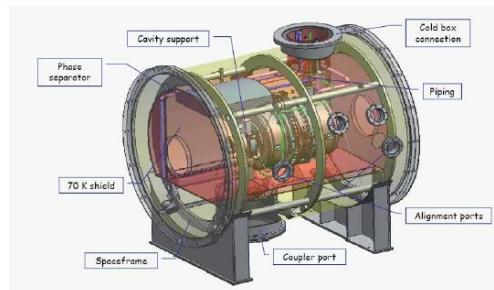
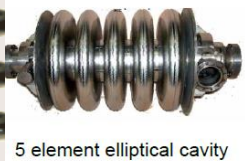
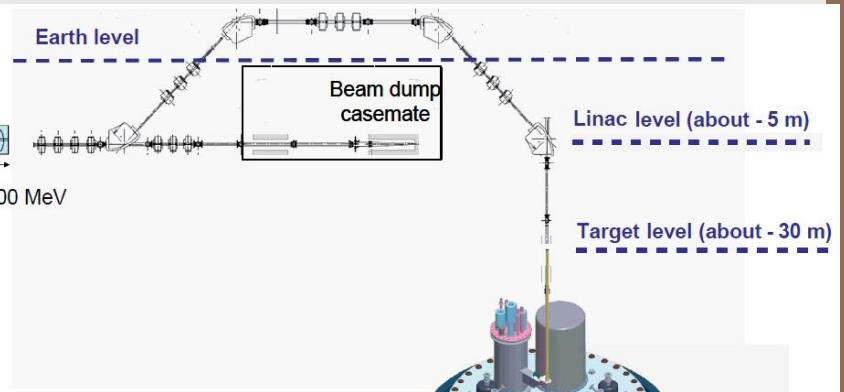
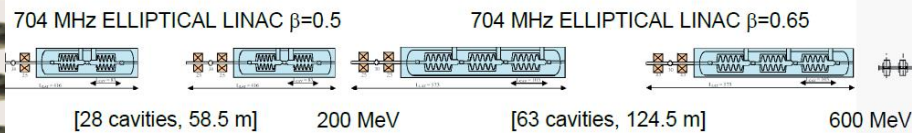


*Transmutacja jądrowa aktynowców w gazowych reaktorach, współpracujących ze spalacyjnym źródłem neutronów.*

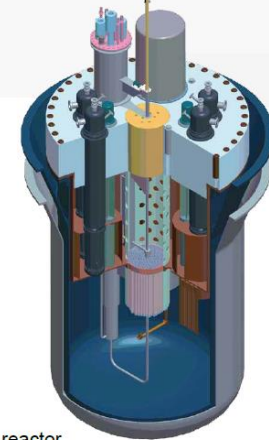
*Aleksander Polański*

*Narodowe Centrum Badań Jądrowych, TJ1.*

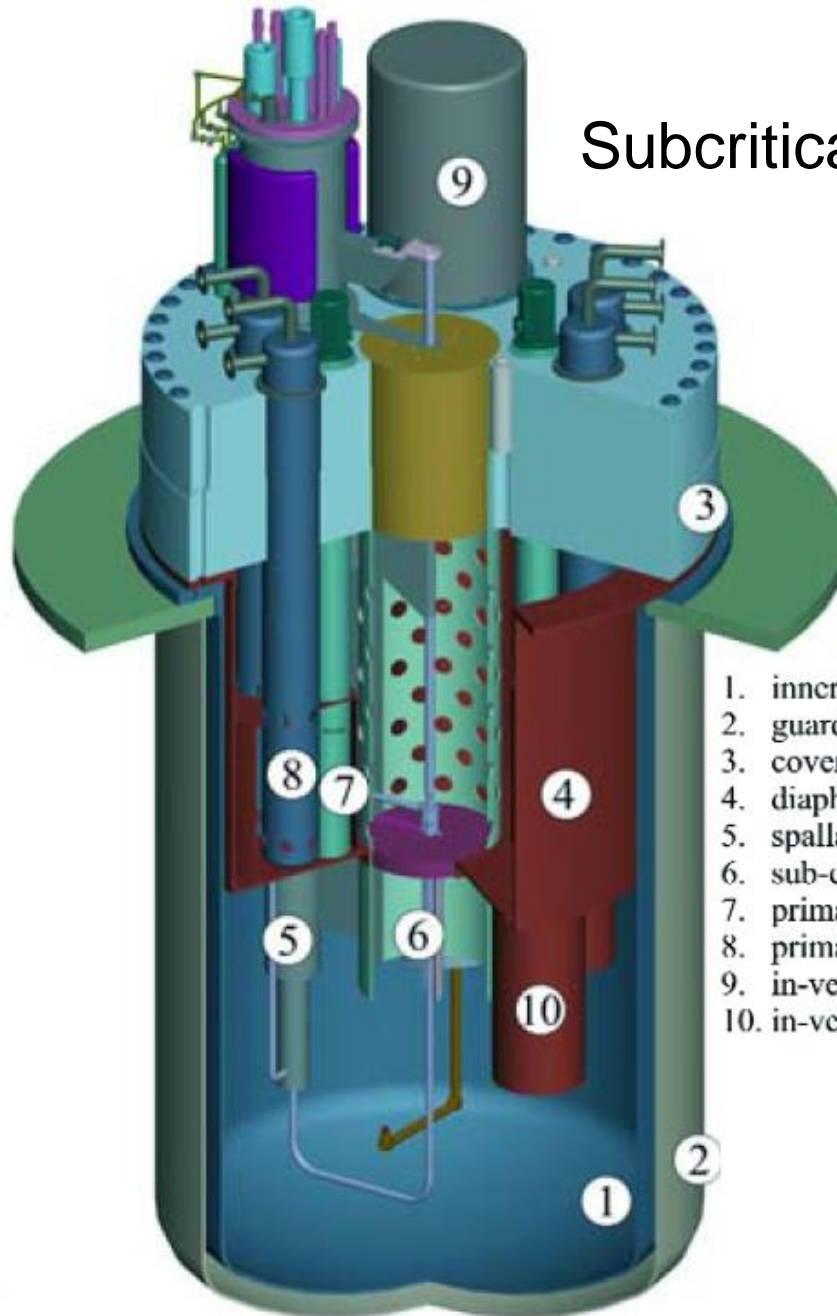
# Podkrytyczny reaktor, współpracujący ze spalacyjnym źródłem neutronów. (MYRRHA)



Cryomodule for the elliptical cavities



## Subcritical assembly



1. inner vessel
2. guard vessel
3. cover
4. diaphragm
5. spallation loop
6. sub-critical core
7. primary pumps
8. primary heat exchangers
9. in-vessel fuel transfer machine
10. in-vessel fuel storage

# Characteristic of subcritical core

Main characteristics	MYRRHA	Unit
Core power	50.-100.	MW <sub>th</sub>
Active core average power density	250.	W/cm <sup>3</sup>
Accelerator energy	600.	MeV
Accelerator current	3.5	mA
Total flux (hottest pin)	4.7E+15	n/cm <sup>2</sup> /s
Fast flux above 0.75 MeV (hottest pin)	1.01E+15	n/cm <sup>2</sup> /s
Ppm He/dpa (hottest pin/target zone)	3.8/6.4	
Inlet temperature	270.	°C
Coolant delta T	130.	°C
Velocity (fuel rod)	1.9	m/sec
Temperature at cladding surface	500.	°C
Maximum linear power	370.	W/cm
k-eff	0.945	

# Monte Carlo Calculations

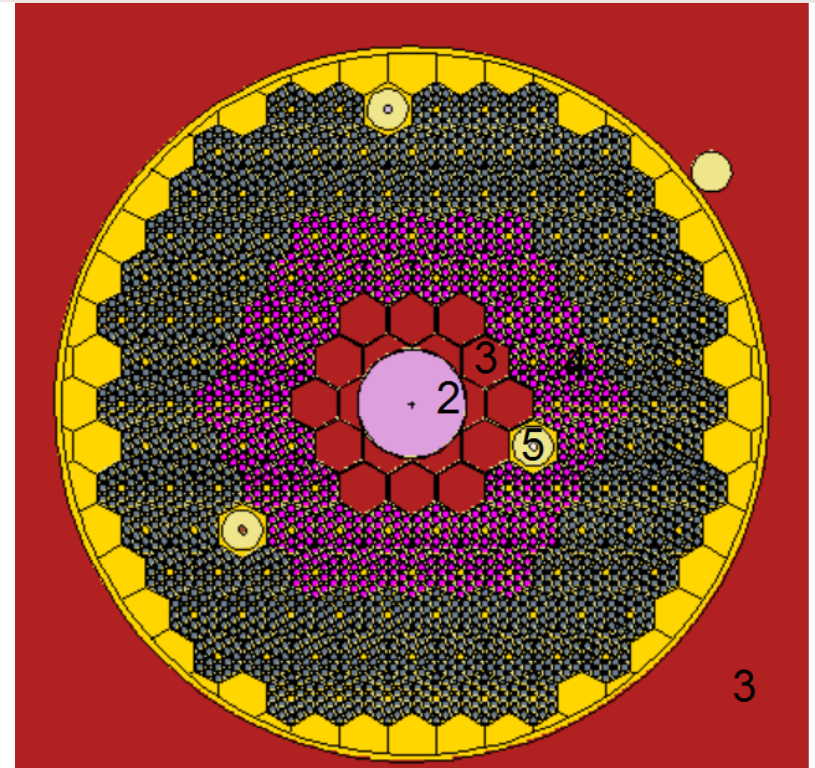
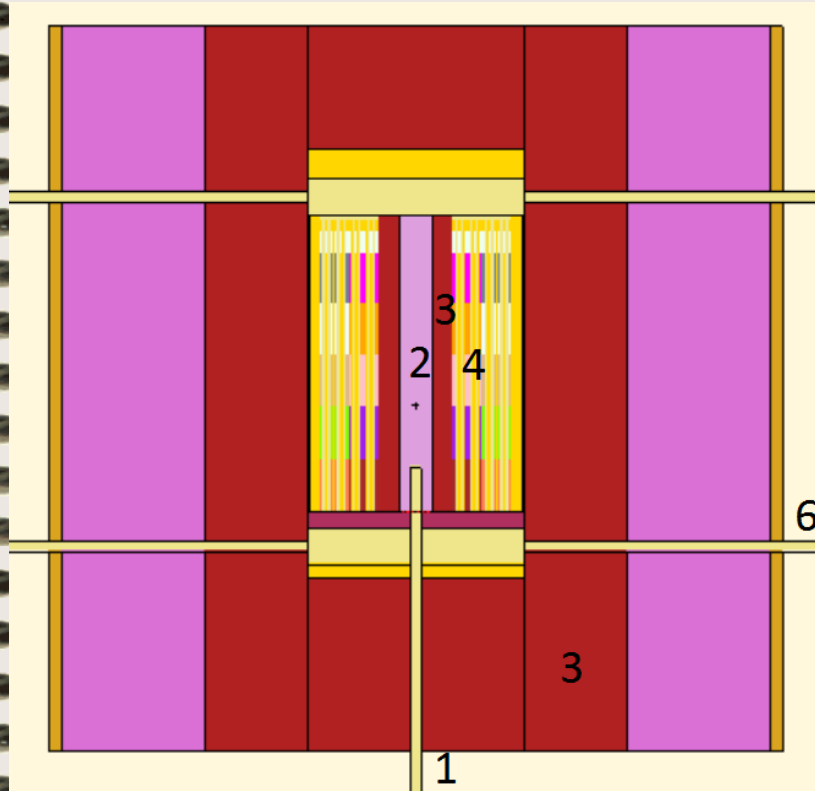
**MCNP** (Monte Carlo N-Particle code) is developed by Los Alamos National Lab (LANL) to simulate the transport of neutrons, gamma rays and electrons by the Monte Carlo method. It simulates a coupled transport, i.e., it also accounts for transport of secondary particle resulting the interaction of primary particles.

**MCNPX** (Monte Carlo N-Particle eXtended) extends the capacities of MCNP to other high energy particles (e.g. charged particles, heavy ions, protons, pions, etc.)

**CINDER90** LANL code and library, developed for the description of time evolution of nuclide inventories produced in nuclear reactors and accelerators.

# Geometry of subcritical core

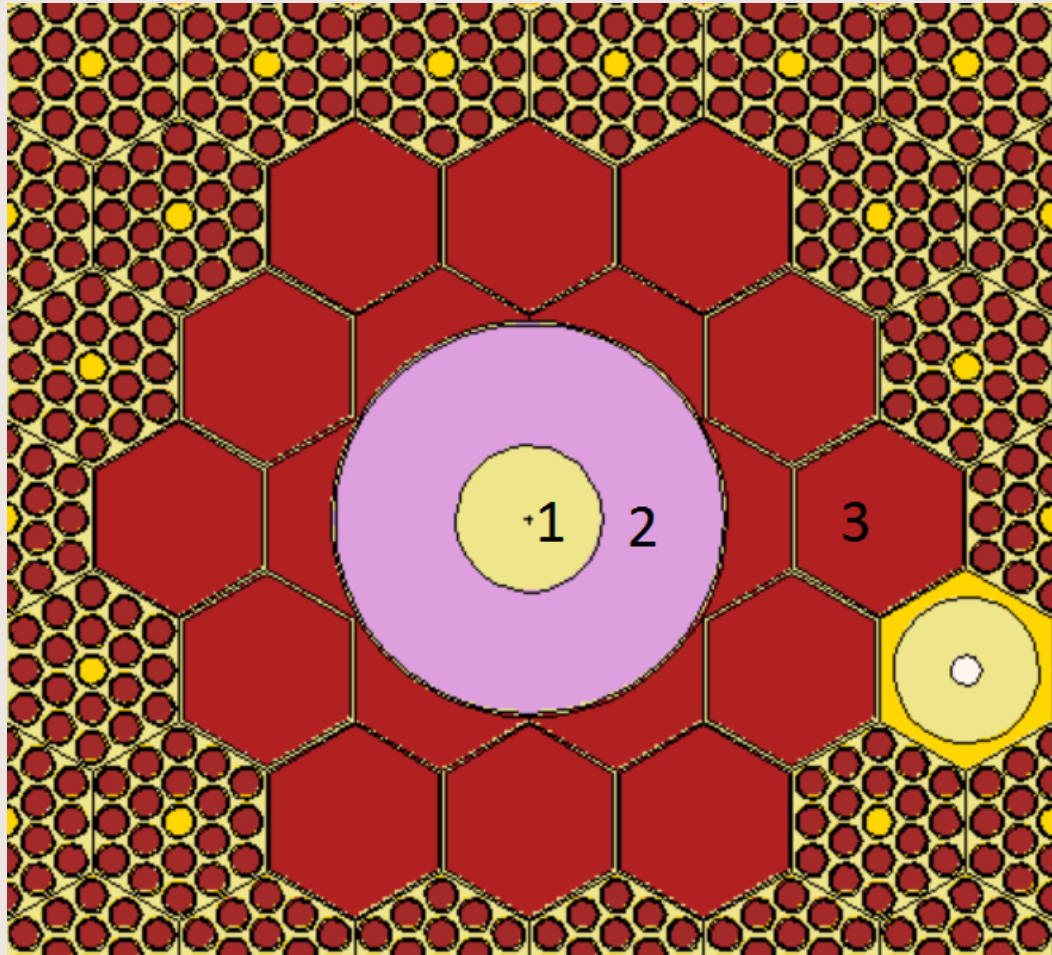
## Vertical and horizontal cross section



1. Particle beam
2. Spallation target
3. Lead reflector

4. Fuel rods filled with MOX
5. Experimental channel
6. Cooling system of core

Fuel rods filled with MOX  
(30 % PuO<sub>2</sub> + 70 % UO<sub>2</sub>)



- 1. Particle beam
- 2. Spallation target
- 3. Lead reflector
- 4. Fuel rods
- 5. Exp. Channel Ch1

Nuclide	Fraction (wt%)
<sup>237</sup> Np	5.33
<sup>238</sup> Pu	3.11
<sup>239</sup> Pu	46.15
<sup>240</sup> Pu	21.19
<sup>241</sup> Pu	11.48
<sup>242</sup> Pu	7.03
<sup>241</sup> Am	2.81
<sup>243</sup> Am	2.07
<sup>244</sup> Cm	0.74
<sup>245</sup> Cm	0.07

## Fraction of TRU of spent fuel

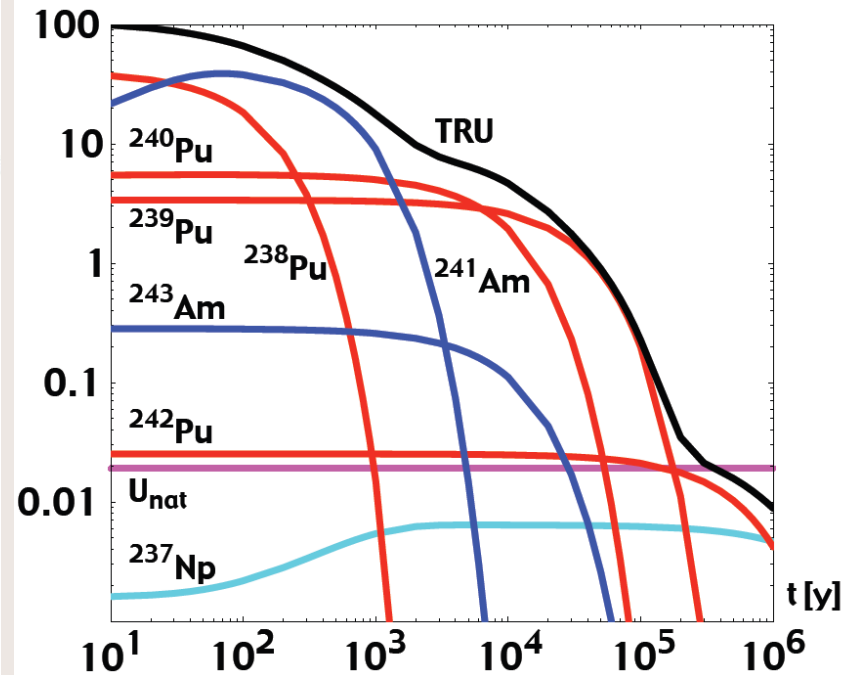
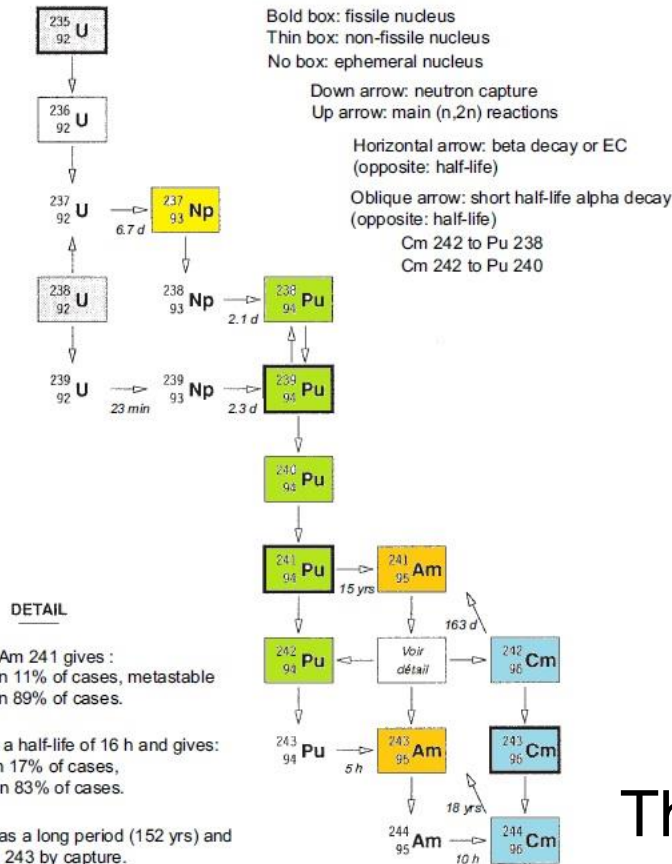
Fraction after 4 years of cooling spent fuel of LWR:U-93.305%,FP5.145%,TRU-1.35%

Fuel rods filled with MOX:  
(30 % PuO<sub>2</sub> + 70 % UO<sub>2</sub>)

## Fraction of MA

no.	zaid	mass	activity	spec.act.	atom den.	atom fr.	mass fr.
	(gm)	(Ci)	(Ci/gm)	(a/b-cm)			
1	93237	2.987E+02	0.000E+00	0.000E+00	2.051E-02	4.840E-01	4.786E-01
2	95241	1.601E+02	0.000E+00	0.000E+00	1.081E-02	2.550E-01	2.564E-01
3	95243	1.190E+02	0.000E+00	0.000E+00	7.967E-03	1.880E-01	1.906E-01
4	96244	4.258E+01	0.000E+00	0.000E+00	2.839E-03	6.700E-02	6.821E-02
5	96245	3.829E+00	0.000E+00	0.000E+00	2.543E-04	6.000E-03	6.134E-03

# Long term radiotoxic inventory of spent fuel



The major contributors to long term radiotoxicity are americium and plutonium.

Nuclide	$\epsilon$ [nSv/Bq]
$^{237}\text{Np}$	110
$^{238}\text{Pu}$	230
$^{239}\text{Pu}$	250
$^{240}\text{Pu}$	250
$^{241}\text{Pu}$	5
$^{242}\text{Pu}$	240
$^{241}\text{Am}$	200
$^{243}\text{Am}$	200
$^{244}\text{Cm}$	120
$^{245}\text{Cm}$	210

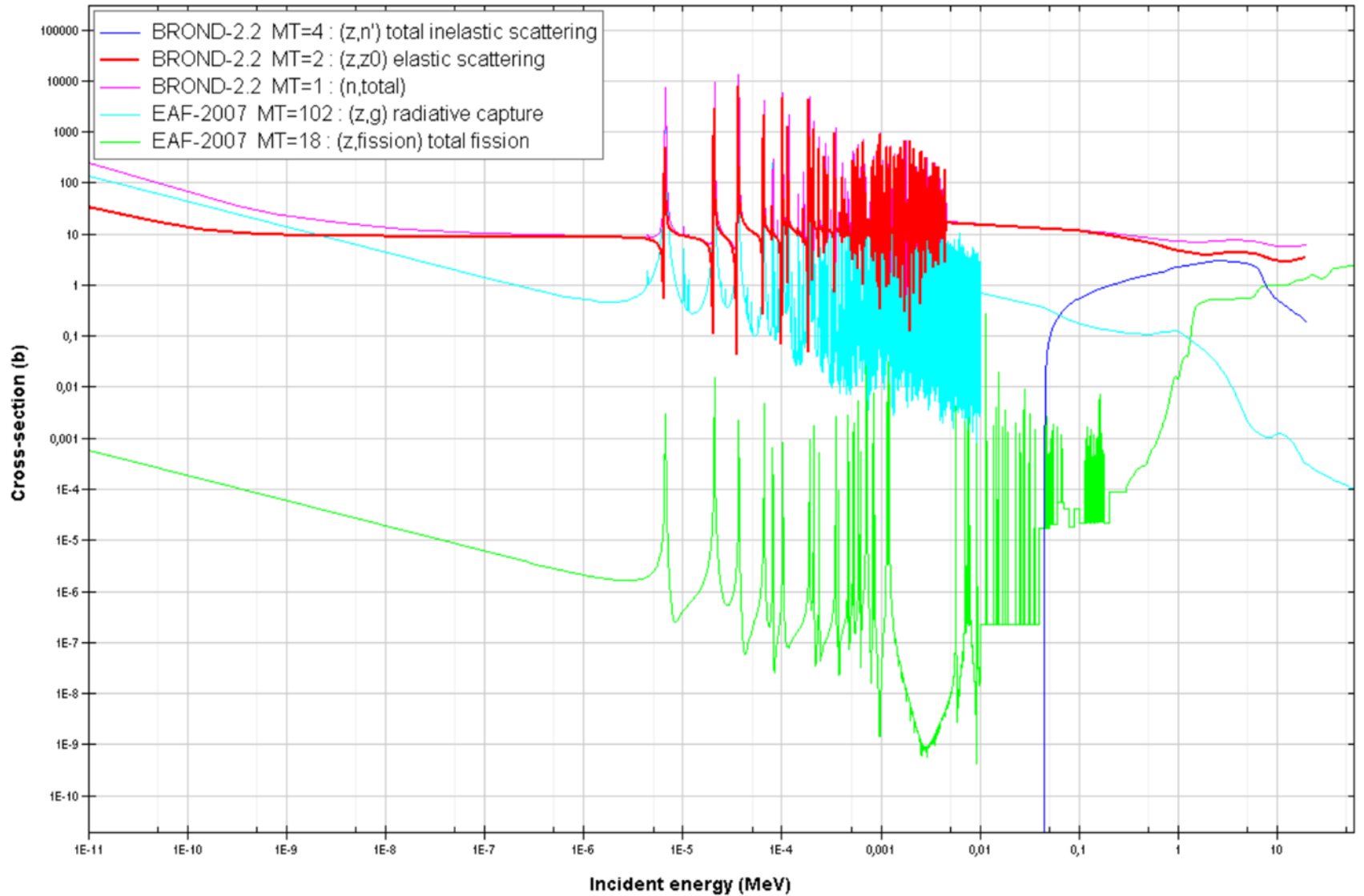
Radiotoxicity =  $\epsilon * A$

Radiotoxicity in Sv

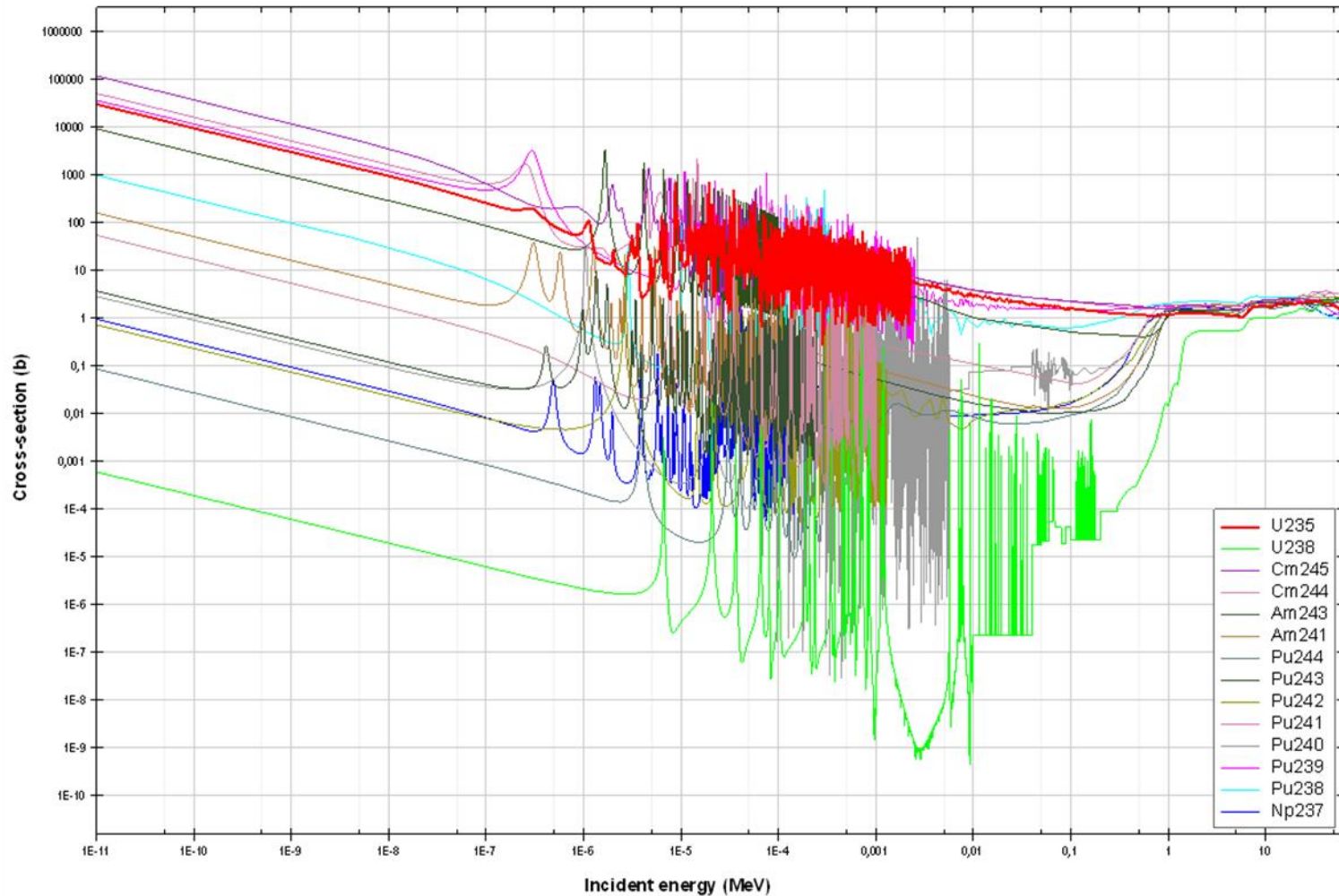
Activity in Bq

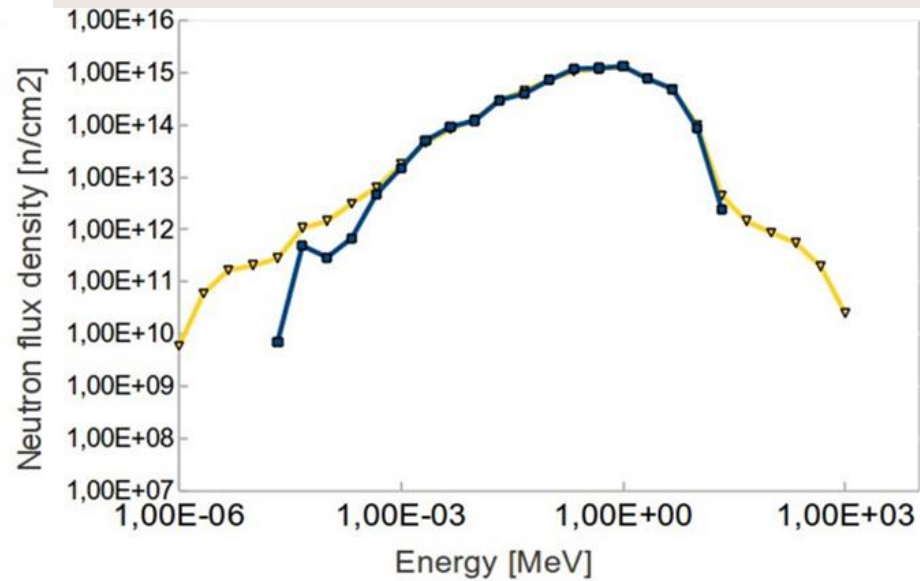
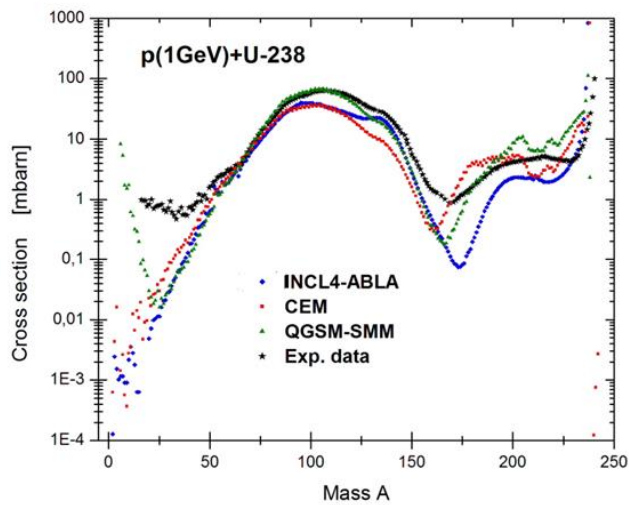
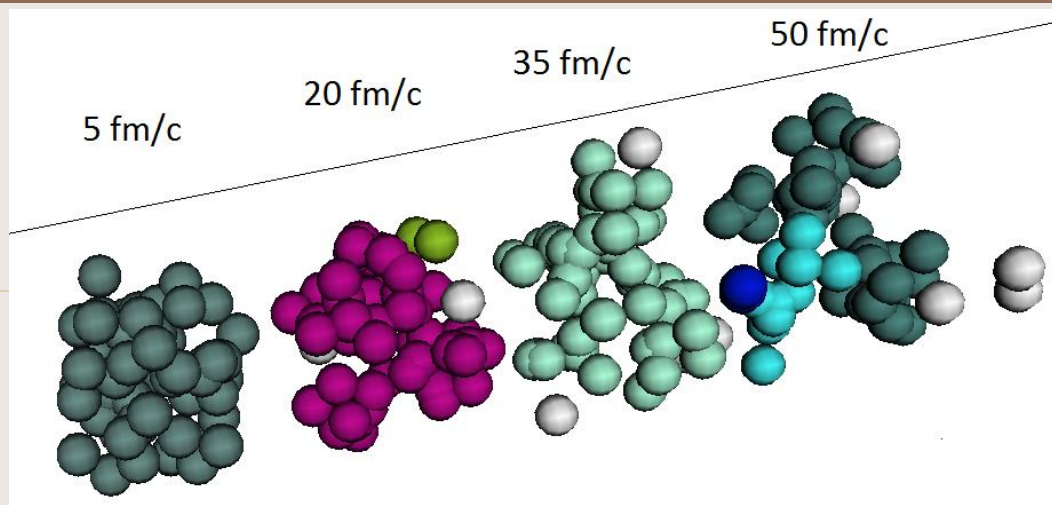
$\epsilon$  is an estimation  
based on observation

### Incident neutron data // U238 // Cross section

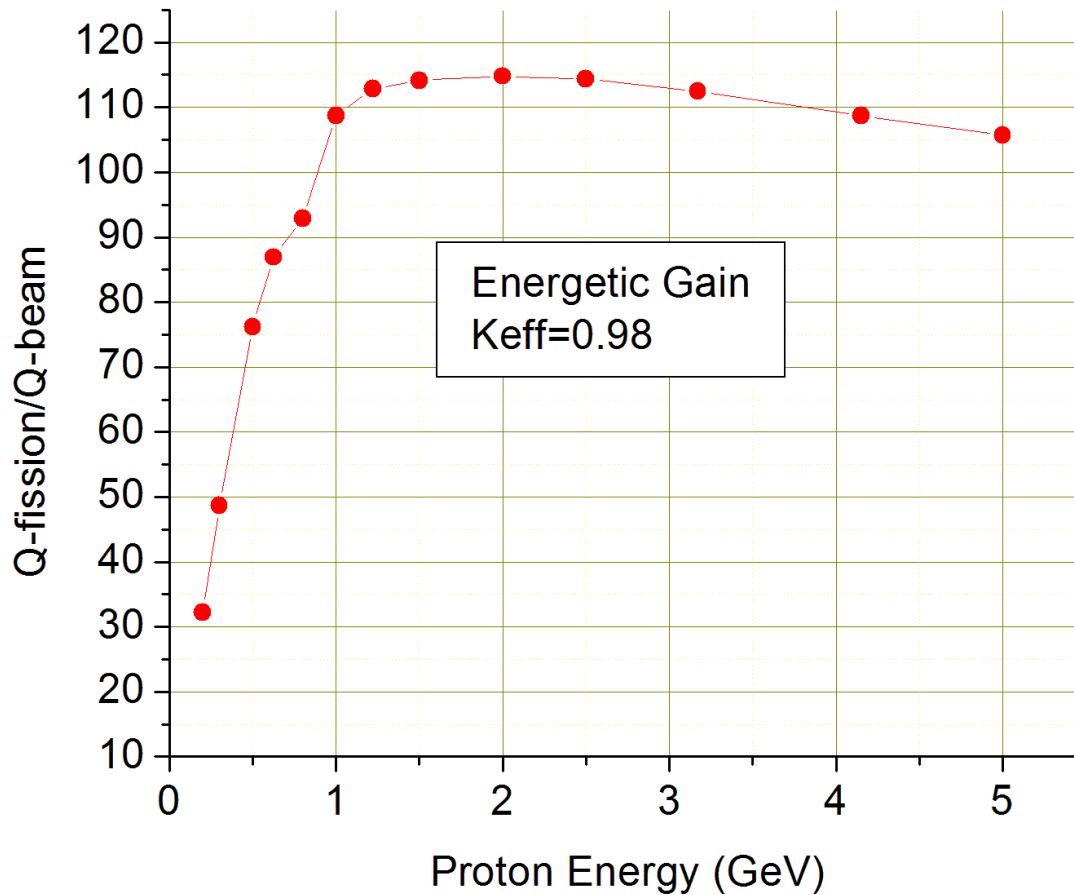


Incident neutron data / EAF-2007 // MT=18 : (z,fission) total fission / Cross section



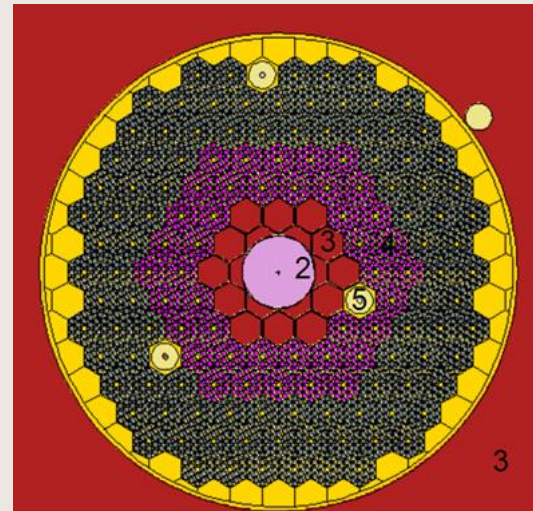
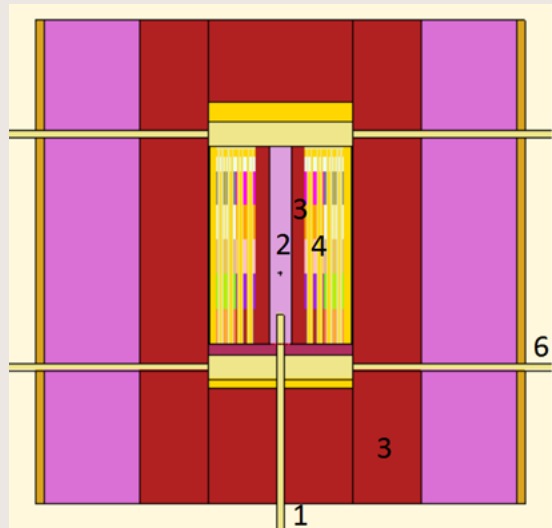


# Energetic Gain Subcritical Core

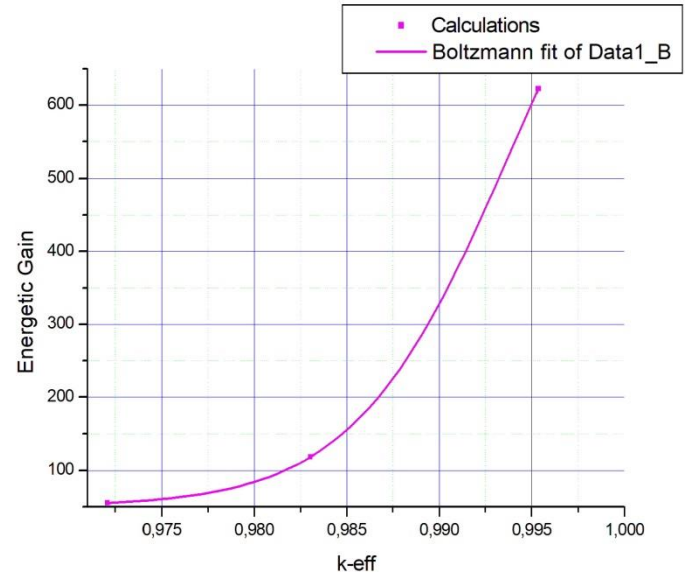
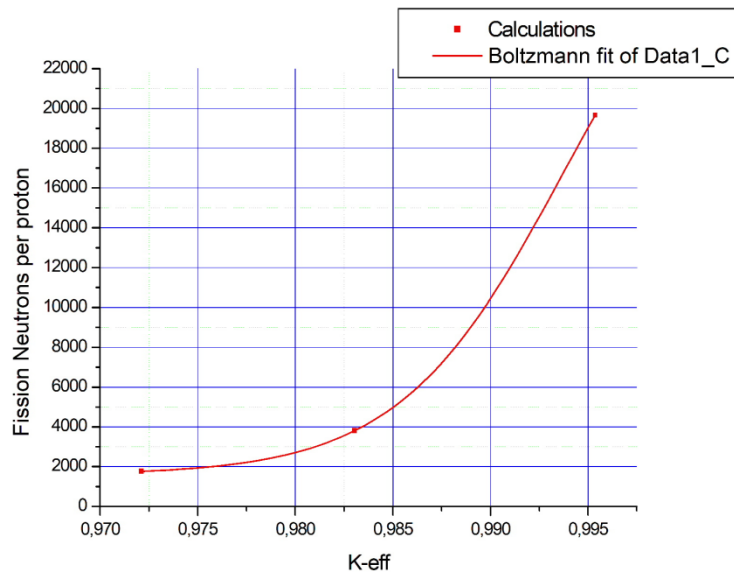


# Proton energy 2 [GeV]

Target	Cross sec	Target neut.	Core neut.	Fission neut.	Gain	k-eff
Pb	14,14	33,47	26750	19667	622	0,99536
U	17,41	70,01	5221	3809	118,5	0,98304
W	12,86	39,42	2440	1760	55,7	0,9721
Fe	4,28	12,08				



# Proton energy 2 [GeV]

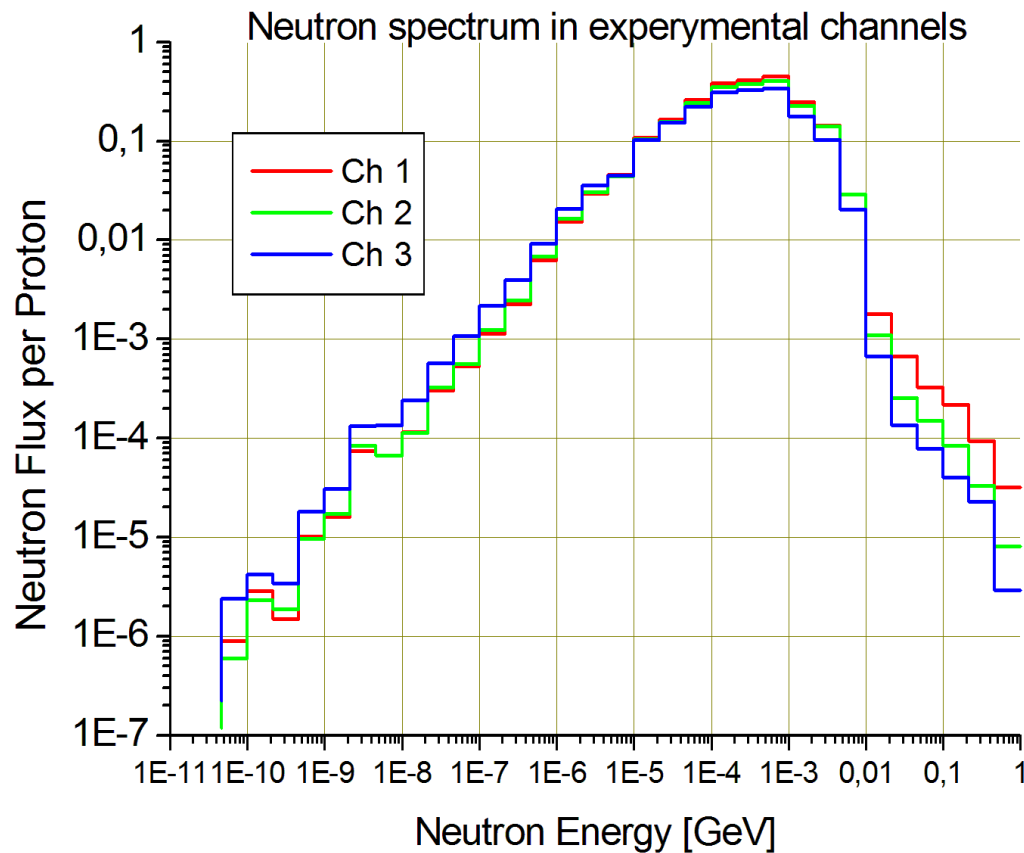


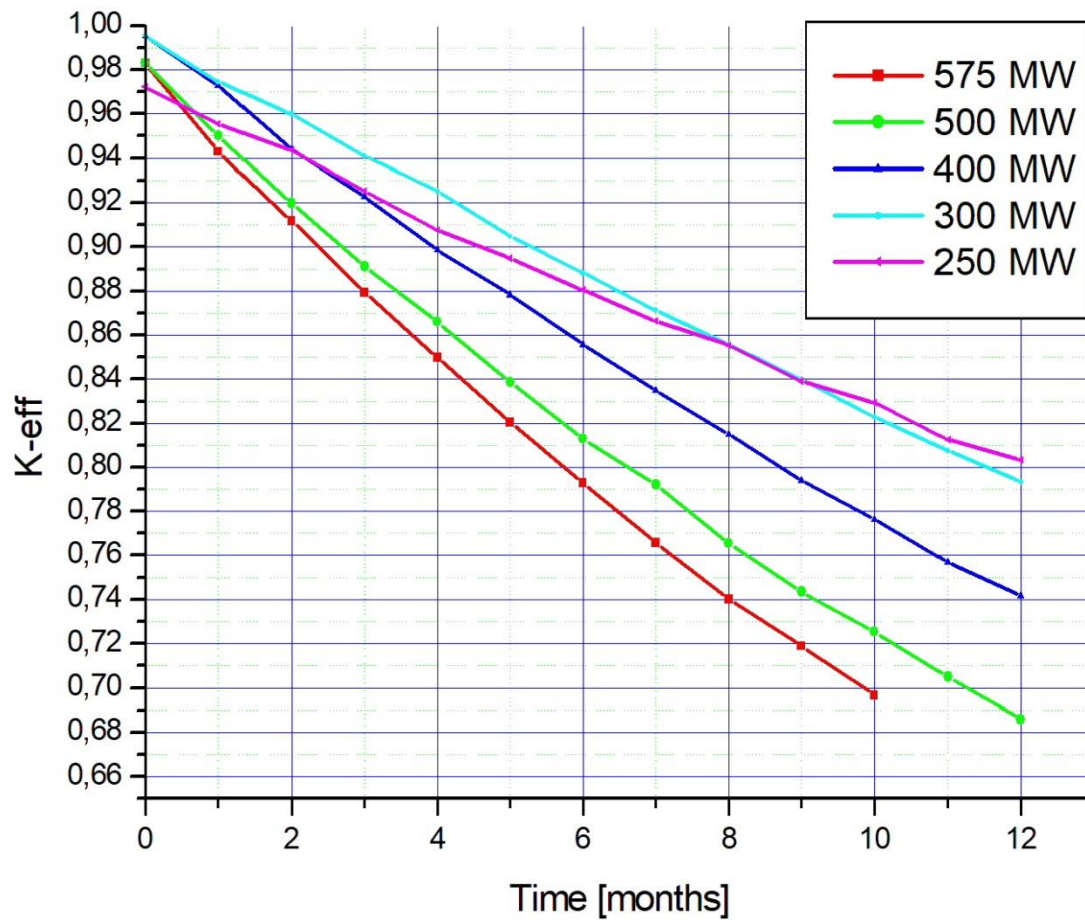
# Characteristic of subcritical core

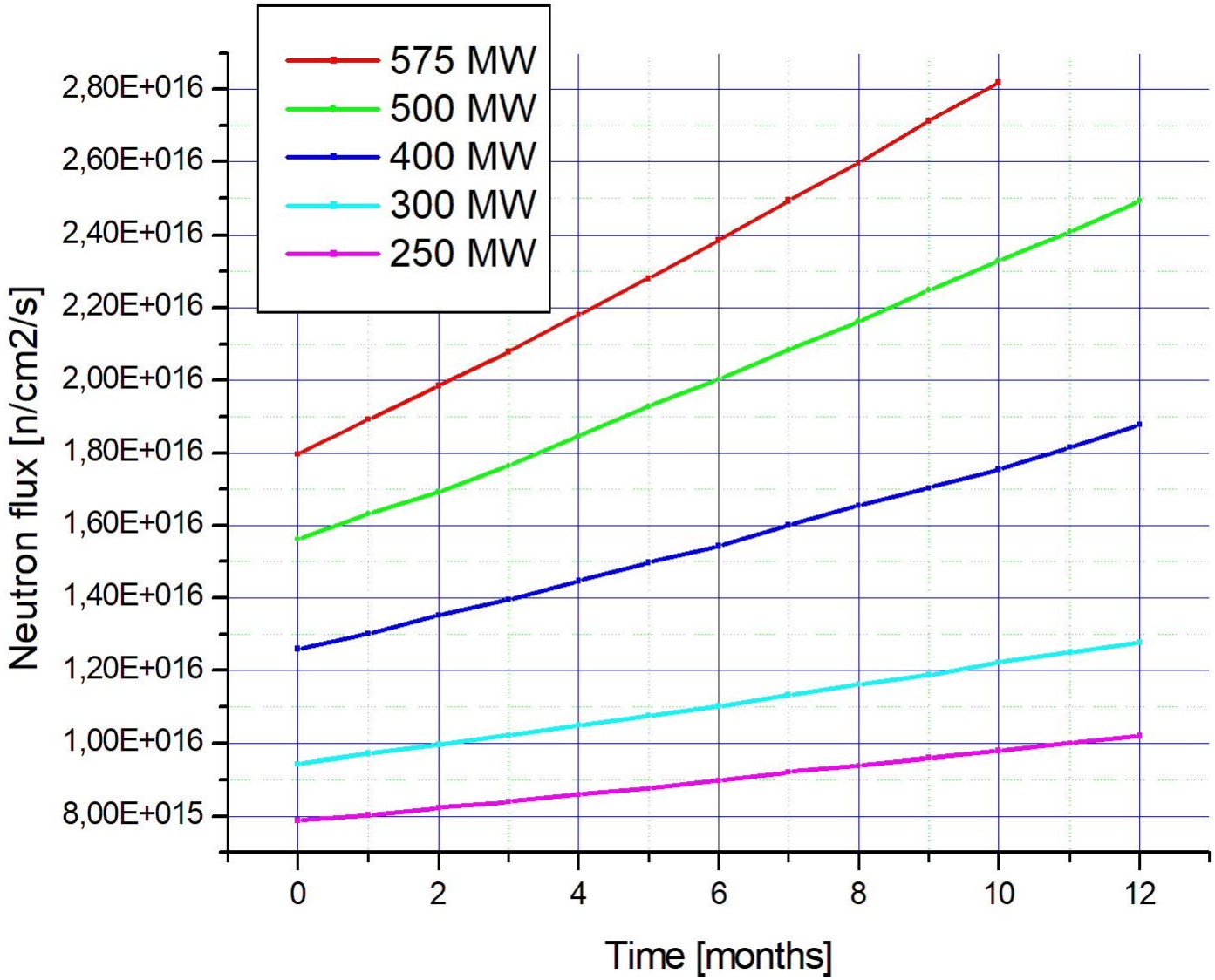
Target l=135 cm fi=8 cm	Pb	U	W
Accelerator energy [GeV]	2	2	2
Accelerator current [mA]		2,5	
Accelerator power [MW]	5	5	5
Max core power [MW]	3110	592	278
Core power [MW]	300	300	250
K-eff	0,995	0,983	0,9721
Radius of core [cm]	26	26	26
Hight of core [cm]	140	140	140
Size of fuel batch [mm]	36	36	36
Initial neutron flux [n/cm <sup>2</sup> /s]	9,44E+15		
Max (6 y)neutron flux [n/cm <sup>2</sup> /s]	5,00E+16		

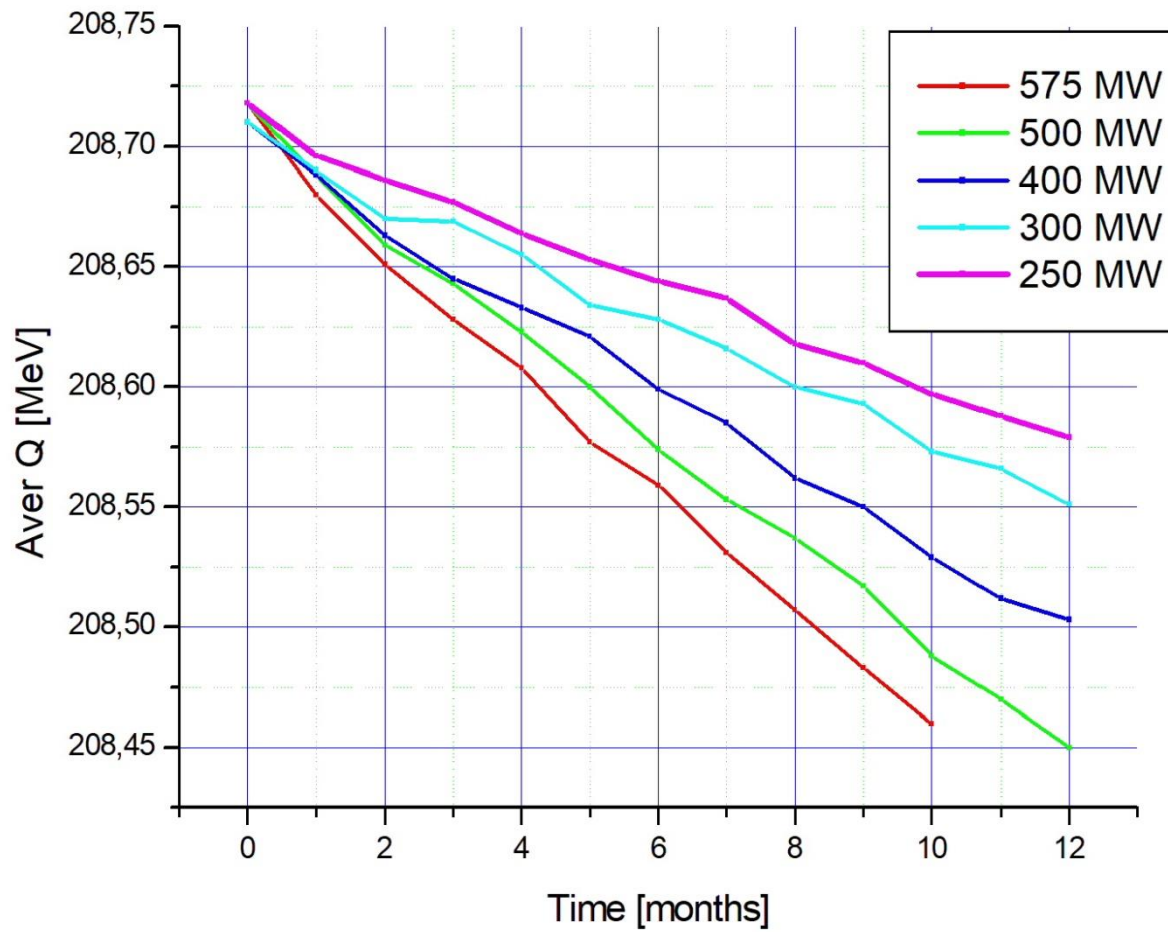
# Neutron spectrum in experimental channels

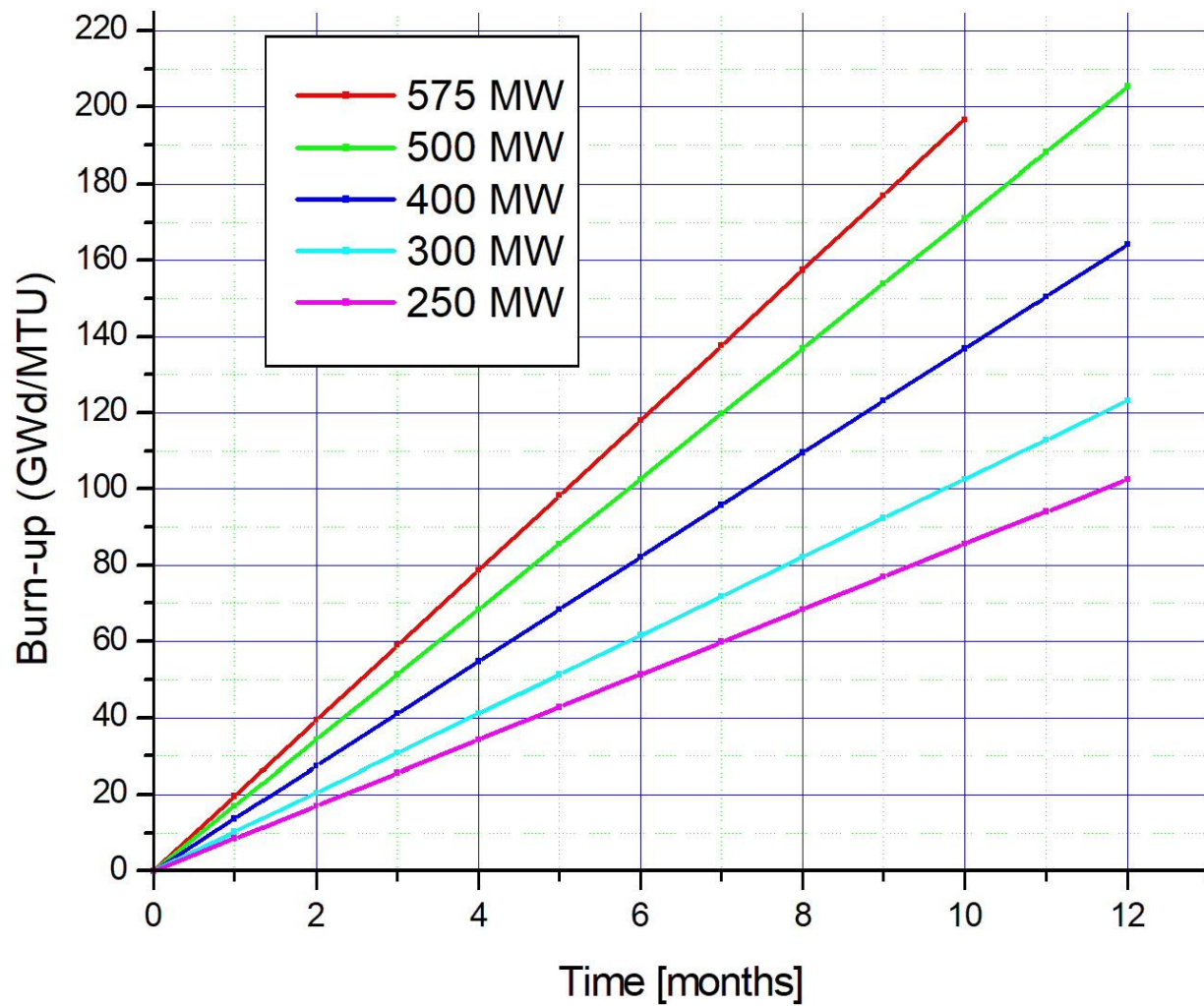
## Energy of protons 2 GeV

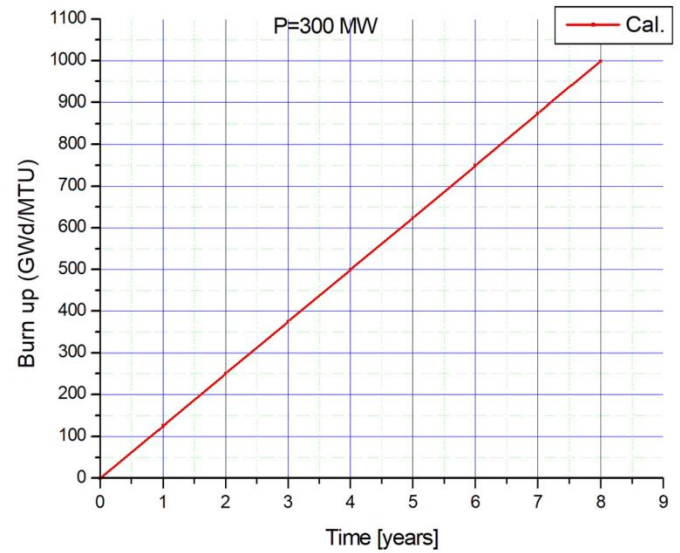
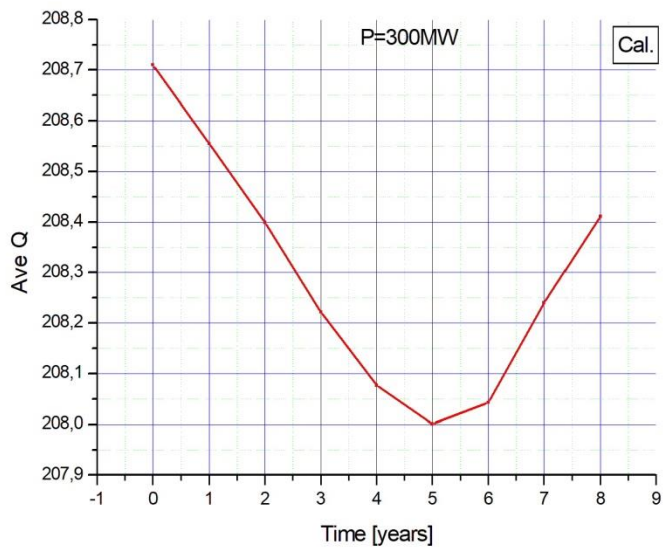
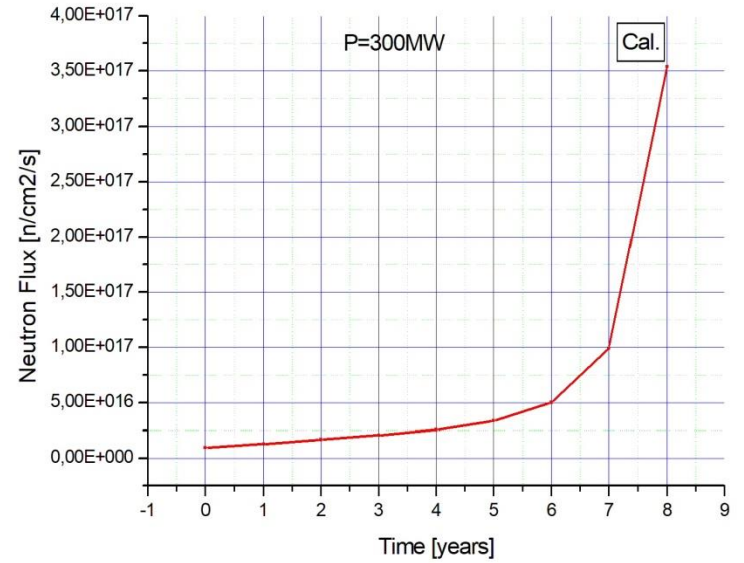
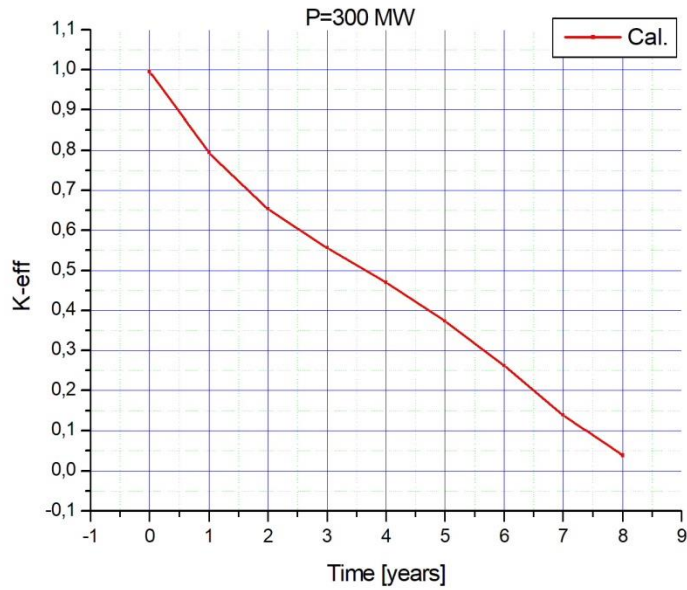




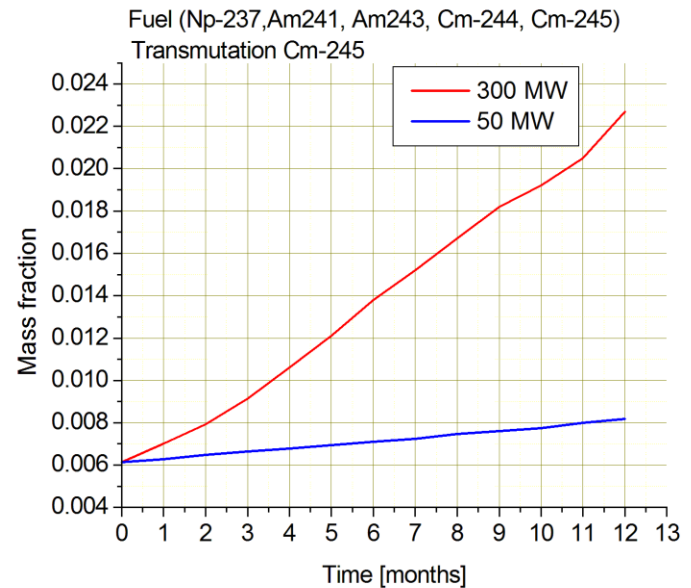
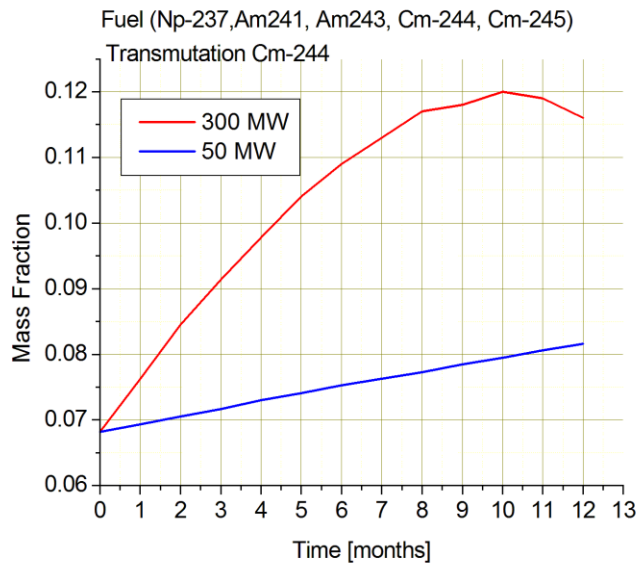
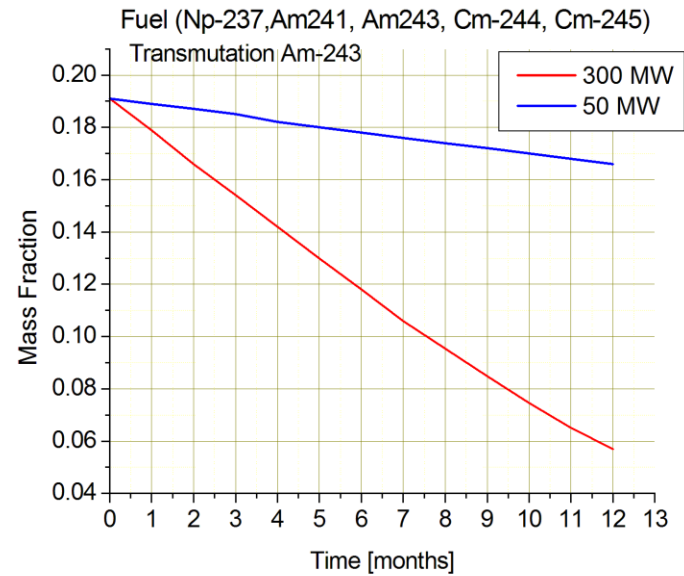
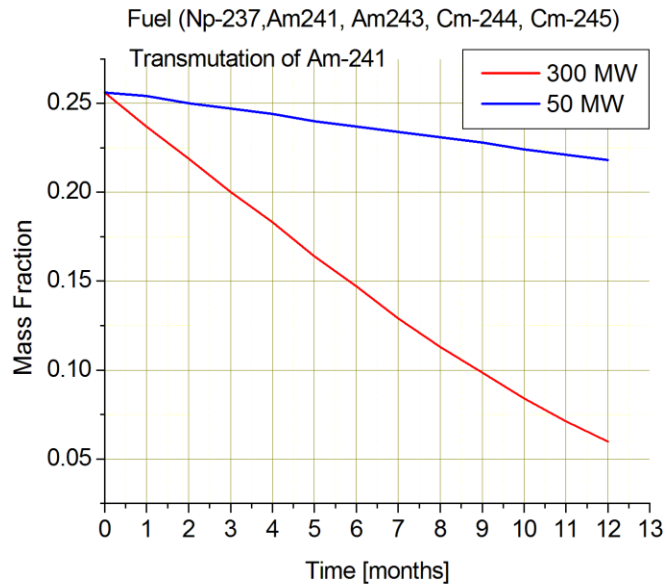




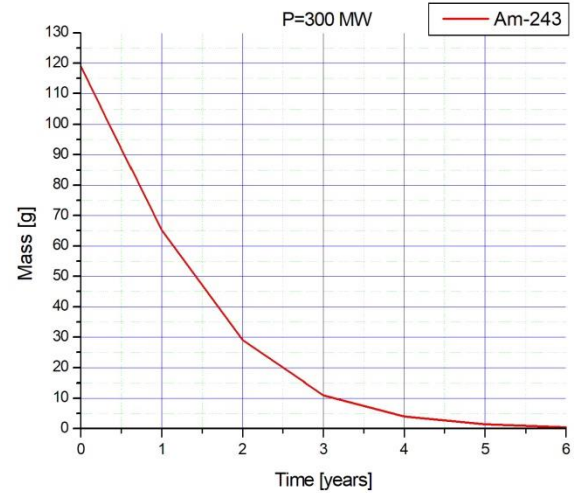
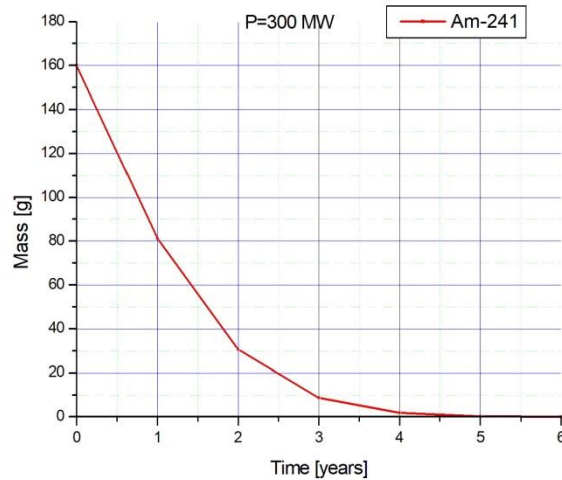
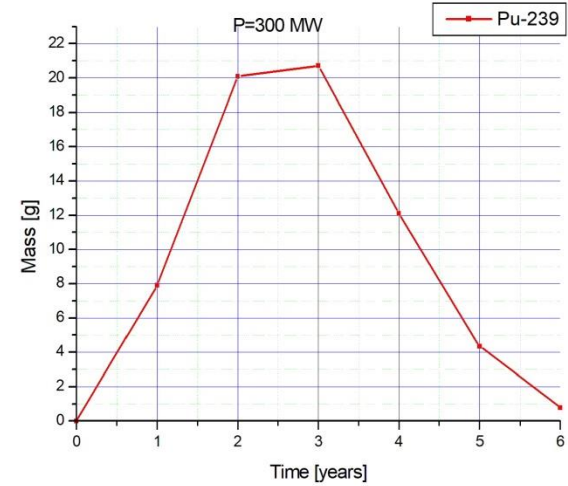
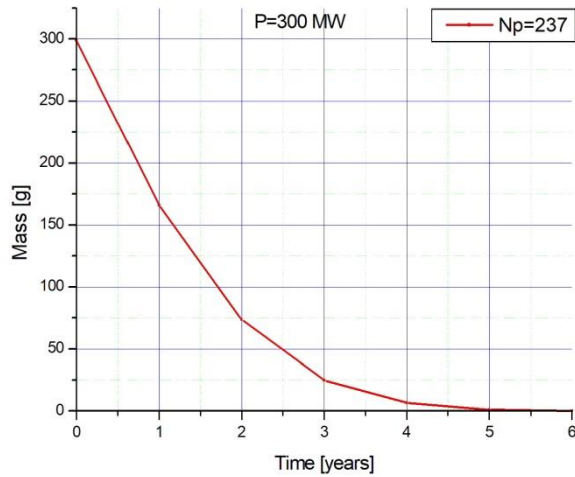


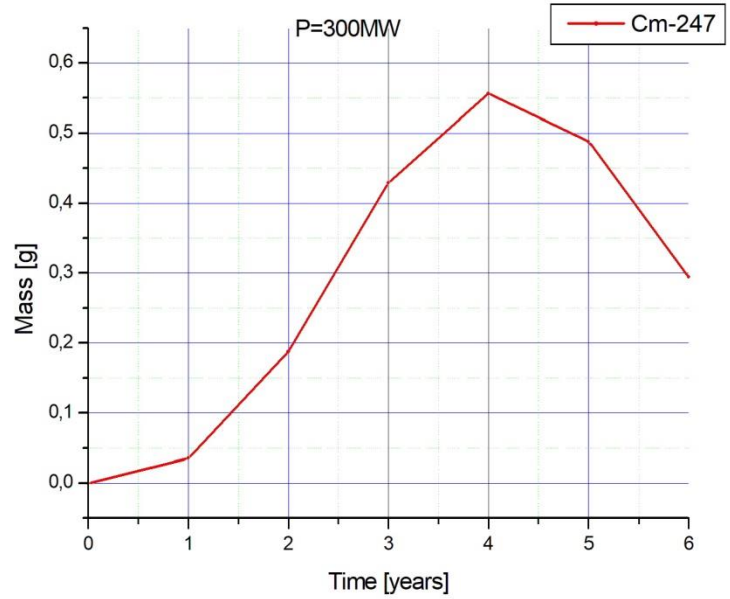
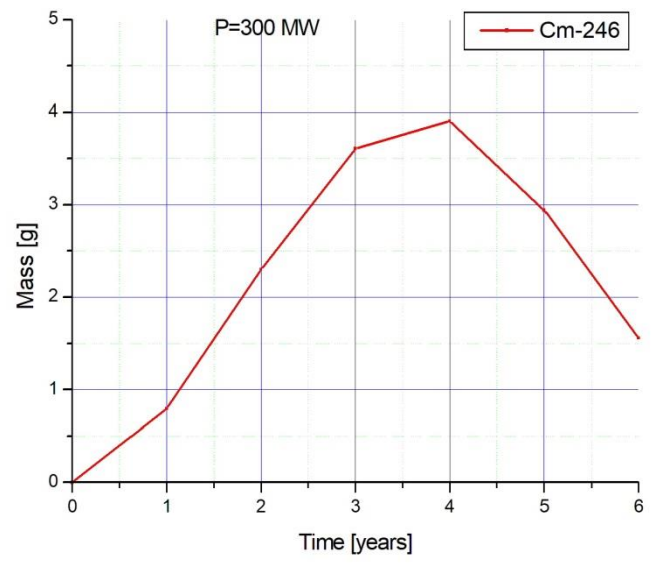
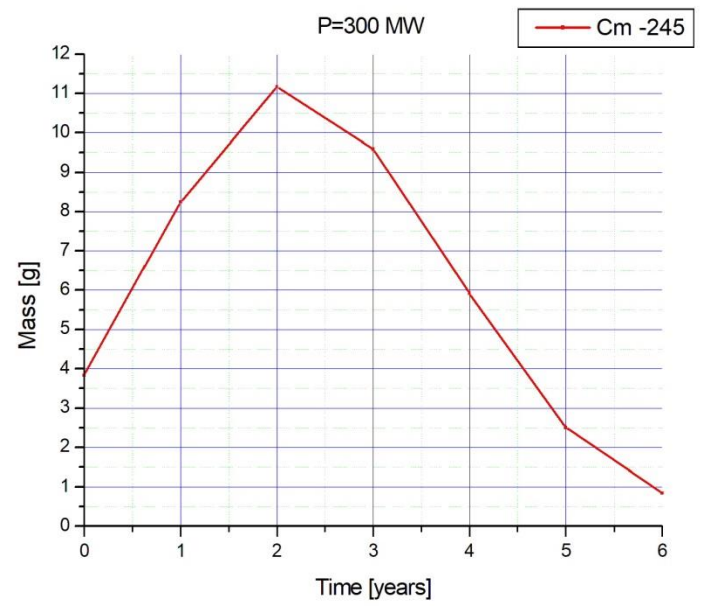
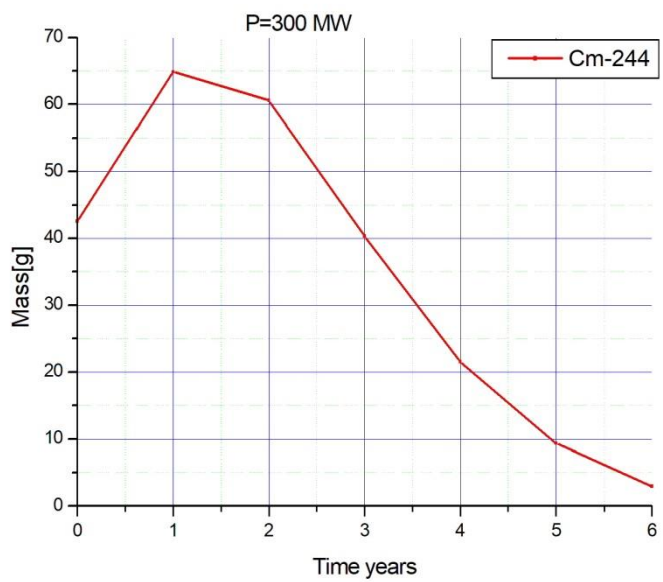


# Transmutation of MA ( Am, Cm)



# Transmutation of Actinides ( Np-237, Pu-239, Am)





# FR

