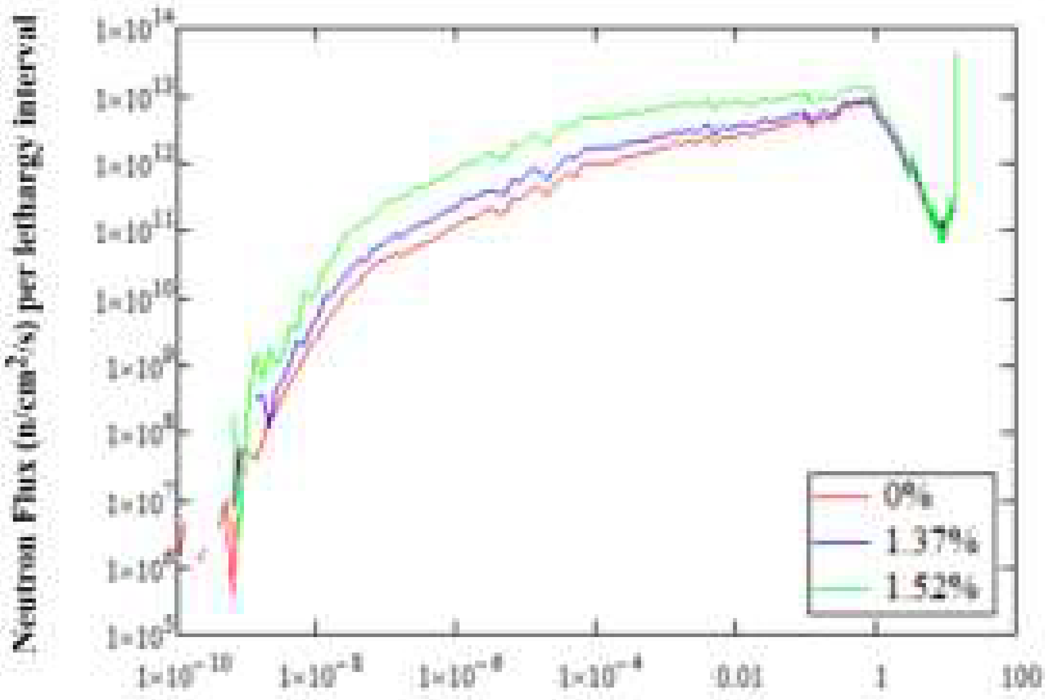


$^{232}ThO_2$+D_2O + ^{233}U



Neutrons spectra

Neutrons spectra on the wall



Neutrons spectra in the blanket

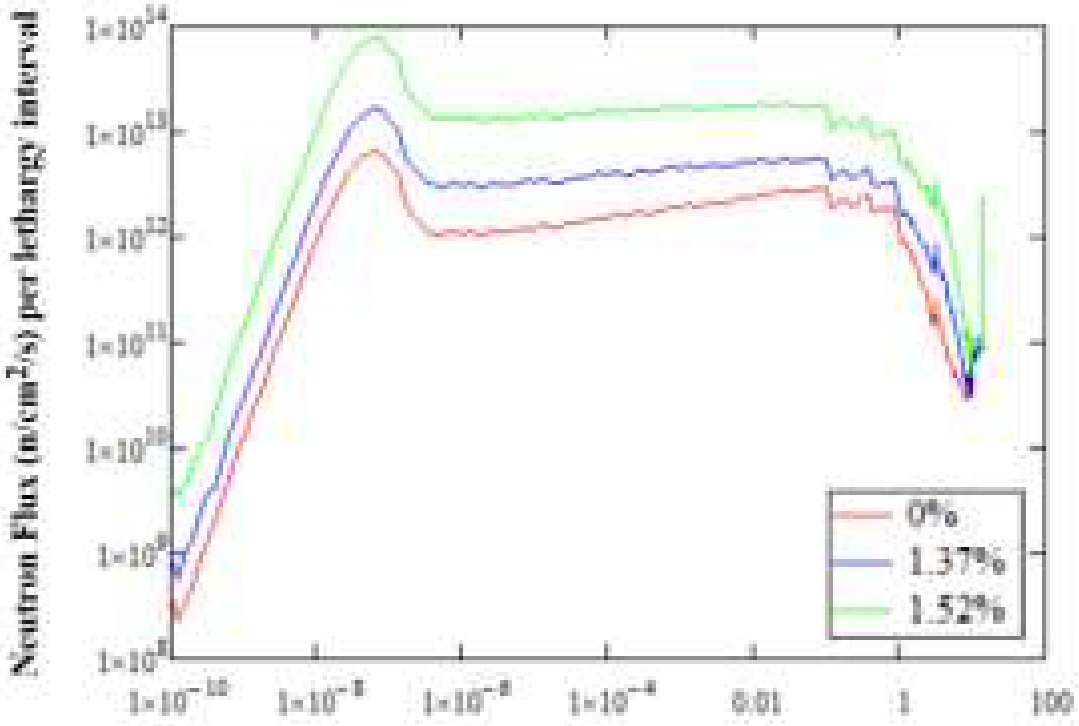


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TABLE 10. CONVERSION COEFFICIENTS

Unit of machine	Neutron flux ($n\ cm^{-2}\ s^{-1}$)	Amount of ^{233}U				
		1.37% nat[a]	1.52% nat	0% iso[b]	1.37% iso	1.5% iso
$^{232}Th + D_2O$	φ_1	1.999×10^{14}	1.999×10^{14}	1.999×10^{14}	1.999×10^{14}	1.999×10^{14}
	φ_2	4.612×10^{14}	1.812×10^{15}	2.087×10^{14}	5.477×10^{14}	2.678×10^{15}
	k	2.31	9.06	1.04	2.74	13.4
First wall	φ_1	2.664×10^{14}	2.664×10^{14}	2.664×10^{14}	2.664×10^{14}	2.664×10^{14}
	φ_2	3.151×10^{14}	5.489×10^{14}	2.678×10^{14}	3.395×10^{14}	6.110×10^{14}
	k	1.18	2.06	1.01	1.27	2.29
^6Li (Li_2O)	φ_1	2.665×10^{14}	2.665×10^{14}	2.665×10^{14}	2.665×10^{14}	2.665×10^{14}
	φ_2	3.190×10^{14}	5.651×10^{14}	2.643×10^{14}	3.372×10^{14}	6.137×10^{14}
	k	1,20	2.12	0.99	1.26	2.30
Pb бланкет	φ_1	2.620×10^{14}	2.620×10^{14}	2.620×10^{14}	2.620×10^{14}	2.620×10^{14}
	φ_2	4.132×10^{14}	1.179×10^{15}	2.673×10^{14}	4.763×10^{14}	1.352×10^{15}
	k	1.58	4.50	1.02	1.82	5.16

[a].Natural materials;

[b] Isotope-enriched materials;

[c].Statistical uncertainty of calculation results.