An ADS irradiation facility for fast and slow neutrons

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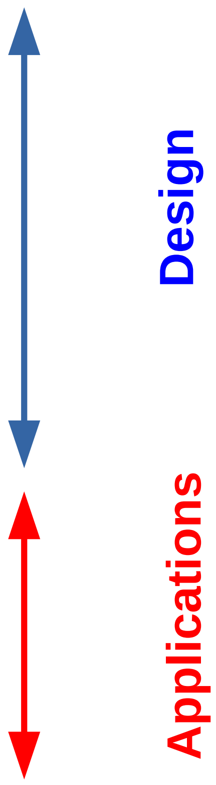
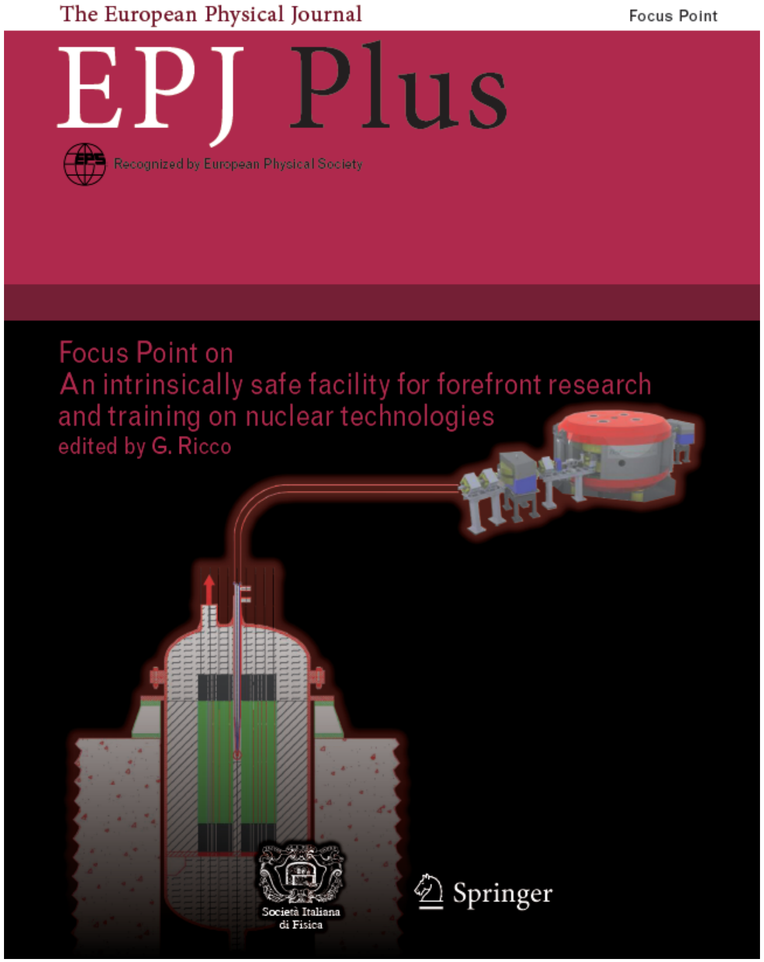
Outline

- **Motivations**
- **”Hybrid fast-slow” ADS: general characteristics**
- **In-core neutron flux spectra (MCNP-6)**
- **In-core thermal power distribution (MCNP-6)**
- **Neutron fluxes and spectra in light reflector (MCNP-6)**
- **Irradiation channels (MCNP-6)**
- **Reactor shielding (MCNP-6)**
- **Preliminary thermal-hydraulics characterization**
- **FP and actinides samples irradiation MCNP-6/MCB)**
- **Tc99m production (MCB)**
- **Fuel radiotoxicity analysis of test pins (MCB)**
- **Conclusions**



Motivations

We started from a lead based low power ADS for education, training and research on lead systems and waste transmutation (LEADS project).


The European Physical Journal

Focus Point

EPJ Plus

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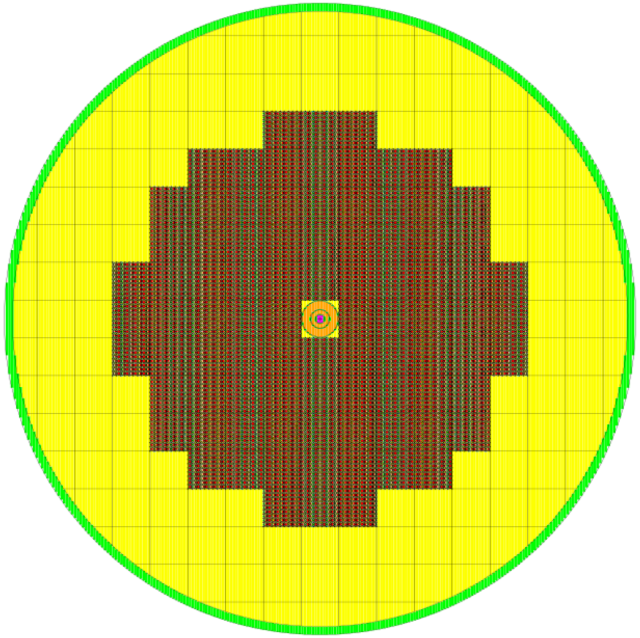
Focus Point on
An intrinsically safe facility for forefront research and training on nuclear technologies
edited by G. Ricco

Società Italiana di Fisica

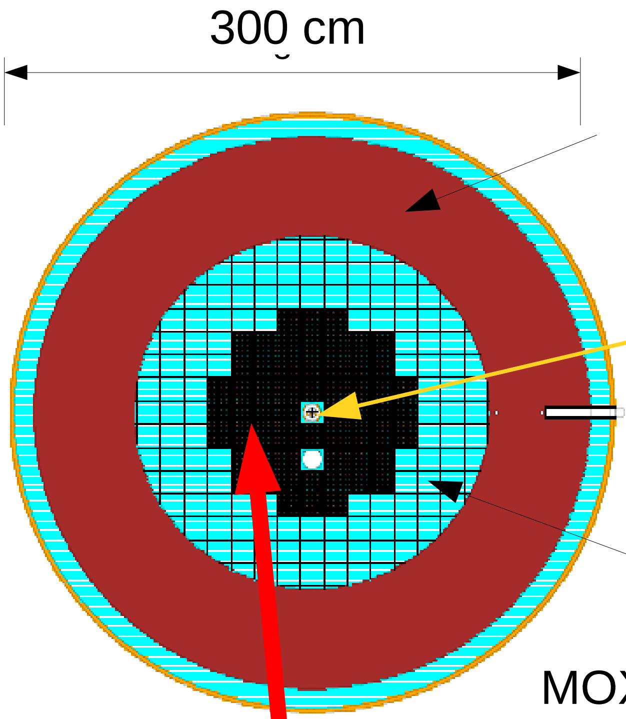
Springer

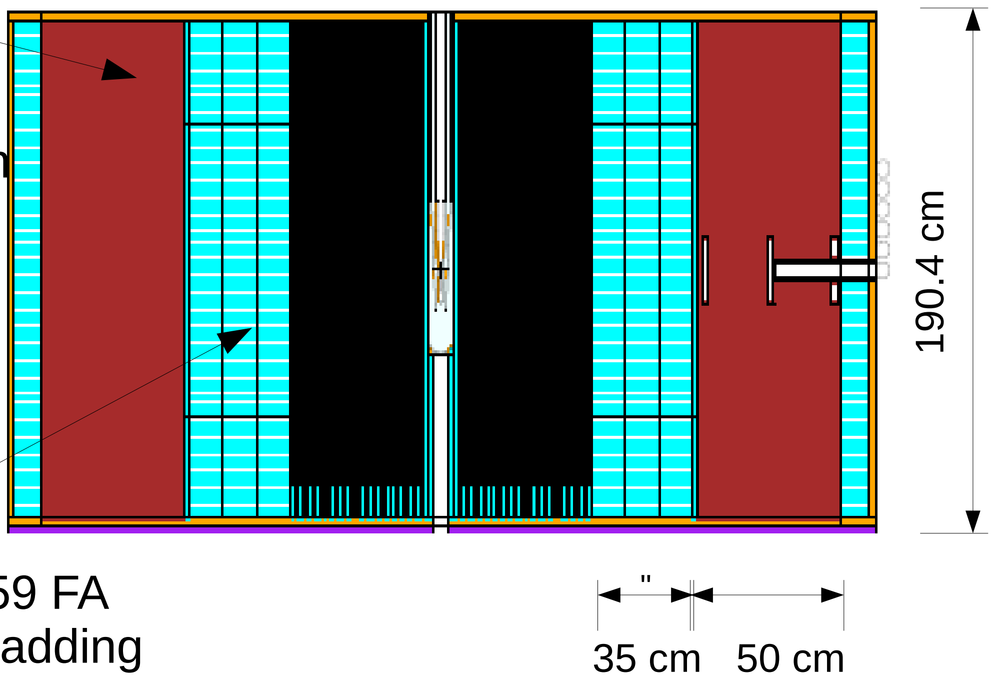
60 Fas, UO_2 (20% U-235)
P=200 kW



G. Ricco *et al.*, Eur. Phys. J. Plus, 129 (2014).

The new system: general characteristics



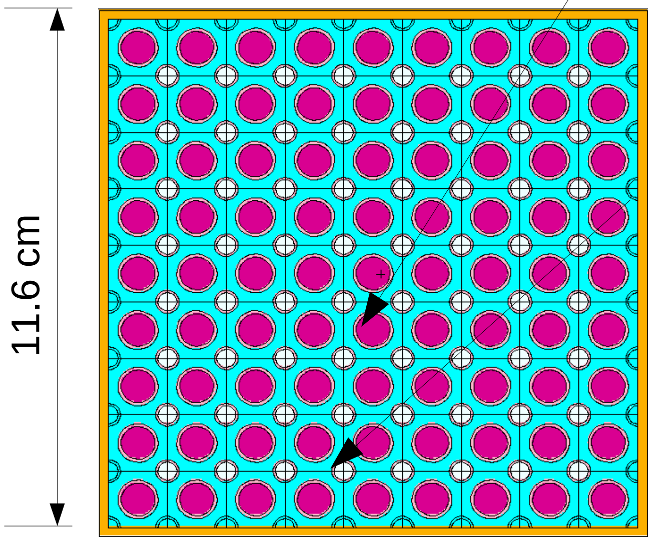


graphite

Source: (p,n) reaction
70 MeV protons
on a beryllium target

Lead interface

MOX pins 22% Pu+Am, 59 FA
d=0.74 cm+0.1 cm Steel cladding
h=87 cm

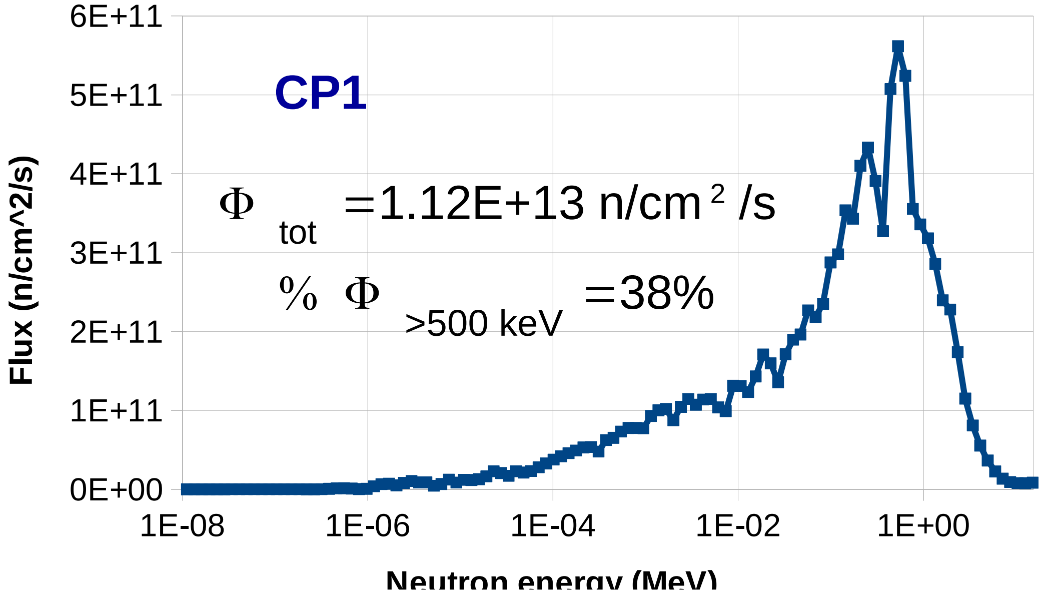


Water cooling
Pipes d=0.5 cm

Thermal power P=527 kW
k_{eff} = 0.972

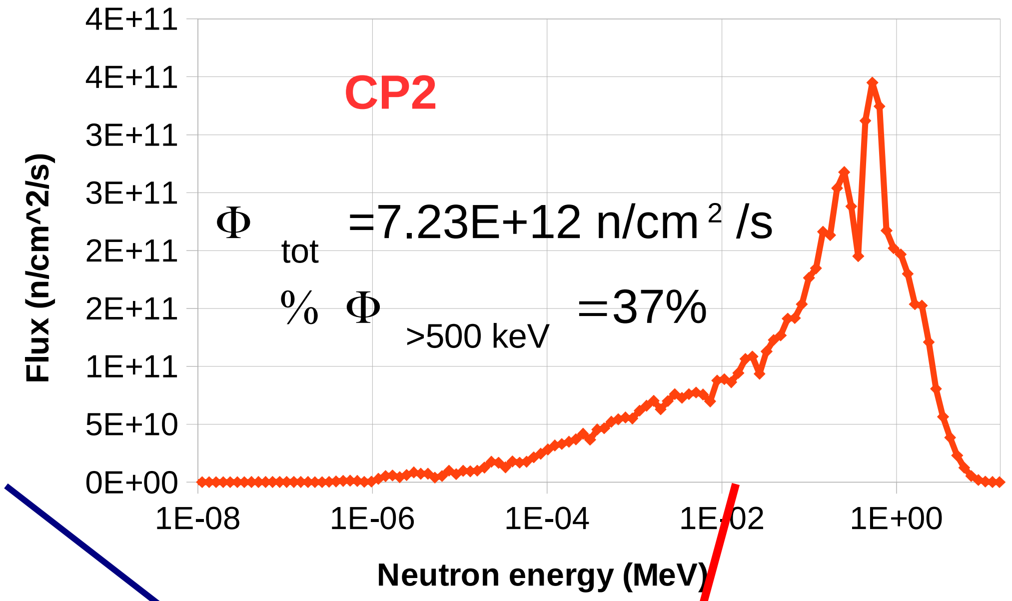
Water acts as a neutron moderator, but does not completely surround the MOX pins. This allows to increase the fission rate, while keeping the FAST characteristics of the core necessary for MA fission

In-core flux energy distribution



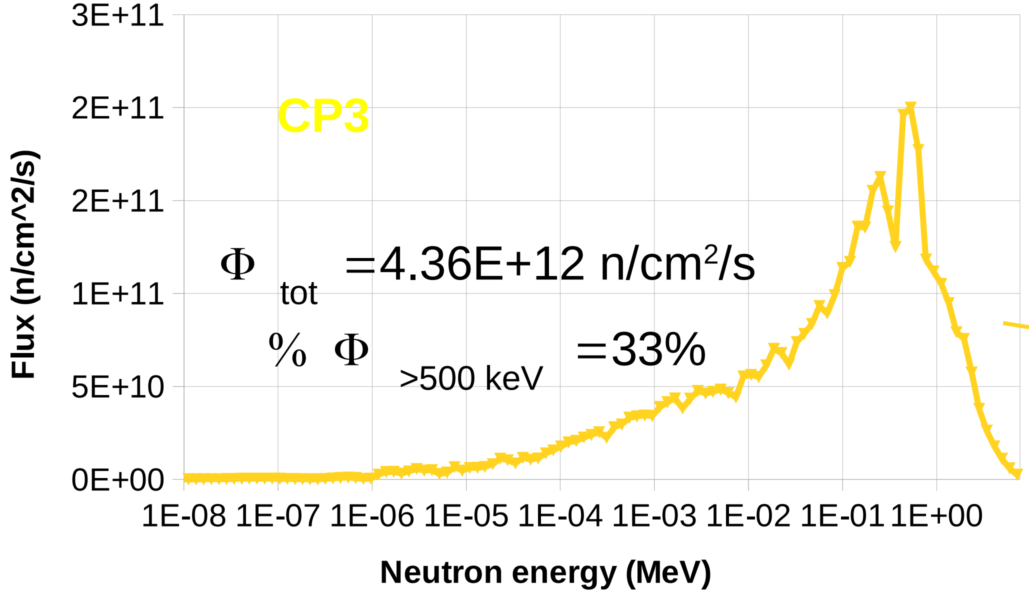
Φ_{tot} =1.12E+13 n/cm^2/s

$\% \, \Phi_{>500\ keV}$ =38%



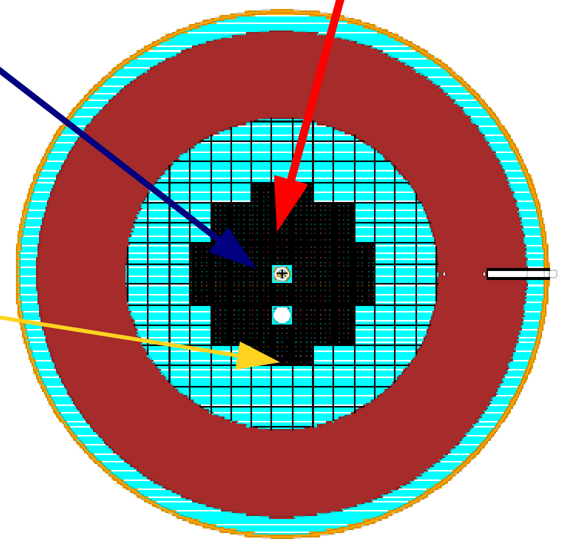
Φ_{tot} =7.23E+12 n/cm^2/s

$\% \, \Phi_{>500\ keV}$ =37%

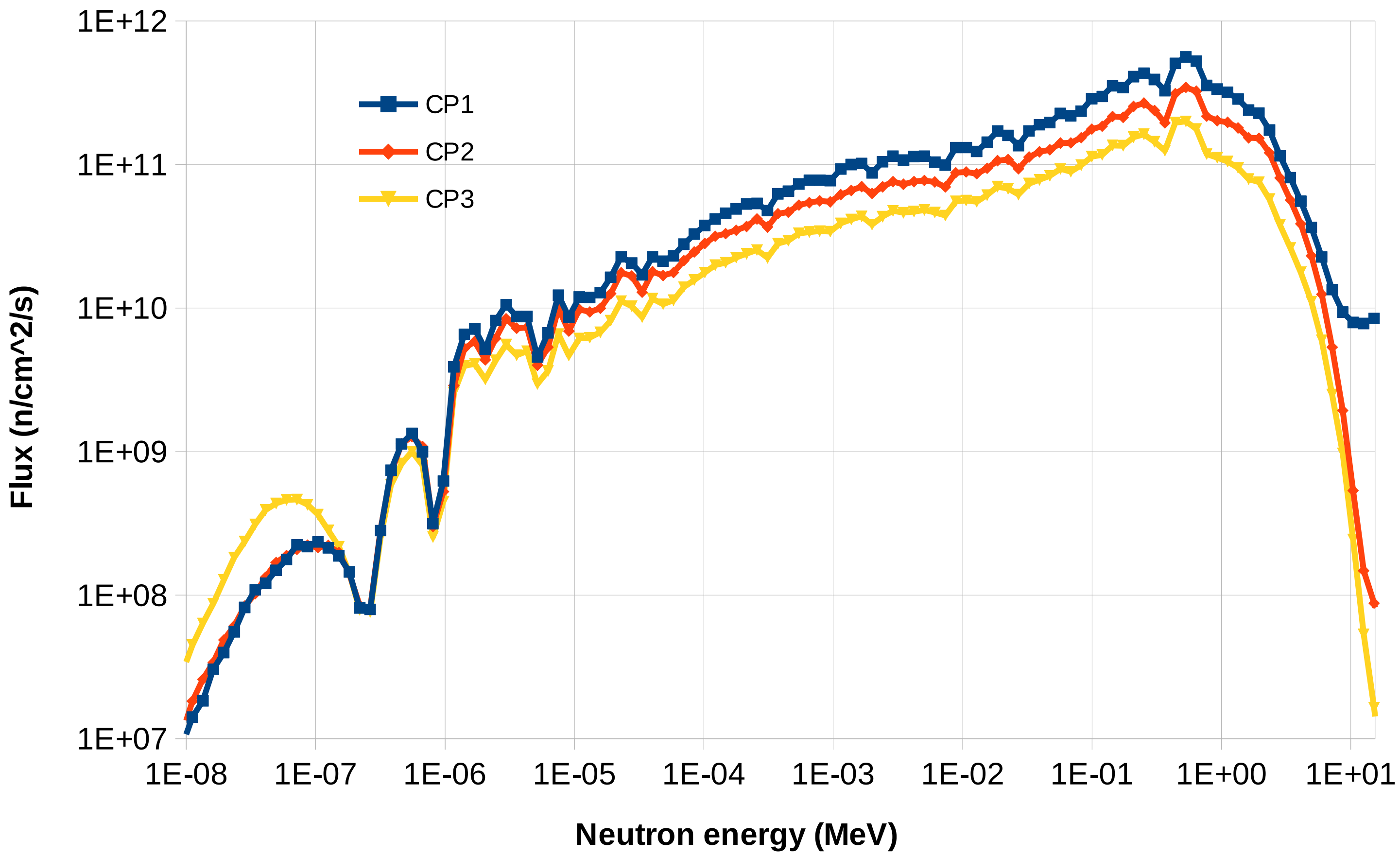


Φ_{tot} =4.36E+12 n/cm^2/s

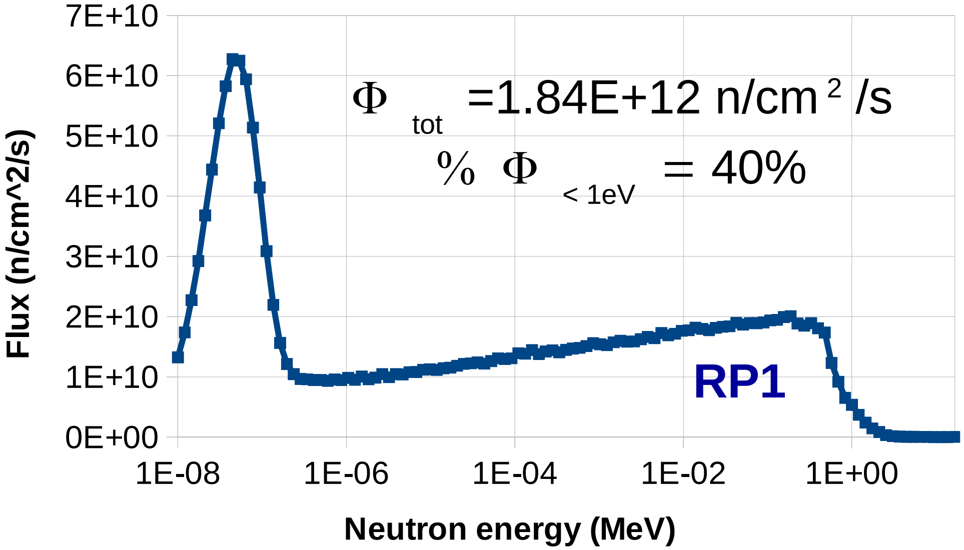
$\% \, \Phi_{>500\ keV}$ =33%



In-core flux energy distribution (2)

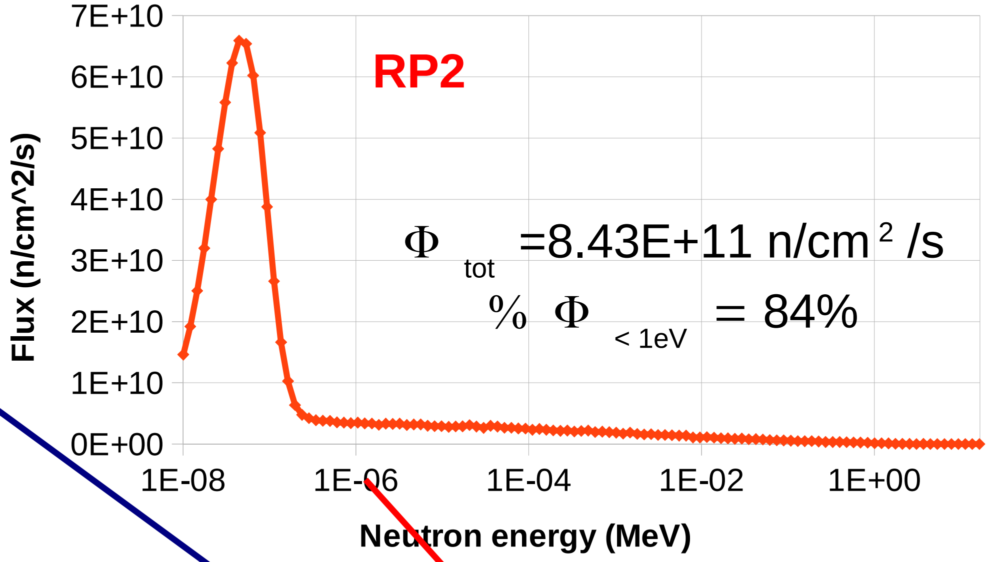


Flux and energy distribution in the graphite shell



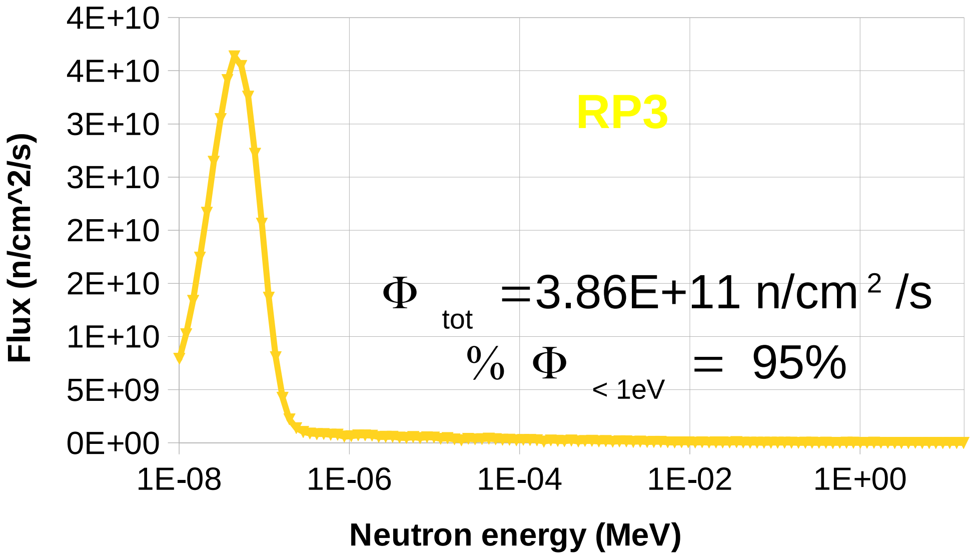
Φ_{tot} =1.84E+12 n/cm^2/s

% $\Phi_{< 1eV}$ = 40%



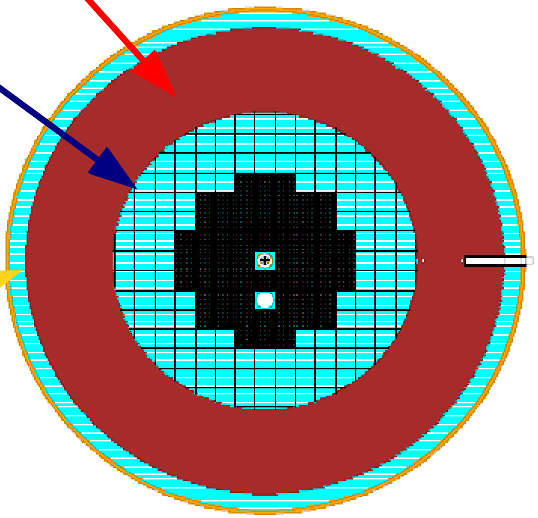
Φ_{tot} =8.43E+11 n/cm^2/s

% $\Phi_{< 1eV}$ = 84%

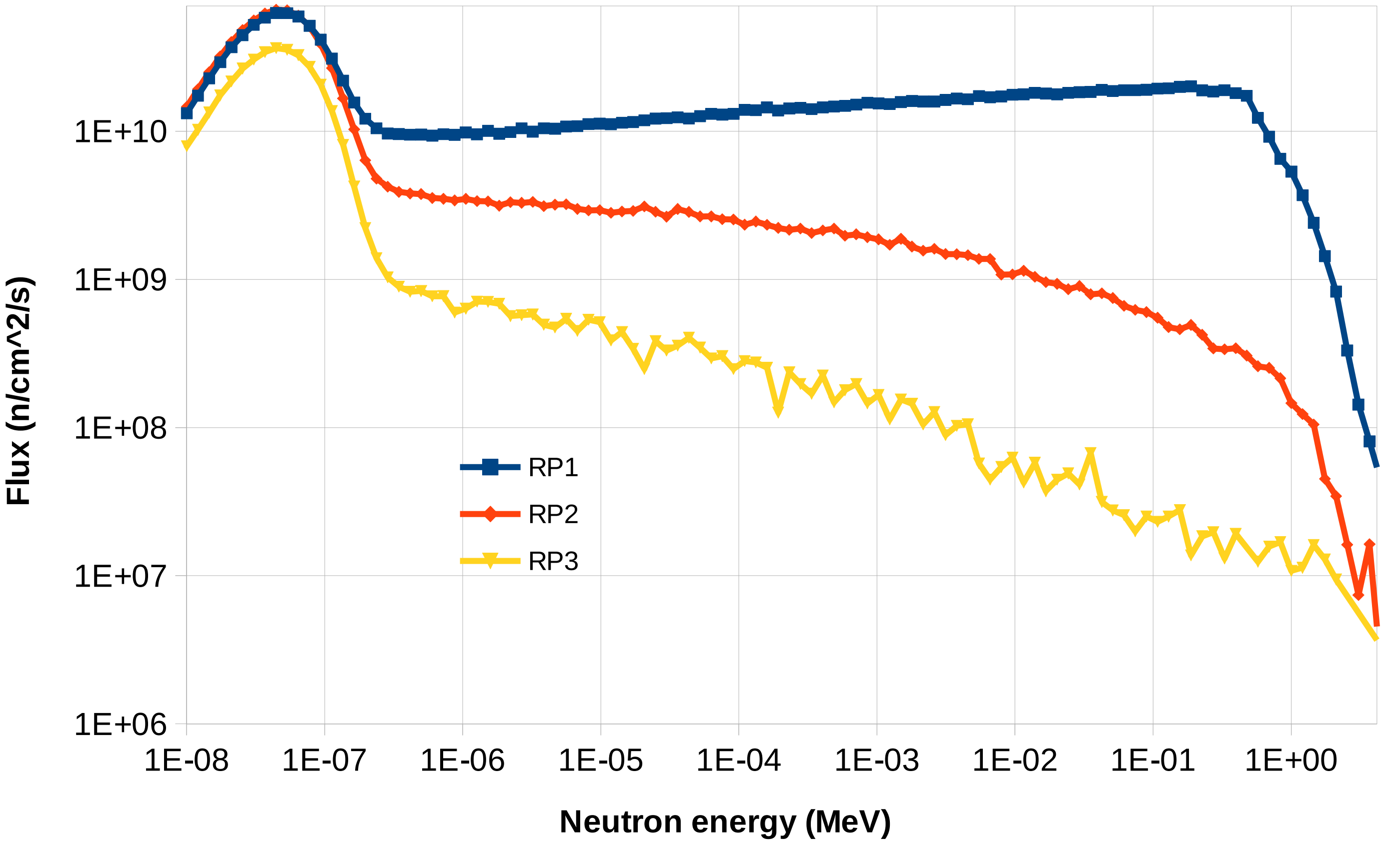


Φ_{tot} =3.86E+11 n/cm^2/s

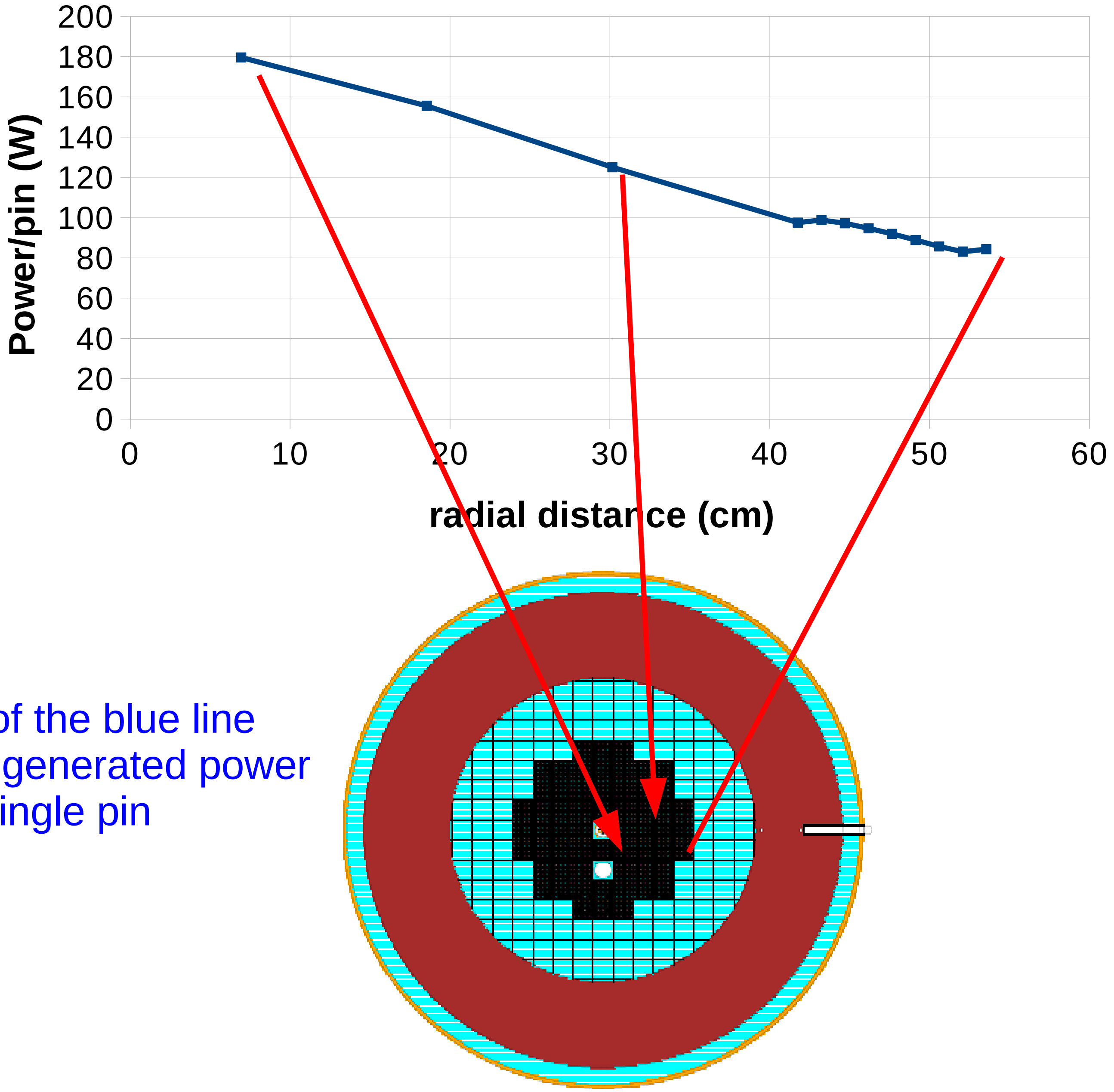
% $\Phi_{< 1eV}$ = 95%



Flux and energy distribution in the graphite shell(2)



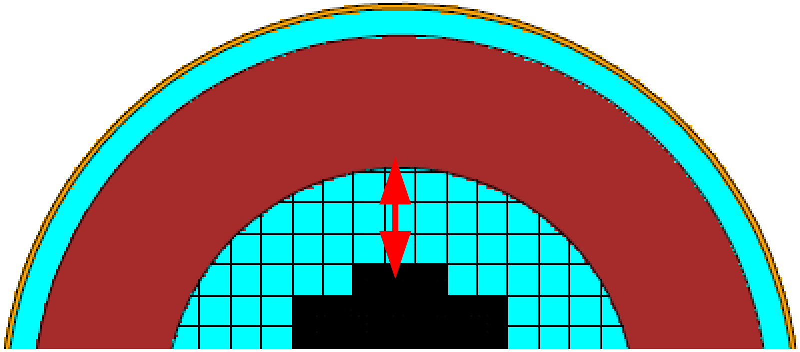
Power radial distribution

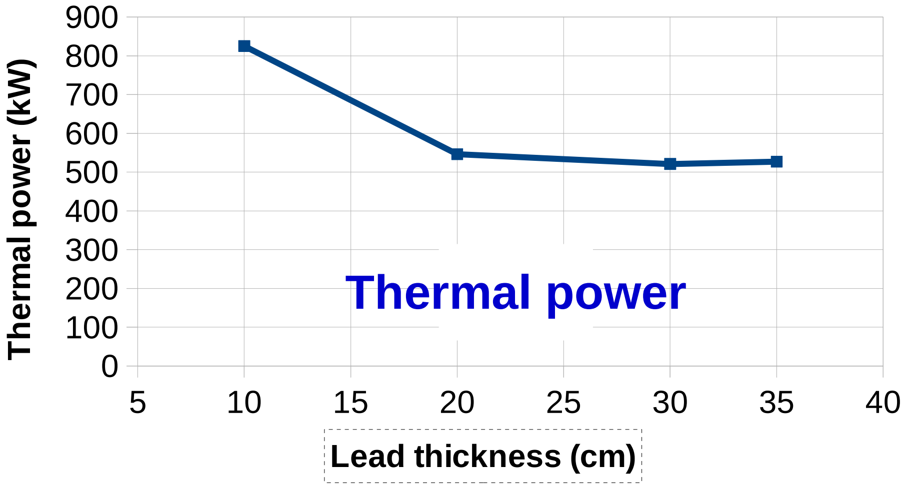


Each point of the blue line
represents the generated power
In a single pin

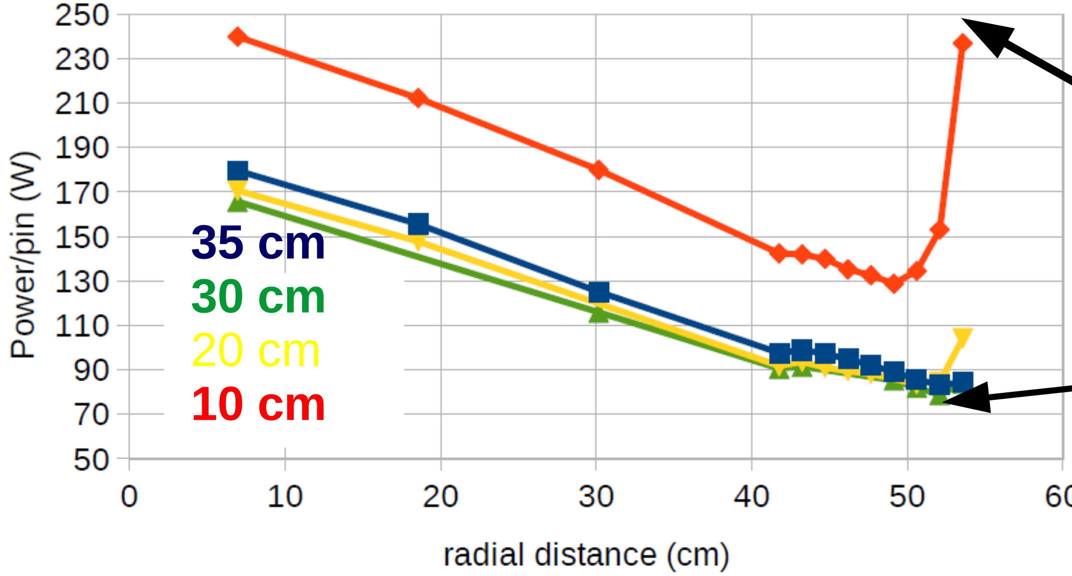
Hybrid reflector

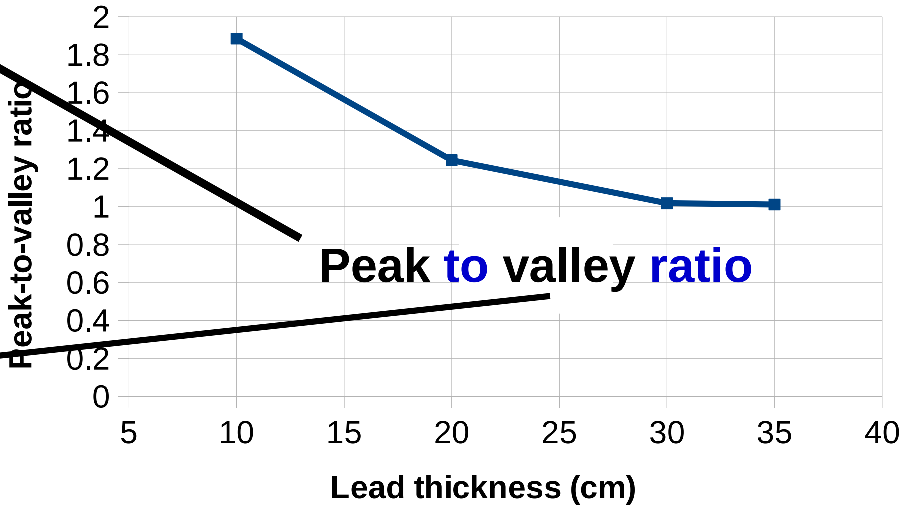
Lead thickness 35 cm





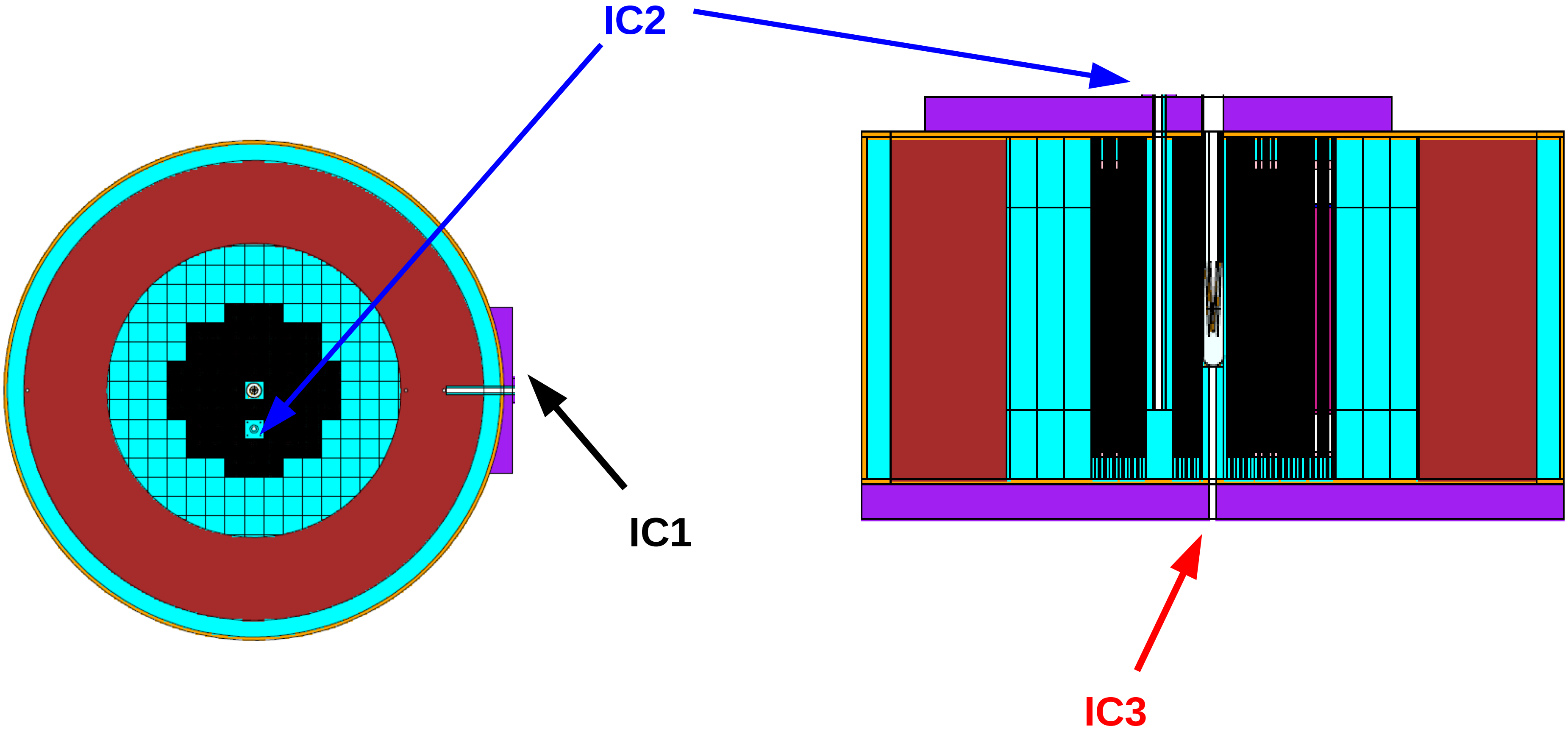
Thermal power





Peak to valley ratio

Irradiation channels

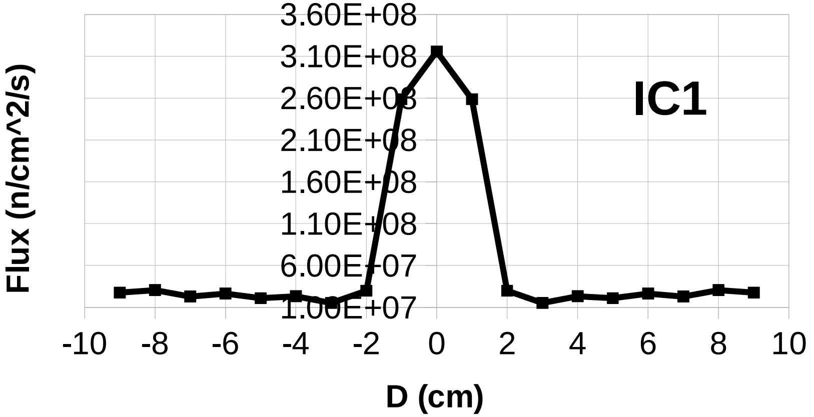


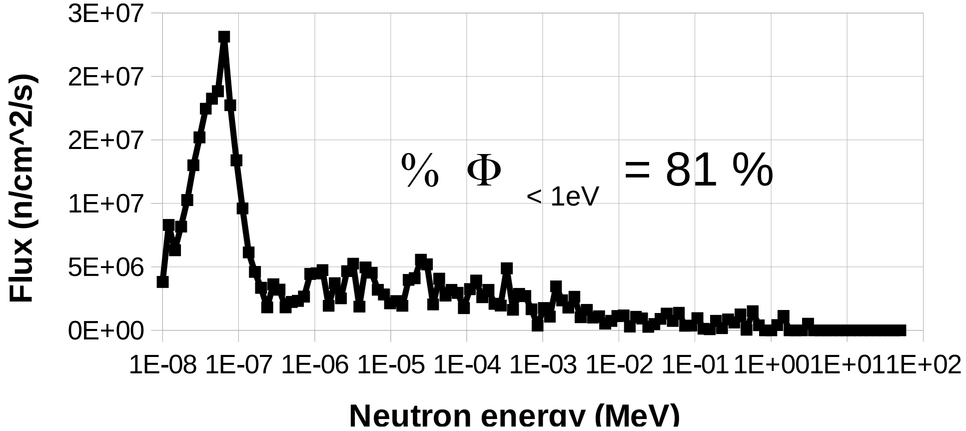
IC1: thermal irradiation channel
IC2: Fast irradiation channel
IC3: Fast irradiation channel (source neutrons)

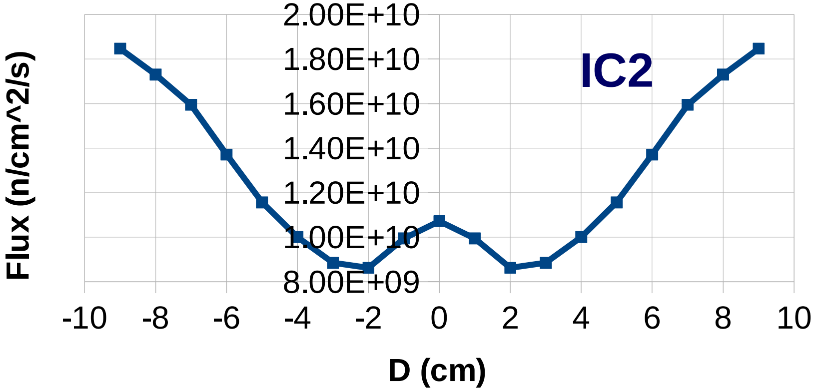
Irradiation channels profiles and spectra

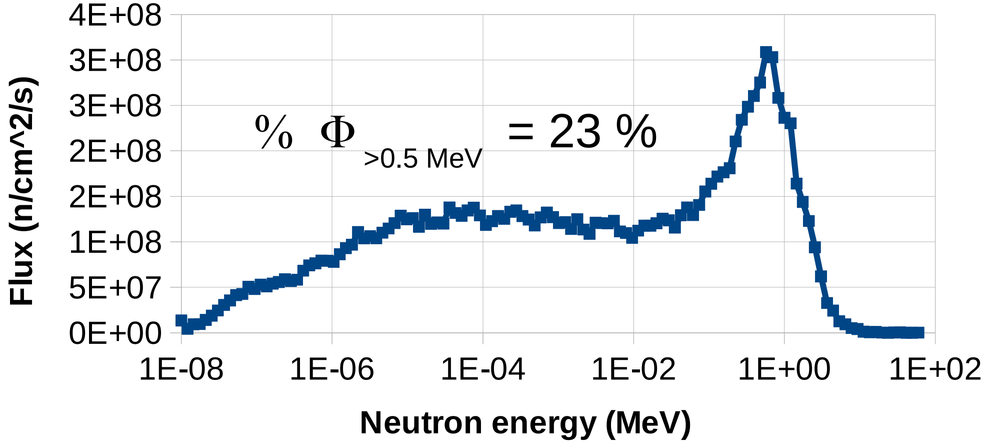
Flux profile

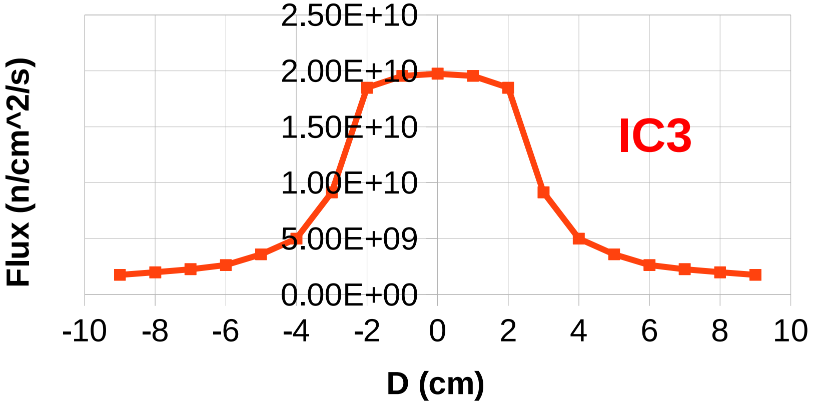
Mean flux distribution

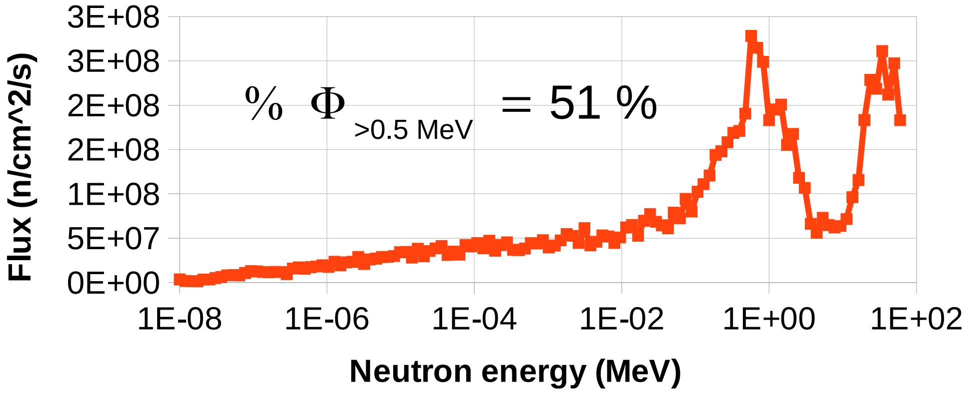








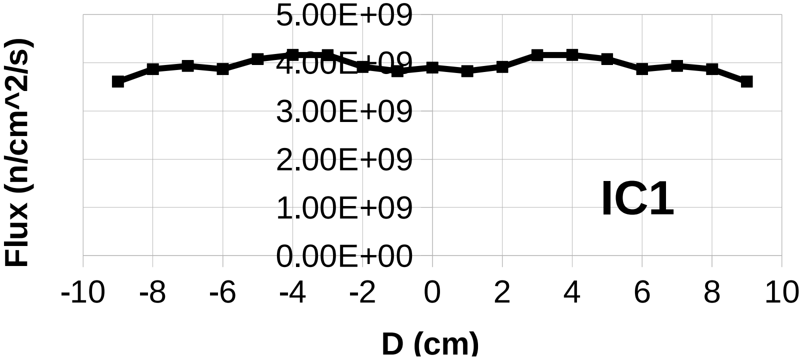


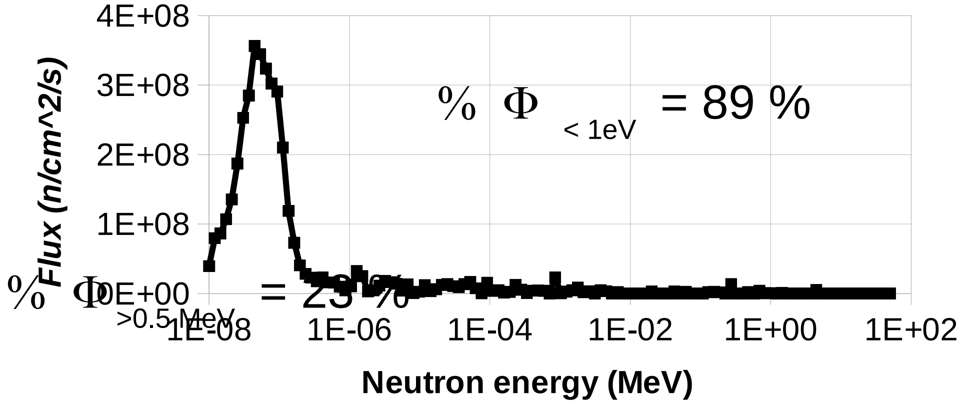


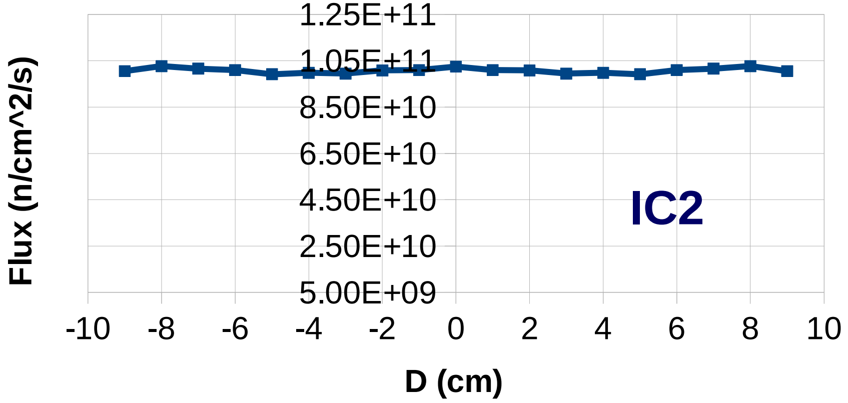
Irradiation channels profiles and spectra (2)

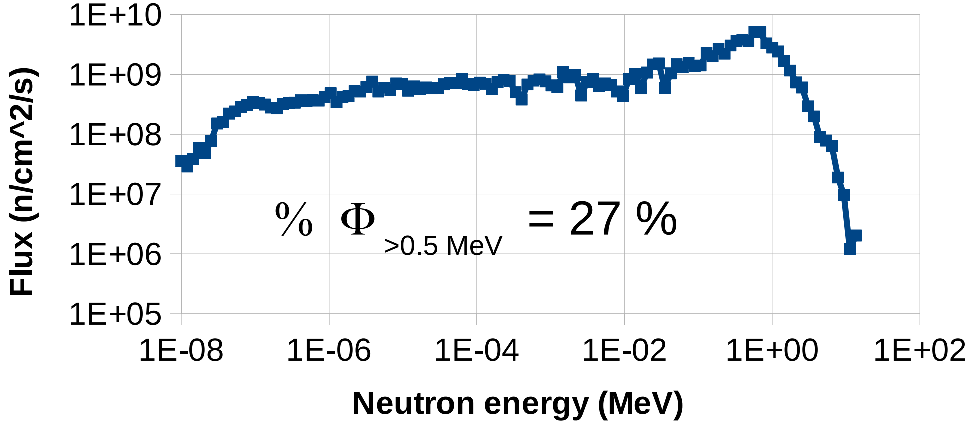
Flux profile

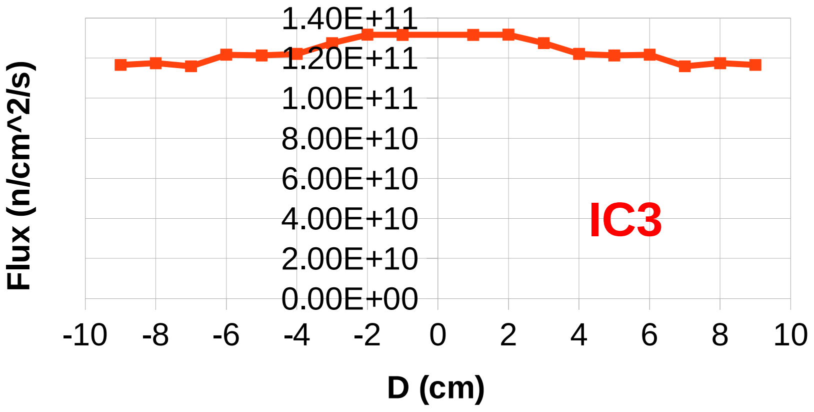
Mean flux distribution

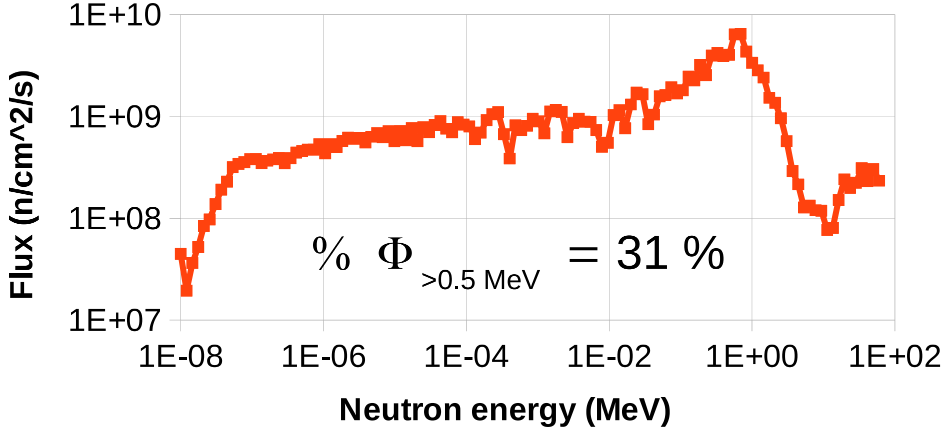








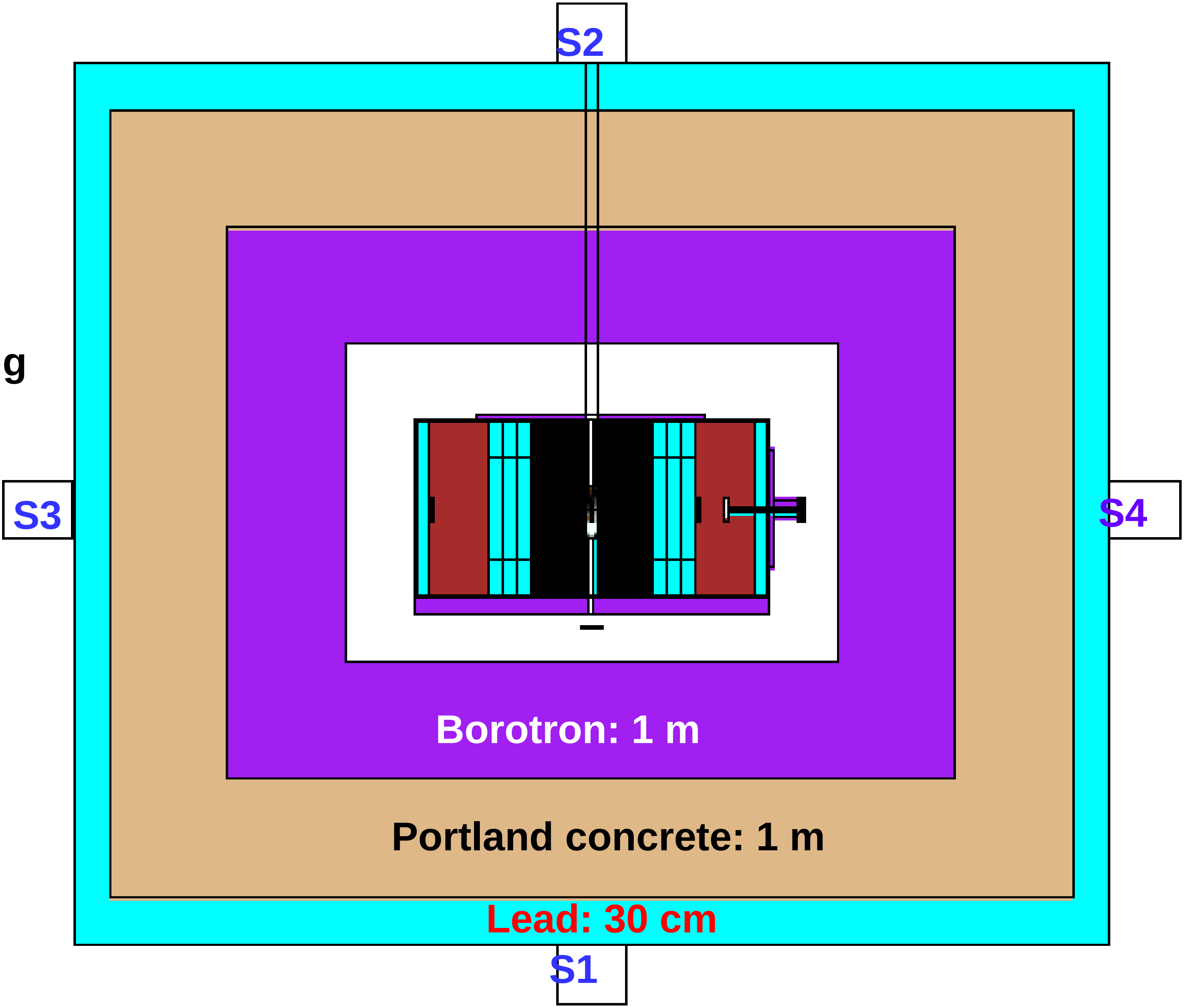




Reactor Shielding

S1, S2
S3, S4

Dose sampling positions



S2

S3

S4

Borotron: 1 m

Portland concrete: 1 m

Lead: 30 cm

S1

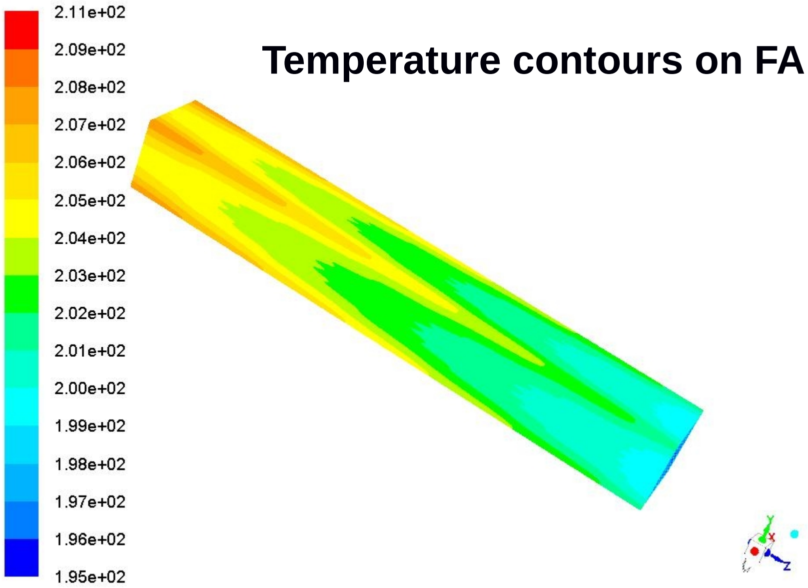
Reactor Shielding (2)

Pos.	γ dose rate (mSv/h) without shield.	γ dose rate (mSv/h) with shield.	Neutron dose rate (mSv/h) without shield.	Neutron .dose rate (mSv/h) with shield.
S1	3.03E+4	~ 0	1,73E+5	~ 0
S2	3.11E+4	~ 0	2.35E+5	~ 0
S3	9,58E+3	~ 0	4.70E+3	~ 0
S4	9,83E+3	~ 0	7.91E+3	~ 0

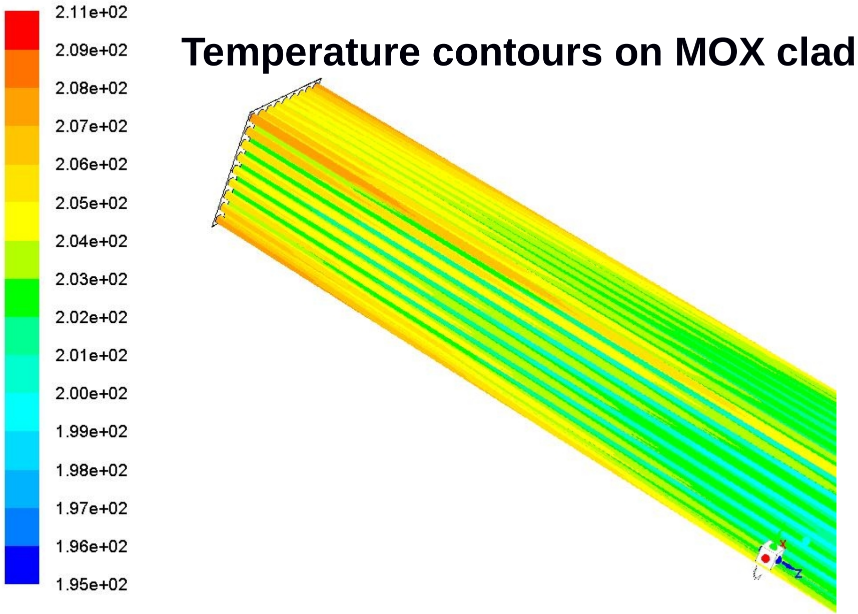
Preliminary thermal-hydraulic characterization

Item	Value	Units
Core Power	**530**	**kW**
Inlet Temperature	**195**	**°C**
Outlet Temperature	**200**	**°C**
Average Temperature	197.5	°C
Average Coolant/MOX ΔT	**11.6**	**°C**
System Pressure	20	bar(a)
Sub-cooling Margin @ Outlet	12.5	°C
Coolant Flow Rate	23.7	kg/s
Coolant Velocity	**0.58**	**m/s**
Pipe Total Losses	0.18	bar

Preliminary thermal-hydraulic characterization CFD

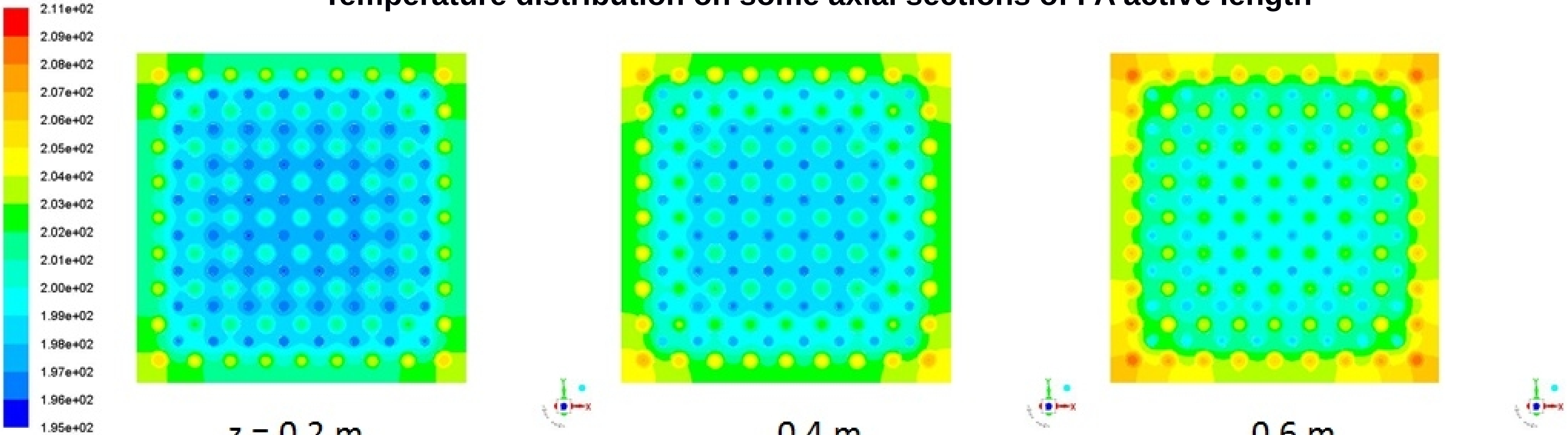


Temperature contours on FA box



Temperature contours on MOX cladding

Temperature distribution on some axial sections of FA active length



z = 0,2 m 0,4 m 0,6 m

Integral measurements of capture rates

Specific measurements can be performed:
- in the core
- in the reflector
- by using the extracted flux

Some examples:

Irradiation of Cs-137 sample ($t_{½}$ =30 y), m=1 mg in the reactor core (CP1):
After an irradiation period of 0.5 d, Cs-138 ($t_{½}$ = 33 m, $E_{´γ}$=1.44 MeV BR=76%, ΔΏ/ Ώ=6.5E-3, ε=2%) gamma activity ~ 78 Bq

Irradiation of I-129 sample ($t_{½}$ = 1.57 x 10^{7} y), m= 1 mg, in the graphite layer (RP1)
After an irradiation period of 12 d, I-130 (($t_{½}$ = 12.36 h, $E_{´γ}$=636 keV, BR=99%, ΔΏ/ Ώ=6.5E-3, ε=5%) gamma activity ~ 7300 Bq

Measurable using a gamma counter-→
→ integral measurement of capture in specific spectrum

Irradiation of Tc-99 sample,($t_{½}$ = 2 x 10^{5} y), m= 1 mg using,the fast irradiation channel (IC2)
prompt gamma detected ~ 80 sec^{-1}

Measurable using a prompt gamma counter-→
→ integral measurement of capture in specific spectrum

Actinides samples irradiation

Some examples:

Irradiation of Np-237 sample ($t_{½}$ =2.14 x 10^{6} y), m=1 μg in the reactor core (CP1):
Fission rate: 2.10 x 10^{4} fiss/s

Irradiation of Am-241 sample ($t_{½}$ =432.2 y), m=1 μg in the reactor core (CP1):
Fission rate: 1.16 x 10^{4} fiss/s

Irradiation of Cm-244 sample ($t_{½}$ =18.1 y), m=1 μg in the reactor core (CP1):
Fission rate: 1.69 x 10^{4} fiss/s

↓

Measurable using a fission chamber →
→ integral measurement of fission in specific spectrum

Irradiation of U-238 sample ($t_{½}$ = 4.46 x 10^{9} y), m= 1 mg, in the graphite layer (RP1)
After an irradiation period of 12 d, Np-239 (($t_{½}$ = 2.35 h, E_{γ}=277 keV, BR=14%, ΔΩ/ Ώ=6.5E-3, ε=9%) gamma activity ~ 3400 Bq

↓

Measurable using a gamma counter-→
→ integral measurement of capture in specific spectrum

Tc99m production

Tc-99m production from:
(satuation time: 6 d)

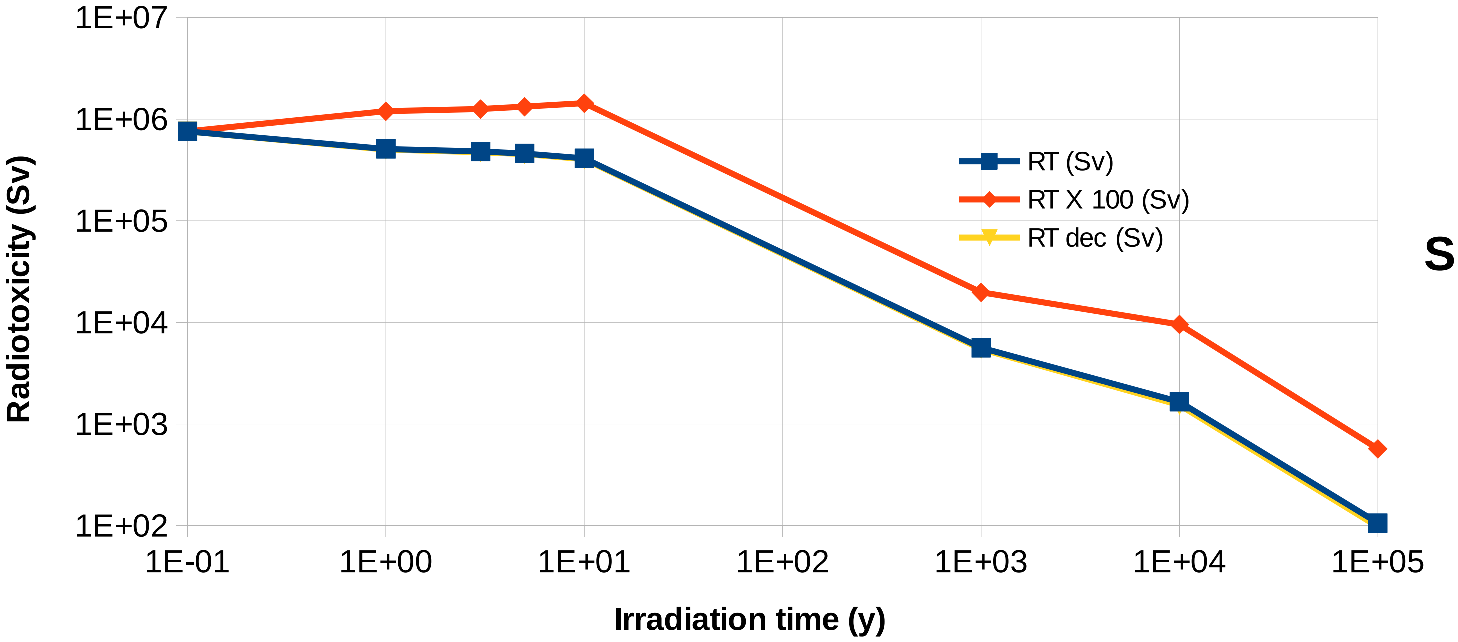
- **Natural Mo sample (m=12 g, 24.29% Mo.98) irradiation in RP1**
  Tc-99m mass: 3.5E-8 g → 7E+9 Bq (after 1 d of decay period)

- **UO_2 sample (m=14 g, 20% U-235) irradiation in RP1**
  Tc-99m mass: 3.2E-7 g → 6E+10 Bq (after 1 d of decay period)

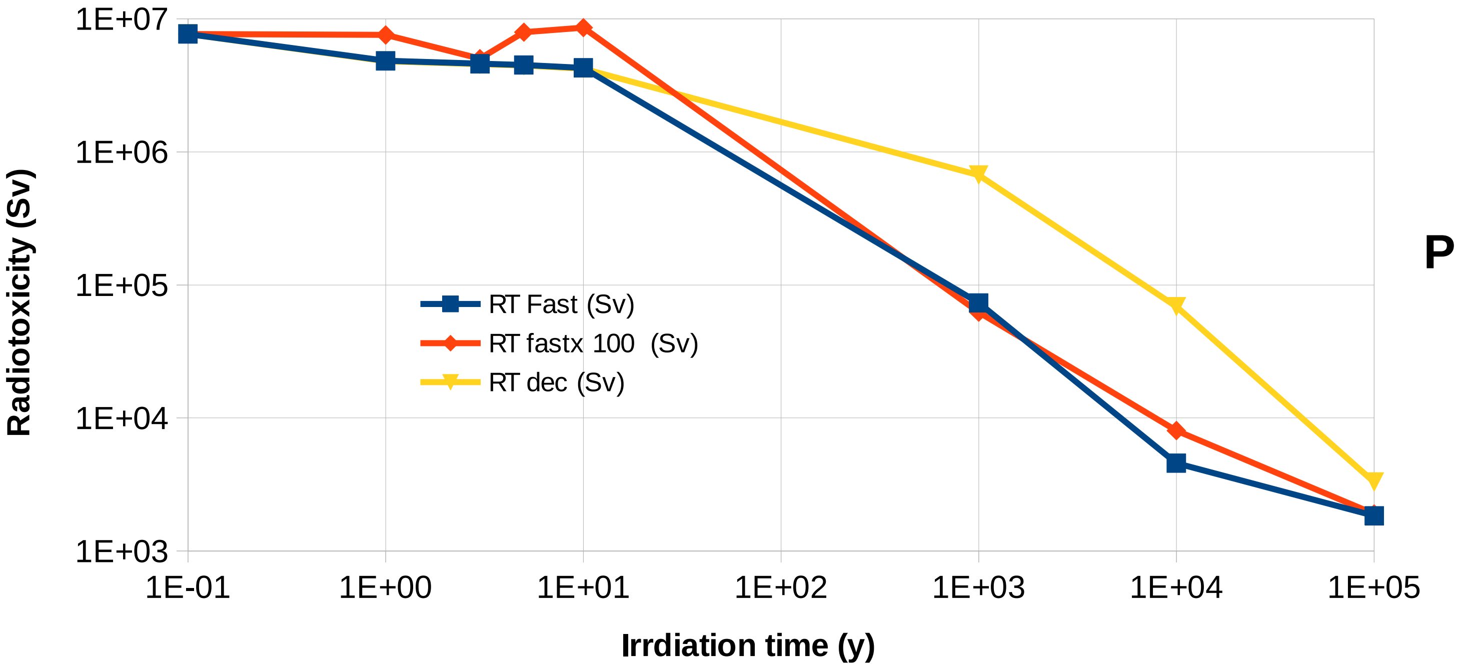
↓

If we consider 30mCi of Tc99m as a single medical treatment, we are able to perform 7 and 60 specimens respectively

Fuel radiotoxicity analysis of test pins



Spent fuel pin

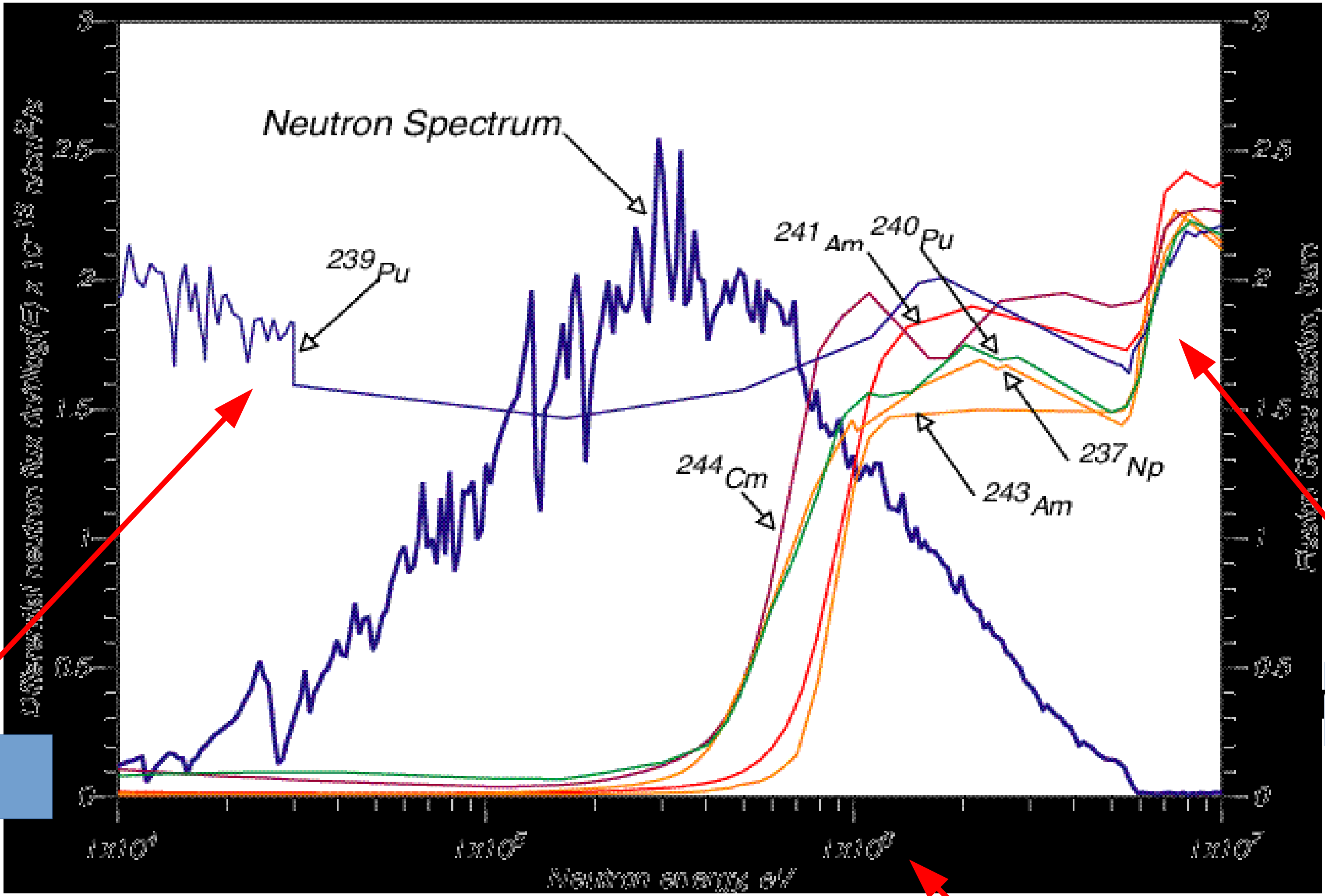


Pu+MA fuel pin

Conclusions

- **We started from a lead model for education, training and research on leads systems and waste transmutation.**
- **We designed a low power, flexible ADS with fast and slow spectra.**
- **New: mixed lead-graphite reflector and water as coolant.**
- **Neutron spectrum fast in the core and slow/thermal in graphite.**
- **Possibility to have both in-system and external integral measurements on fission and capture.**
- **Preliminary thermal-hydraulic calculations performed.**
- **This activity has been supported by INFN, Centro Fermi and European Atomic Energy Commission (Euratom, Seventh Framework Program FP7/2007-2011) under the Project CHANDA.**

Why fast neutrons?

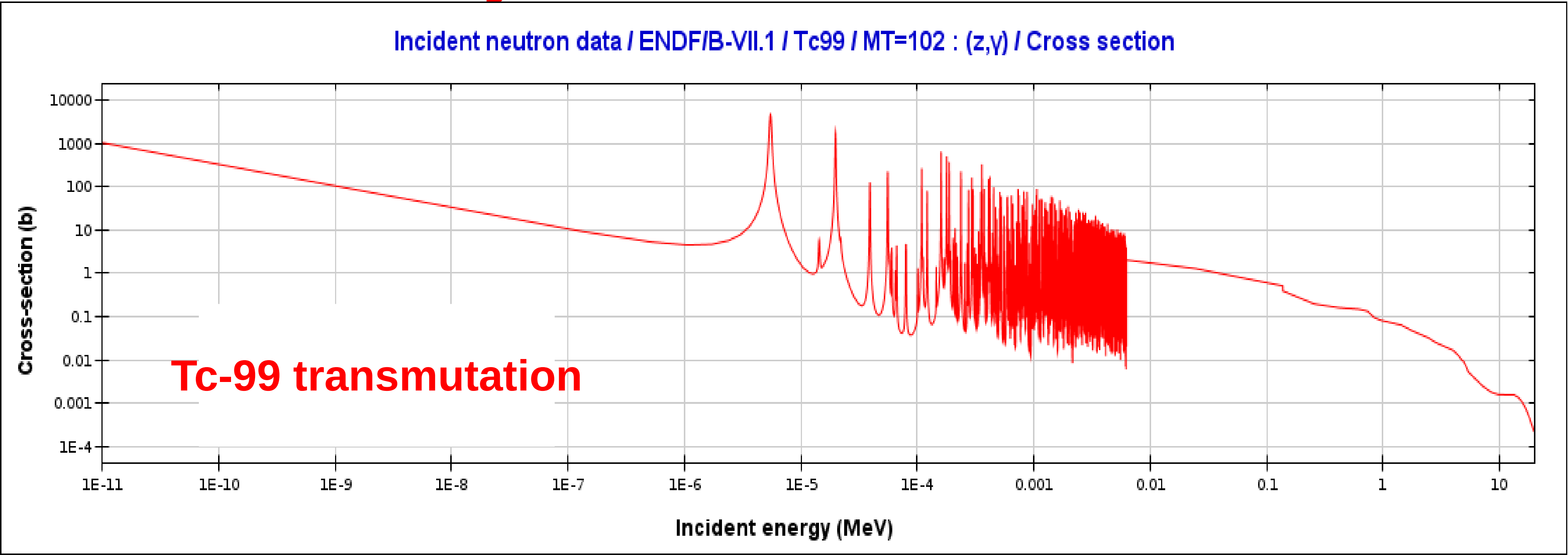


Pu-239

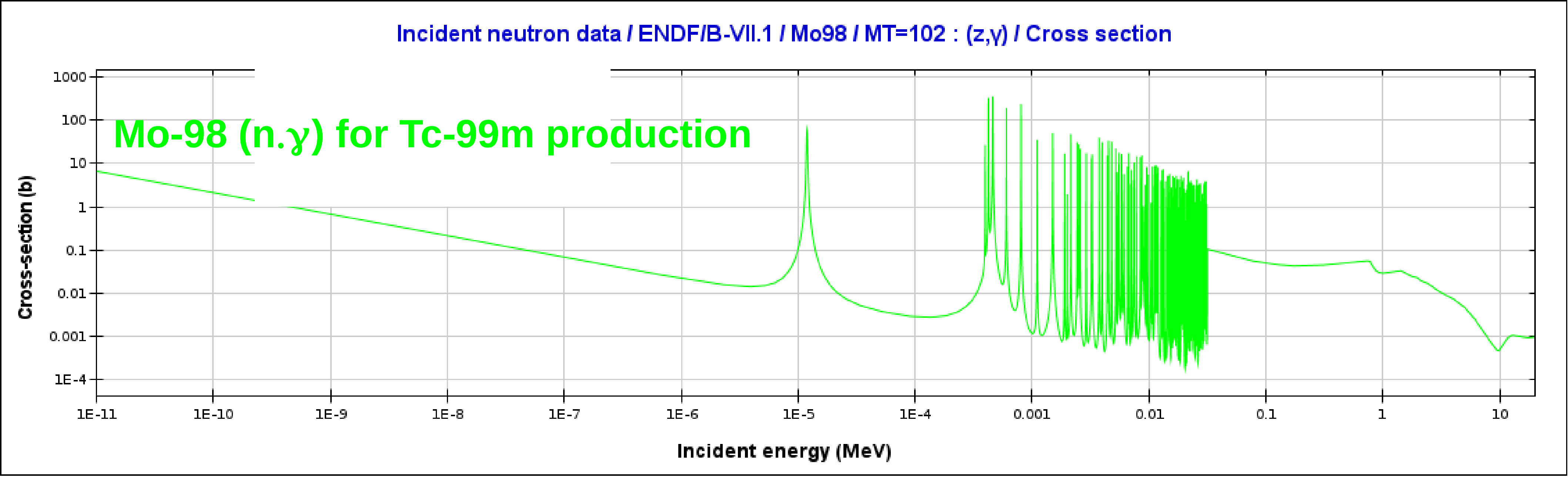
Minor Actinides

1 MeV

Why slower neutrons?



Tc-99 transmutation



Mo-98 (n.γ) for Tc-99m production

Burn-up evaluation