Assisted Photon Systems – APS project

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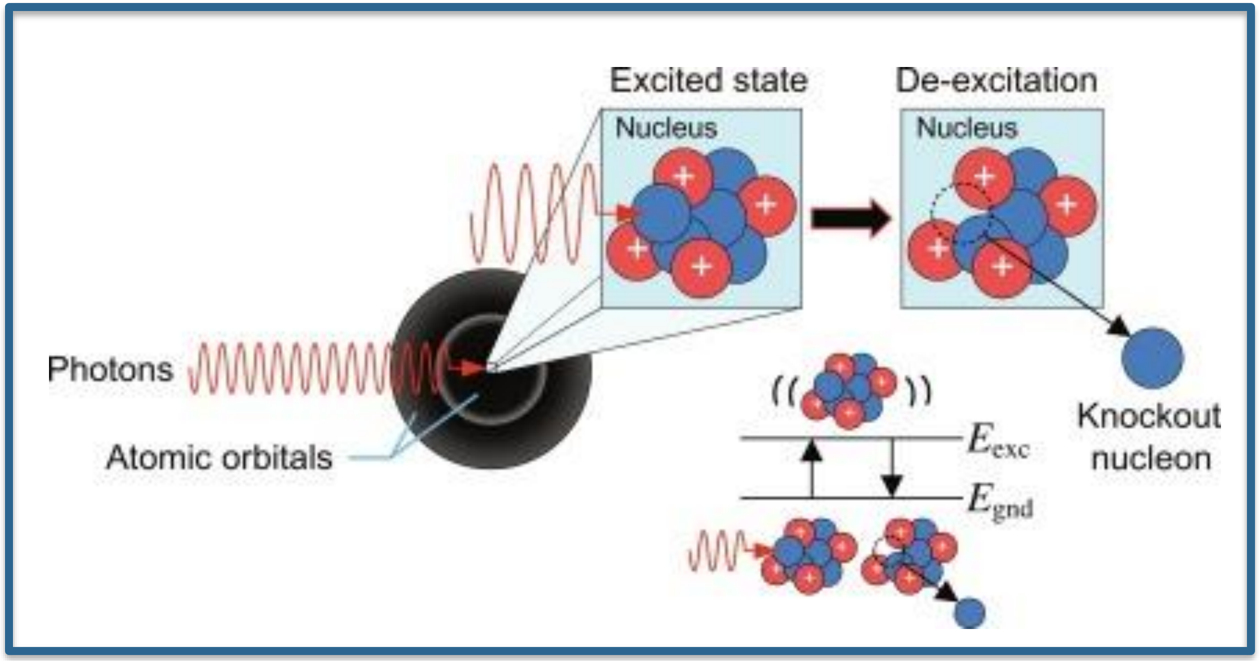
Consiglio di Sezione - 10/07/2025

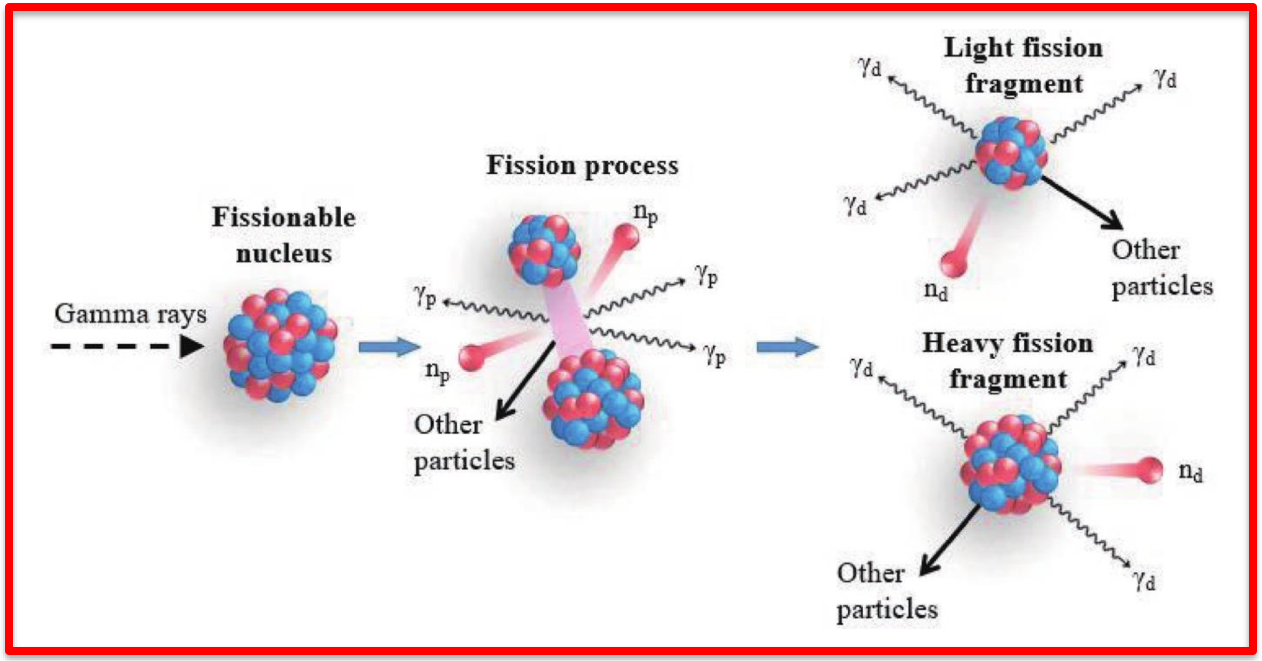
Why photons?

Photonuclear reactions are available channels for inducing

Transmutations



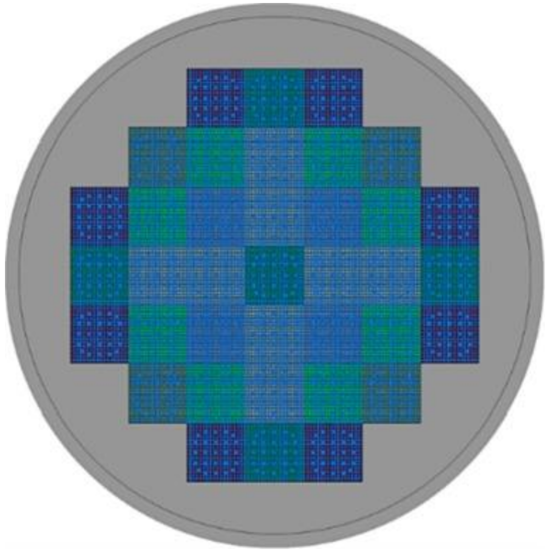
Fissions



Photofission

Aim of this analysis: to evaluate the principles and capabilities of minor actinide transmutation using photon sources

Case study on a SMR spent fuel @ 50 MWd/kg



Isotope	^{241}Am	^{243}Am	^{242}Cm	^{243}Cm	^{244}Cm	^{245}Cm	^{237}Np
Mass (g)	2616	3710	14.08	10.0	2254	217.7	5425

Photon Sources for Transmutation

Bremsstrahlung

- Production: Electrons (40 MeV) decelerated in high-Z target
- Continuous energy spectrum (0-40 MeV)
- Simple and cost-effective implementation
- Well-established technology for industrial applications

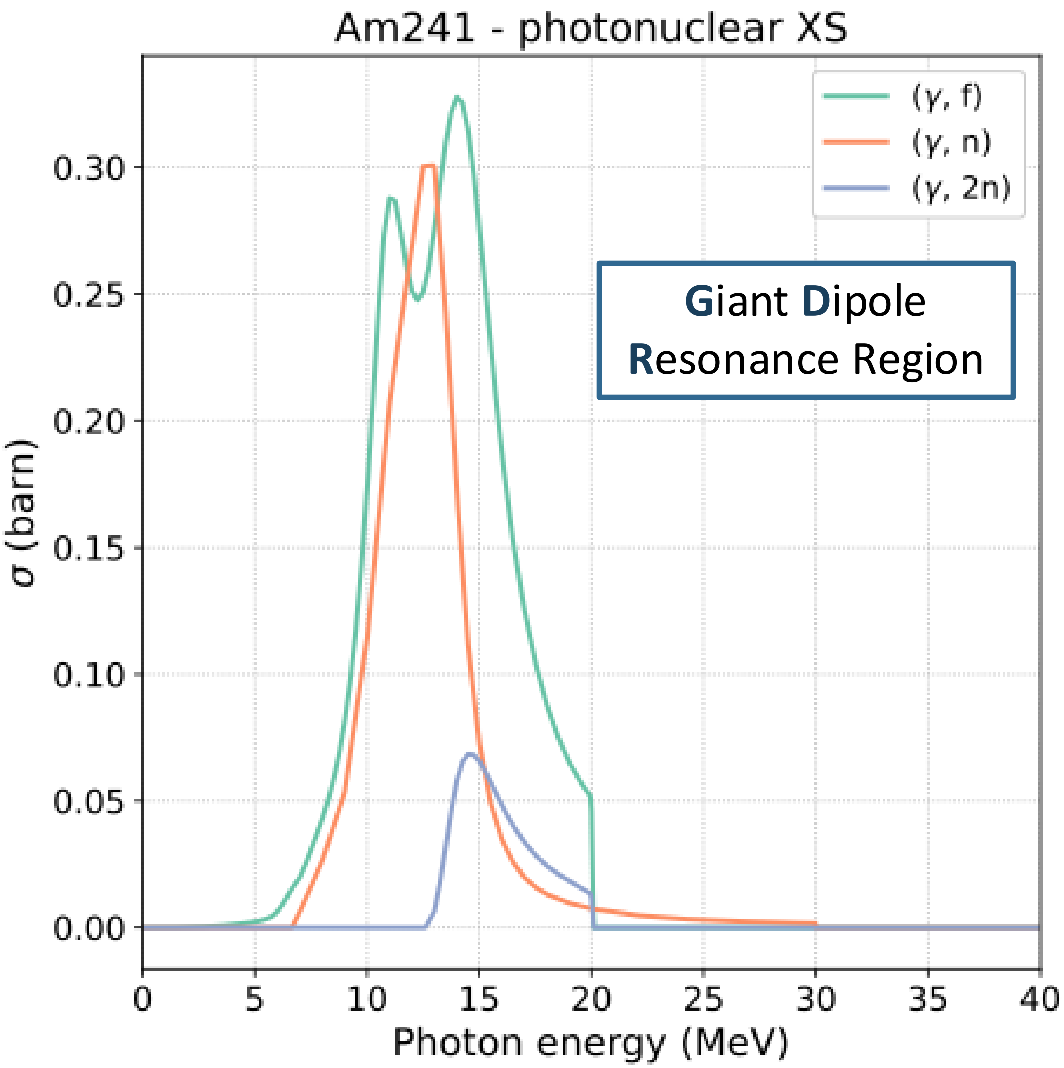
Laser Compton Backscattering (LCB)

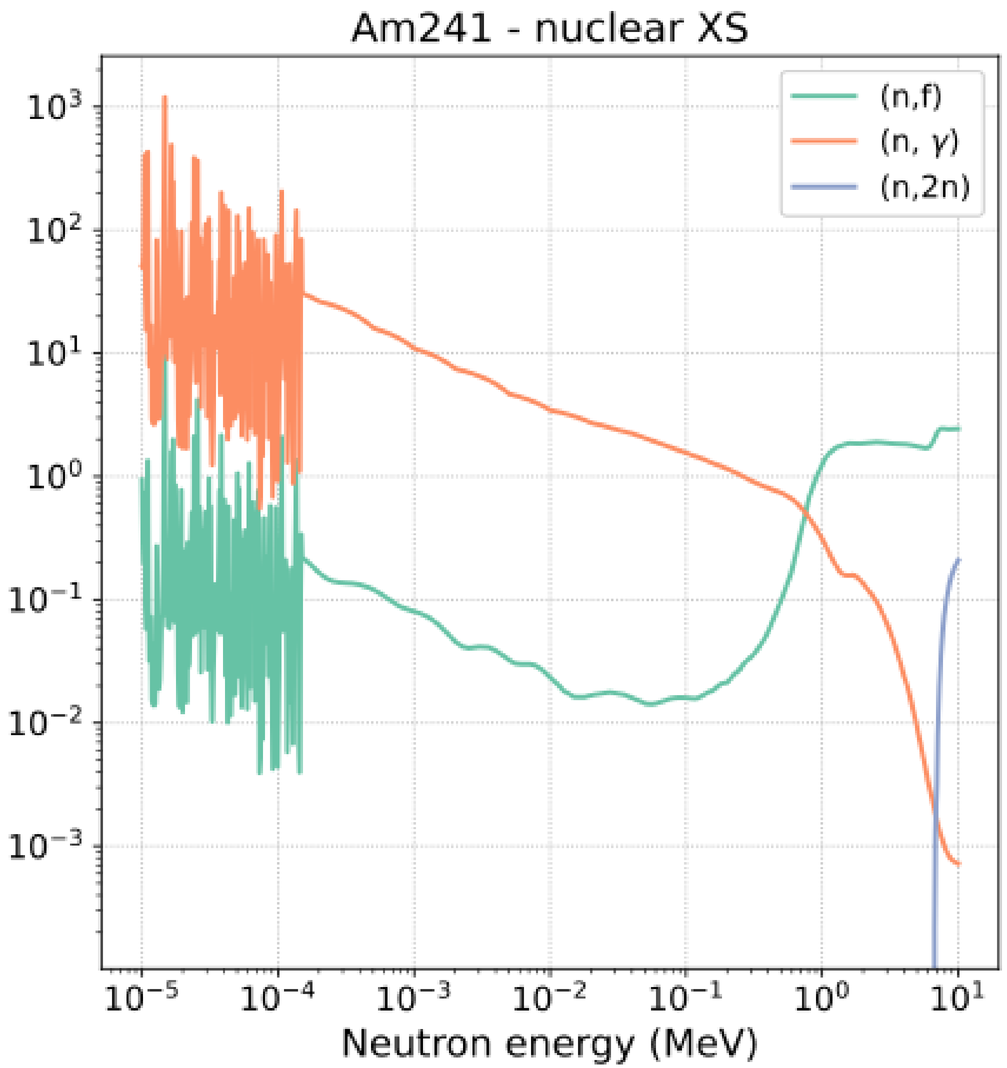
- Production: High-energy electrons collide with laser photons
- Narrow, tunable photon spectrum (quasi-monoenergetic)
- Challenging implementation but offers good energy precision

Synchrotron

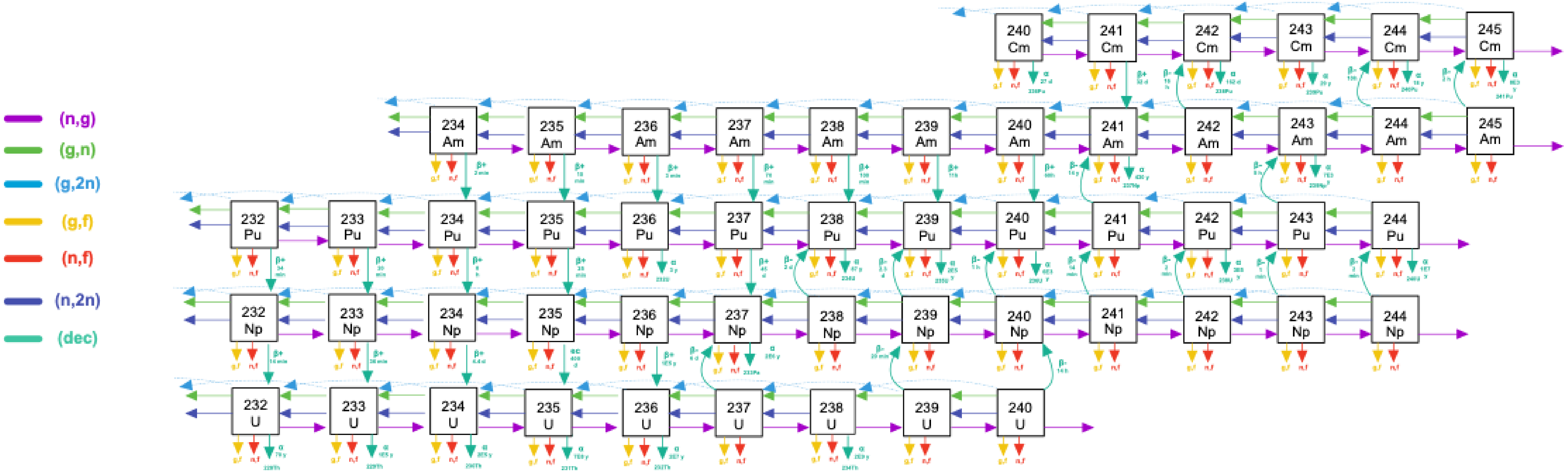
- Requires large electron facility
- High photon fluxes available
- Low energy consumption and excellent beam control

Why photons?


Am241 - photonuclear XS
(γ, f)
(γ, n)
(γ, 2n)
Giant Dipole Resonance Region
σ (barn)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0
5
10
15
20
25
30
35
40
Photon energy (MeV)

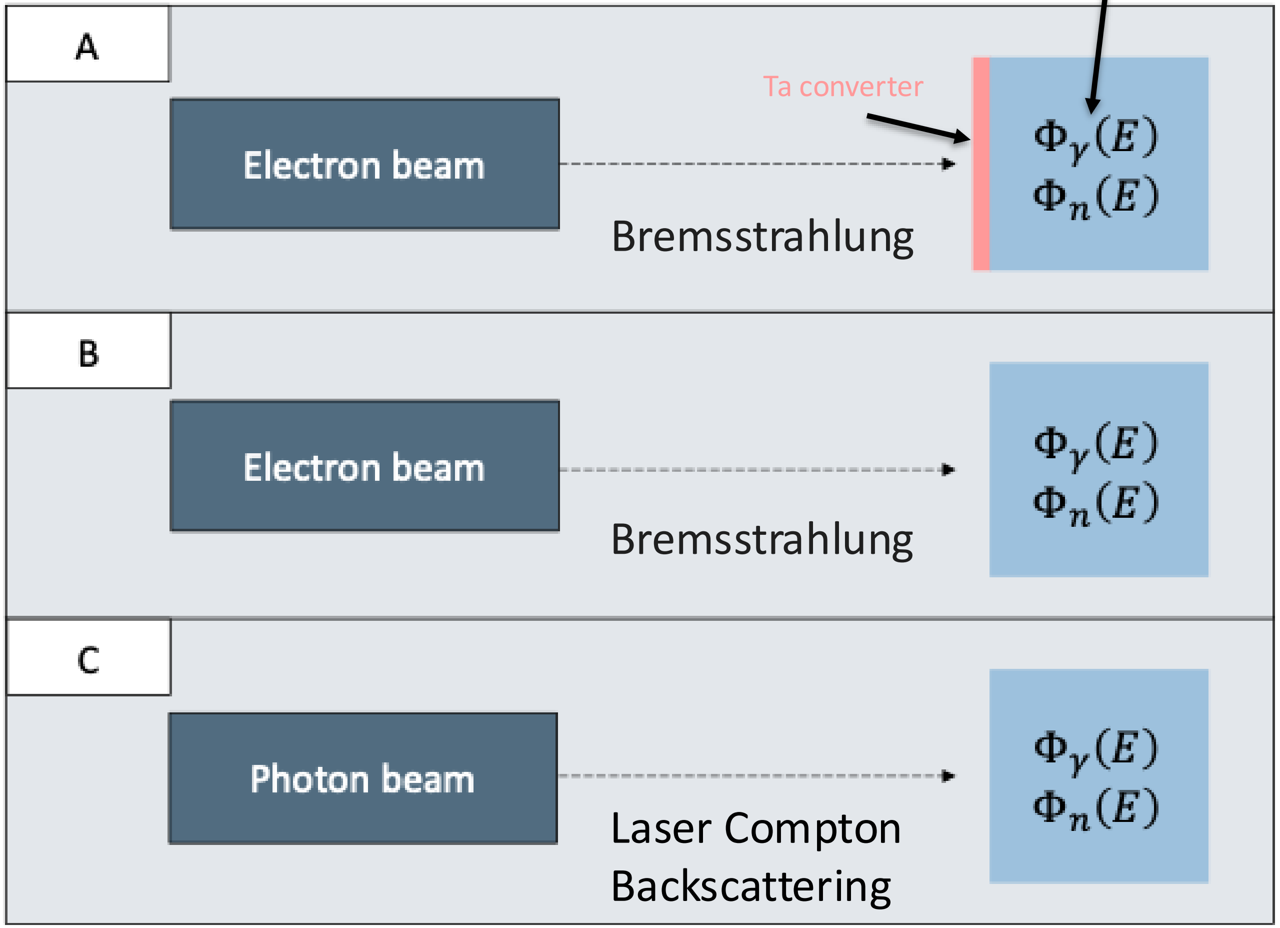

Am241 - nuclear XS
(n,f)
(n, γ)
(n,2n)
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Neutron energy (MeV)

Transmutation channels



Case study description

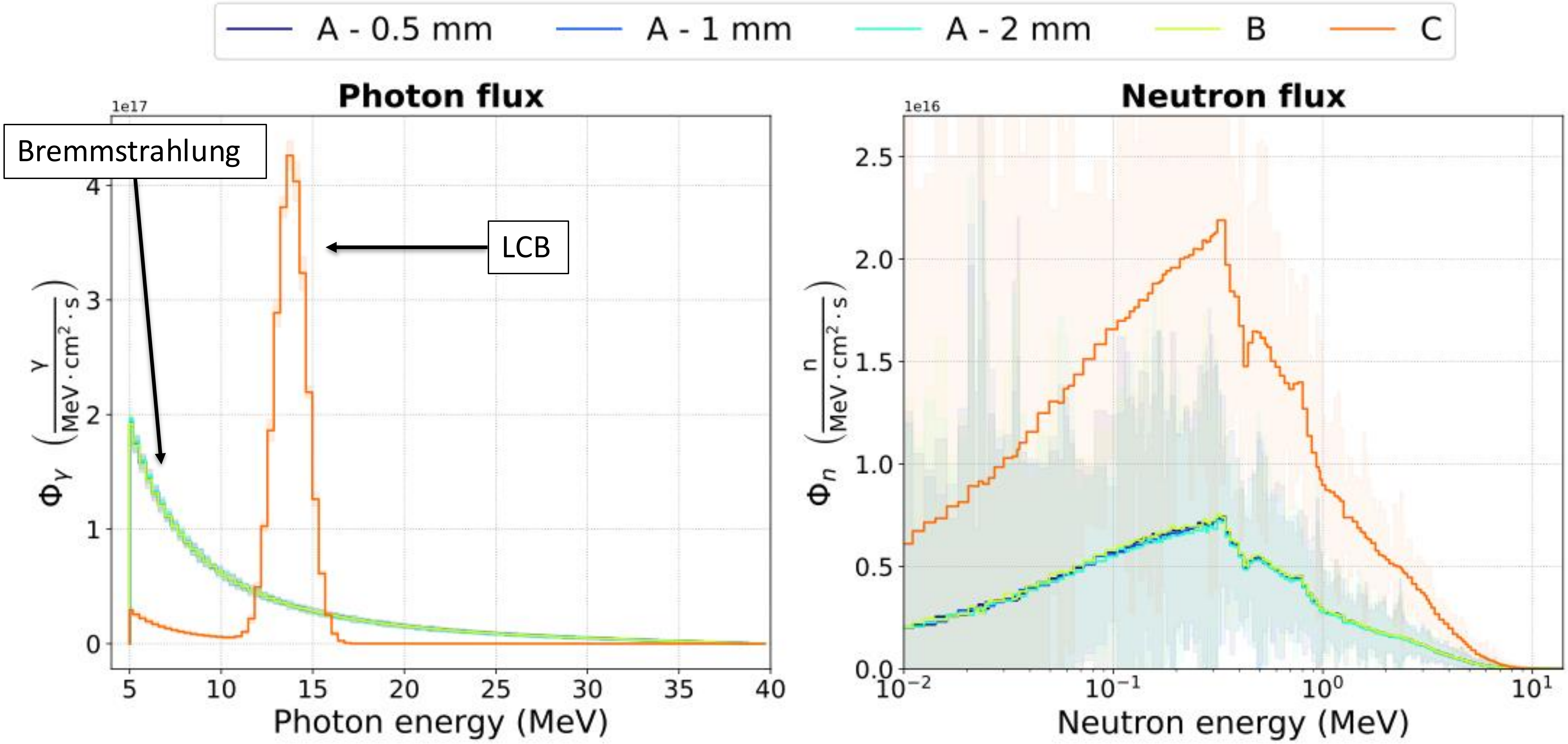
Minor Actinides from SMR spent fuel are separated in a **12 cm³ sample**



FLUKA simulation

- Systems A, B, C simulated with 10^7 primary particles;
- Photon and neutron energy flux distributions calculalated within the spent fuel sample;
- Flux energy spectrum shape was critical for our analysis;
- Flux intensity varied from 10^{17} to 10^{20} γ/cm^2s to evaluate flux-dependent effects.

Flux shape

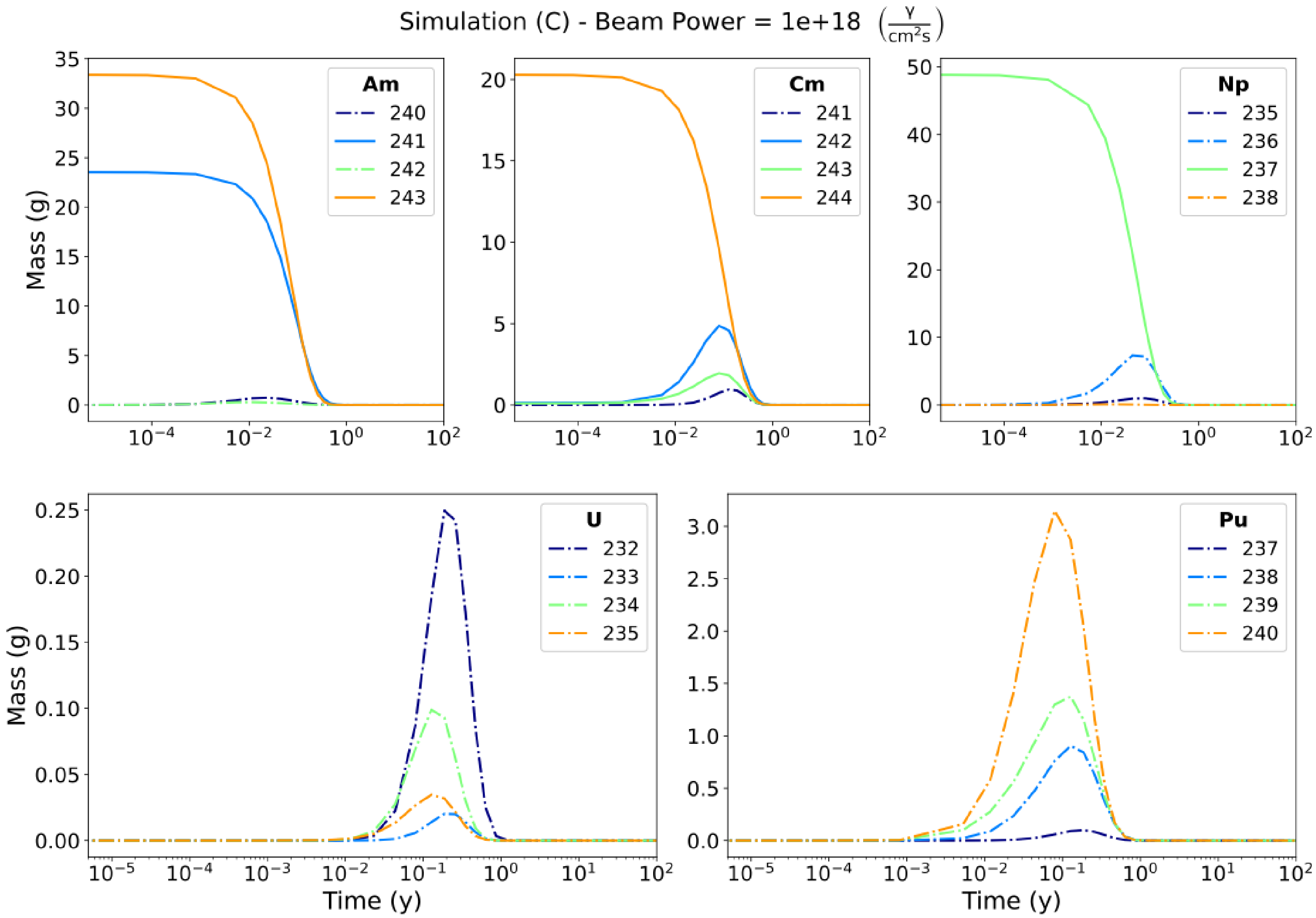

A - 0.5 mm
A - 1 mm
A - 2 mm
B
C
Photon flux
1e17
Bremmstrahlung
LCB
$\Phi_\gamma \left(\frac{\gamma}{\mathrm{MeV \cdot cm^2 \cdot s}}\right)$
0
1
2
3
4
5
10
15
20
25
30
35
40
Photon energy (MeV)
Neutron flux
1e16
$\Phi_n \left(\frac{n}{\mathrm{MeV \cdot cm^2 \cdot s}}\right)$
0.0
0.5
1.0
1.5
2.0
2.5
10^{-2}
10^{-1}
10^{0}
10^{1}
Neutron energy (MeV)

Concentration evolution

$$
\begin{aligned}
\frac{dN_i(t)}{dt} = & \underbrace{-\lambda_i N_i(t)}_{\text{destruction by decay}} + \sum_{j \neq i} \underbrace{\lambda_{j\rightarrow i} N_j(t)}_{\text{creation by decay}} \\
& \underbrace{-N_i(t) \int \left[\sigma^i_{\gamma,f}(E) + \sigma^i_{\gamma,n}(E) + \sigma^i_{\gamma,2n}(E)\right] \Phi_\gamma(E)\, dE}_{\text{destruction by photon capture}} \\
& + \sum_{j \neq i} \underbrace{N_j(t) \int \left[\sigma^{j\rightarrow i}_{\gamma,n}(E) + \sigma^{j\rightarrow i}_{\gamma,2n}(E)\right] \Phi_\gamma(E)\, dE}_{\text{creation by photon reactions}} \\
& \underbrace{-N_i(t) \int \left[\sigma^i_{n,f}(E) + \sigma^i_{n,\gamma}(E) + \sigma^i_{n,2n}(E))\right] \Phi_n(E)\, dE}_{\text{destruction by neutron capture}} \\
& + \sum_{j \neq i} \underbrace{N_j(t) \int \left[\sigma^{j\rightarrow i}_{n,\gamma}(E) + \sigma^{j\rightarrow i}_{n,2n}(E)\right] \Phi_n(E)\, dE}_{\text{creation by neutron reactions}}
\end{aligned}
$$

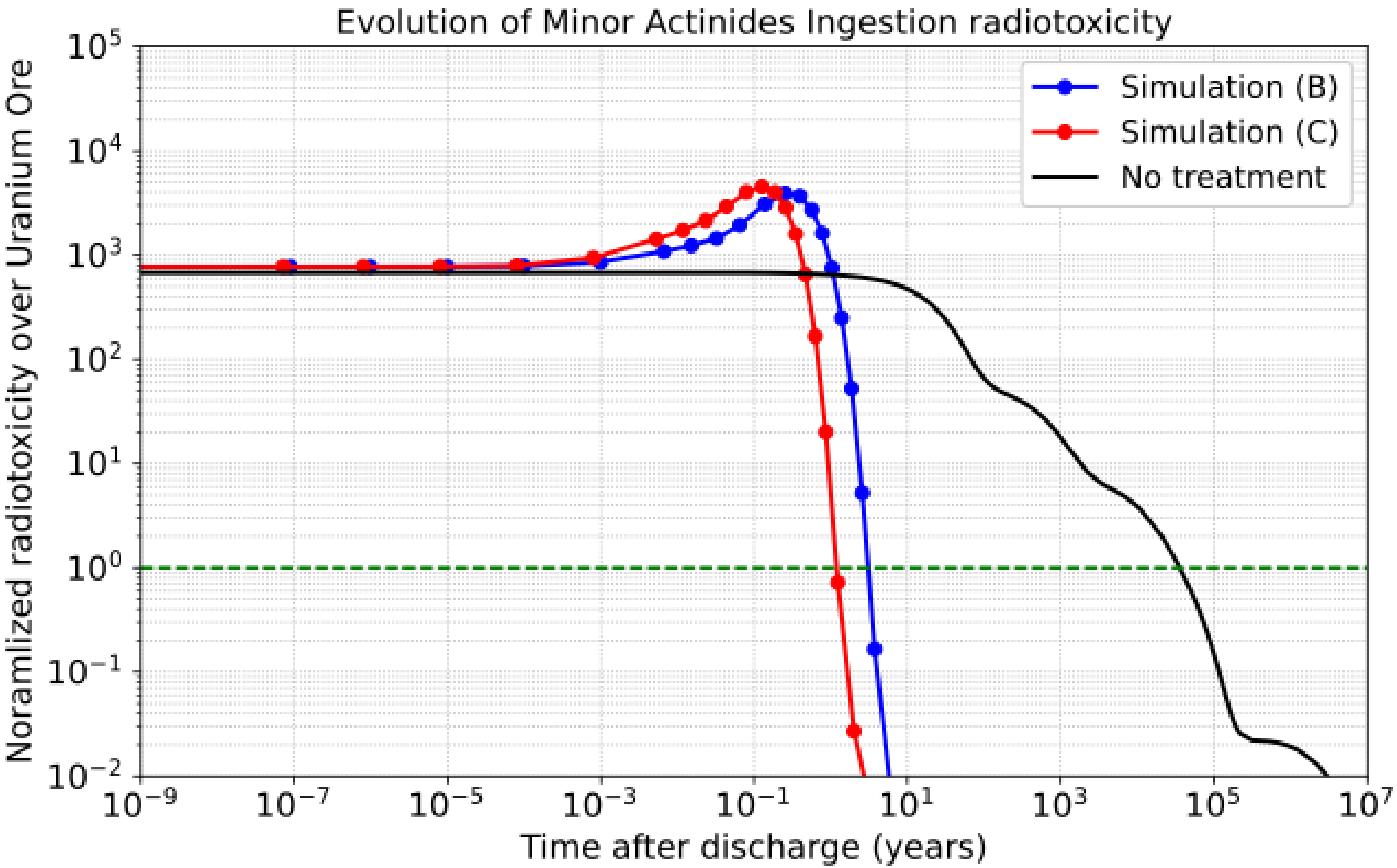
- Fluxes and cross sections were used as input for solving the Bateman equation for the 53 nuclides involved in the transmutation chain;
- A time frame of 100 years was considered;
- Along with the concentration, also the system radiotoxicity was calculated.

Results (1)

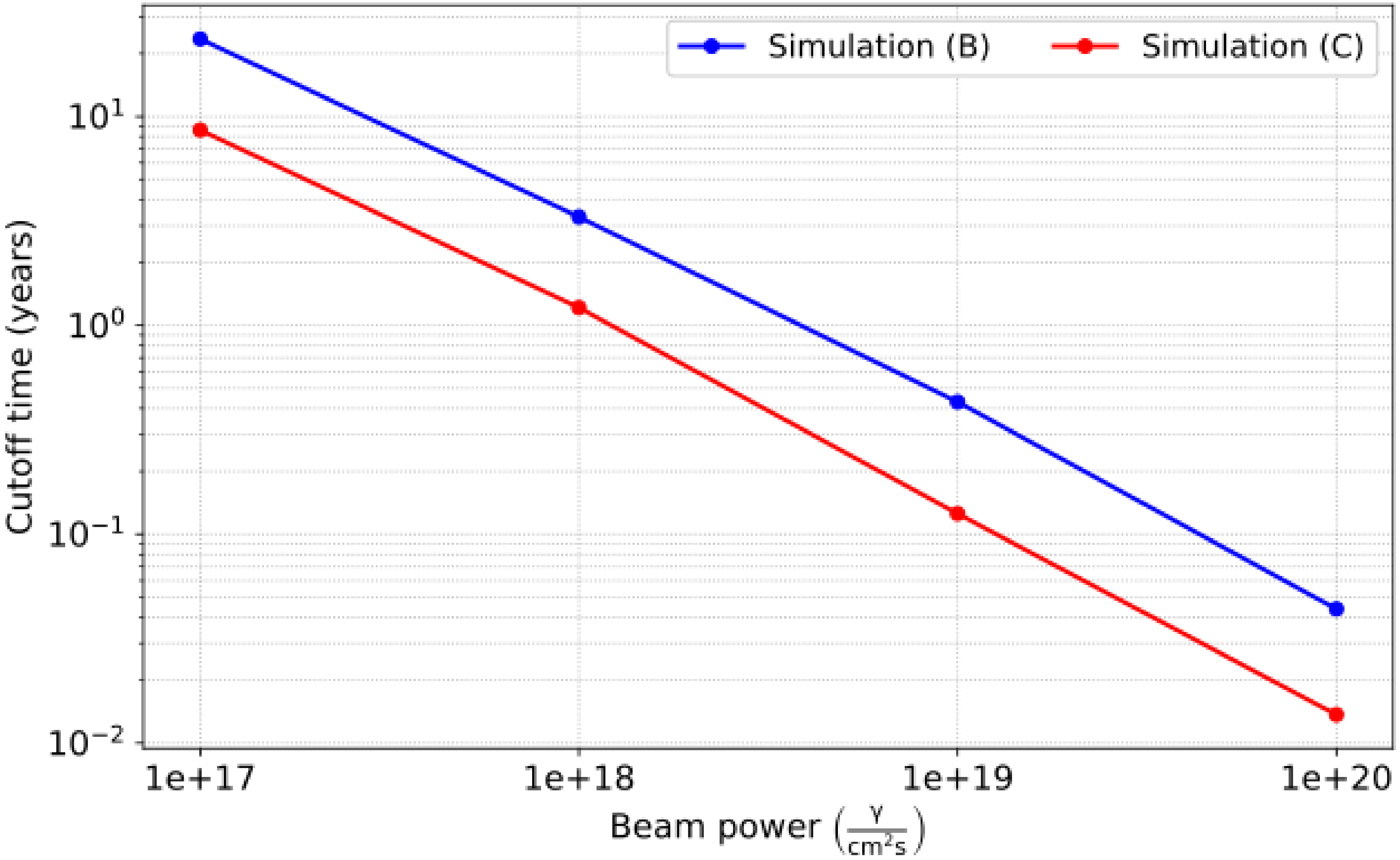


- Solid line = isotopes present in the initial condition
- Dashed line = isotopes produced during the treatment process

Results (2)

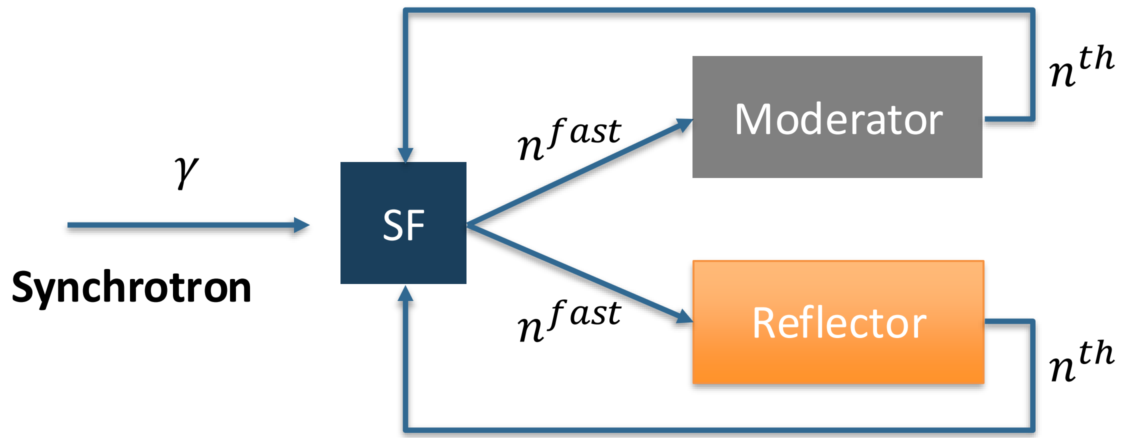

Evolution of Minor Actinides Ingestion radiotoxicity
Simulation (B)
Simulation (C)
No treatment
Noramlized radiotoxicity over Uranium Ore
Time after discharge (years)
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-9}
10^{-7}
10^{-5}
10^{-3}
10^{-1}
10^{1}
10^{3}
10^{5}
10^{7}

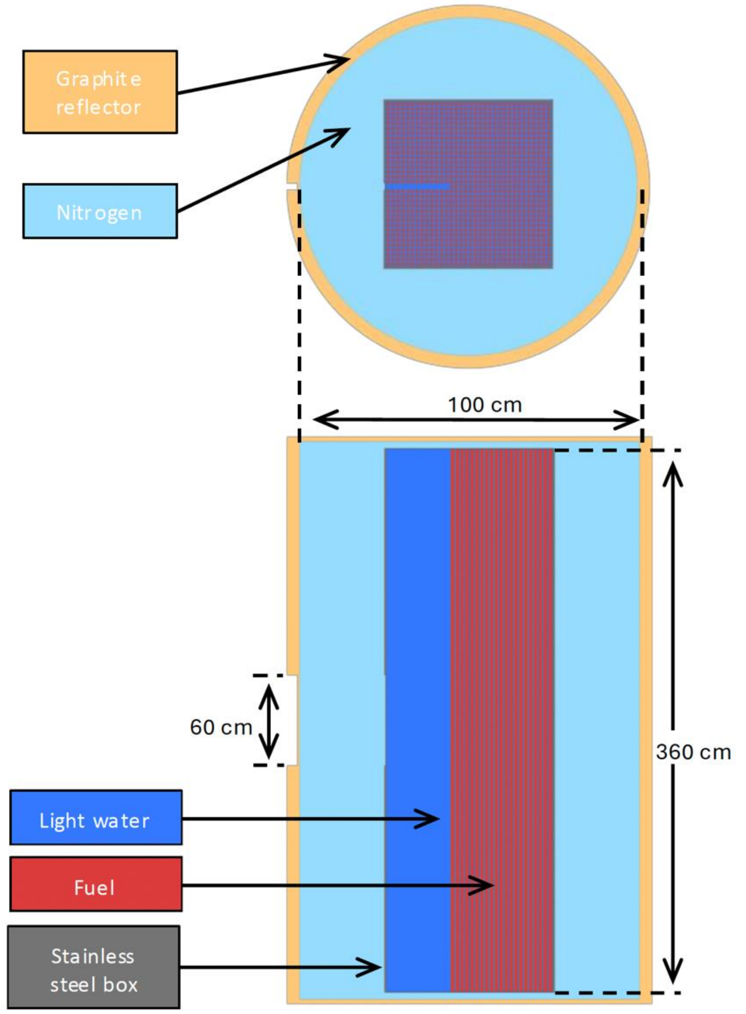
Results (3)


Simulation (B)
Simulation (C)
10^{1}
10^{0}
10^{-1}
10^{-2}
Cutoff time (years)
1e+17
1e+18
1e+19
1e+20
Beam power $\left(\frac{\gamma}{cm^2 s}\right)$

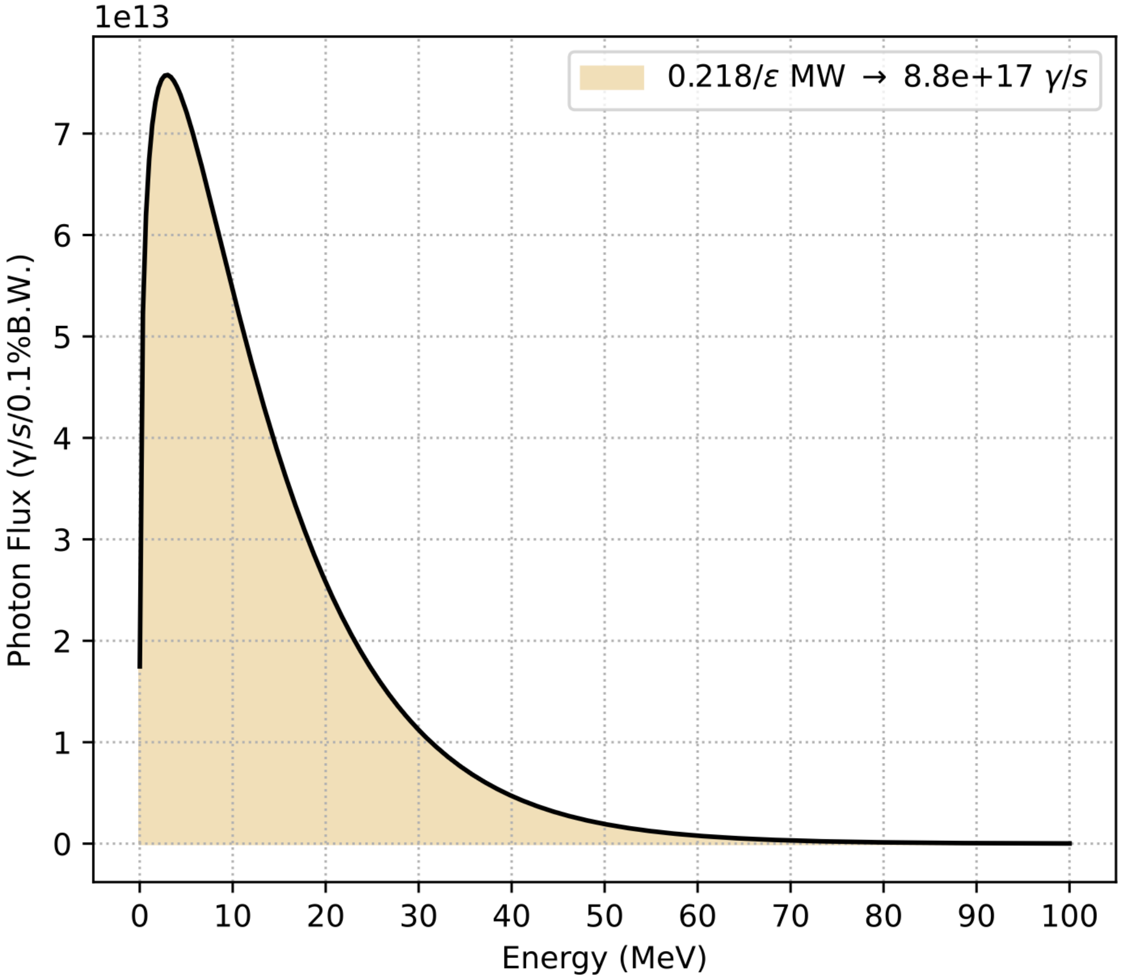
Assisted Photon Systems – APS

Power Generation from Spent Fuel: Photoneutron Source to Start Up a Subcritical Design





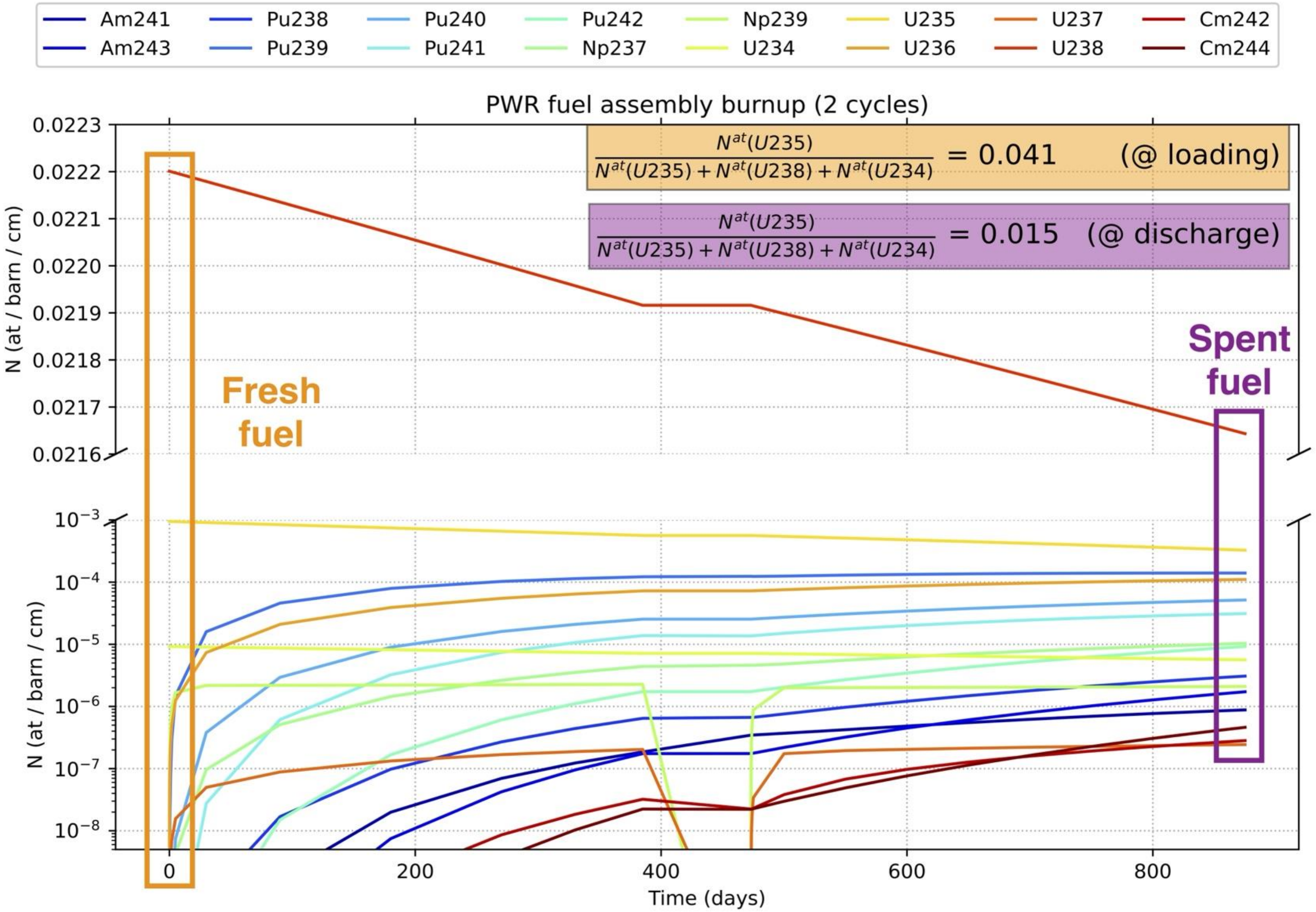
Photon source



Key features:
source strength (S) and consumption (C)

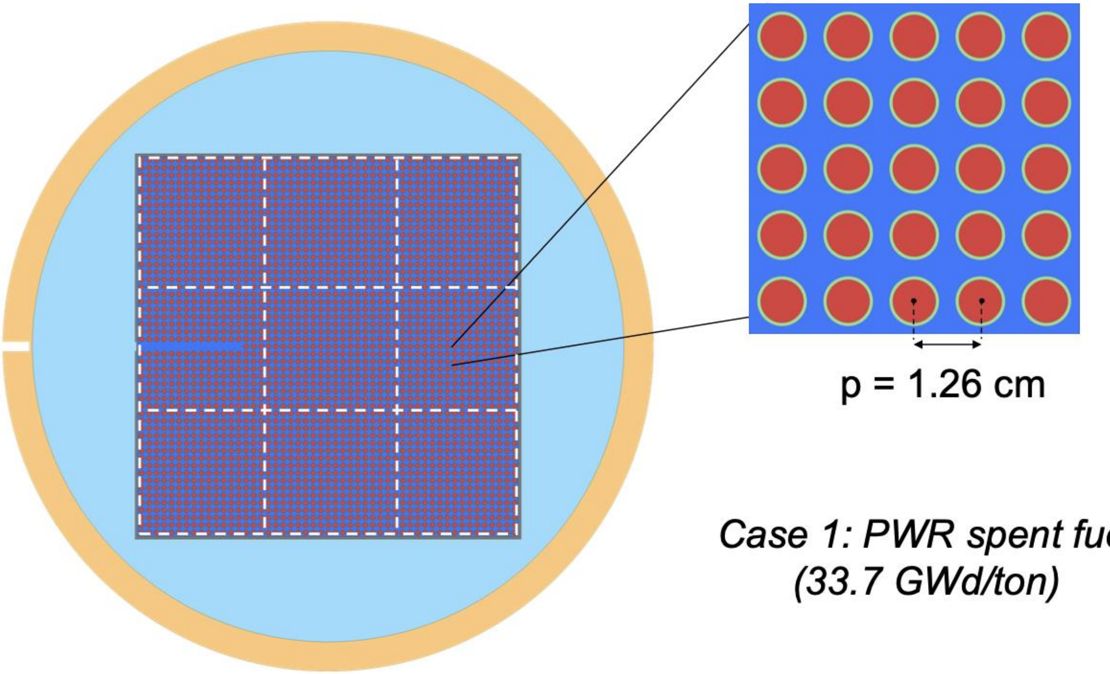
S = 8.8×1017γ/s
C ~ 0.5 MW

Life of a fuel assembly

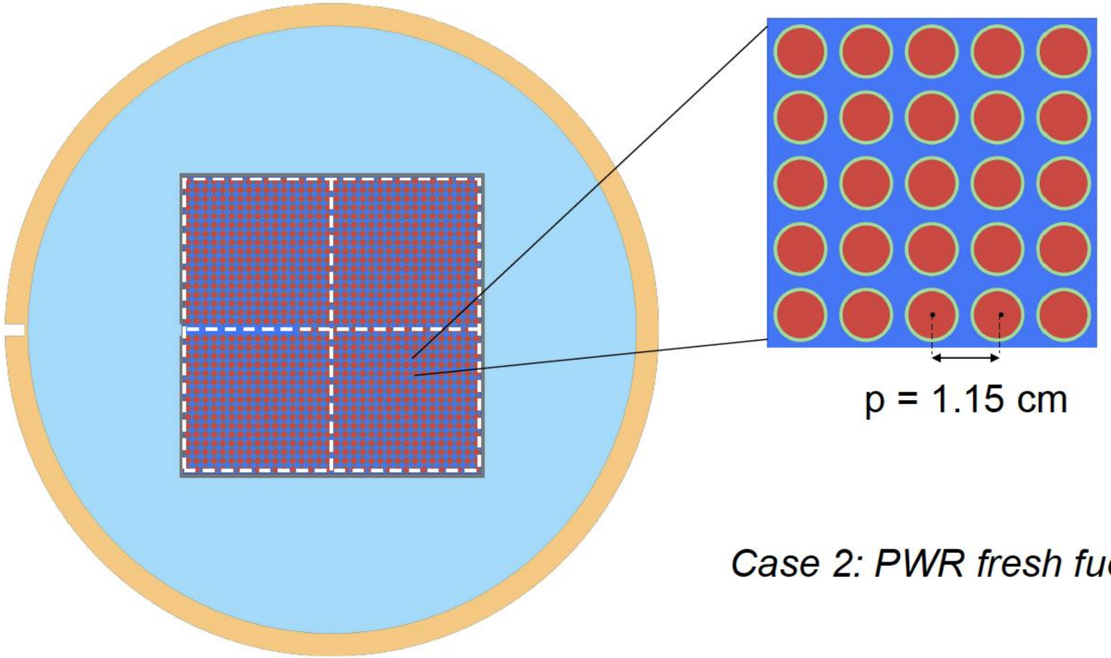


Minor actinides concentrations of the Takahama reactor

Test cases (1)

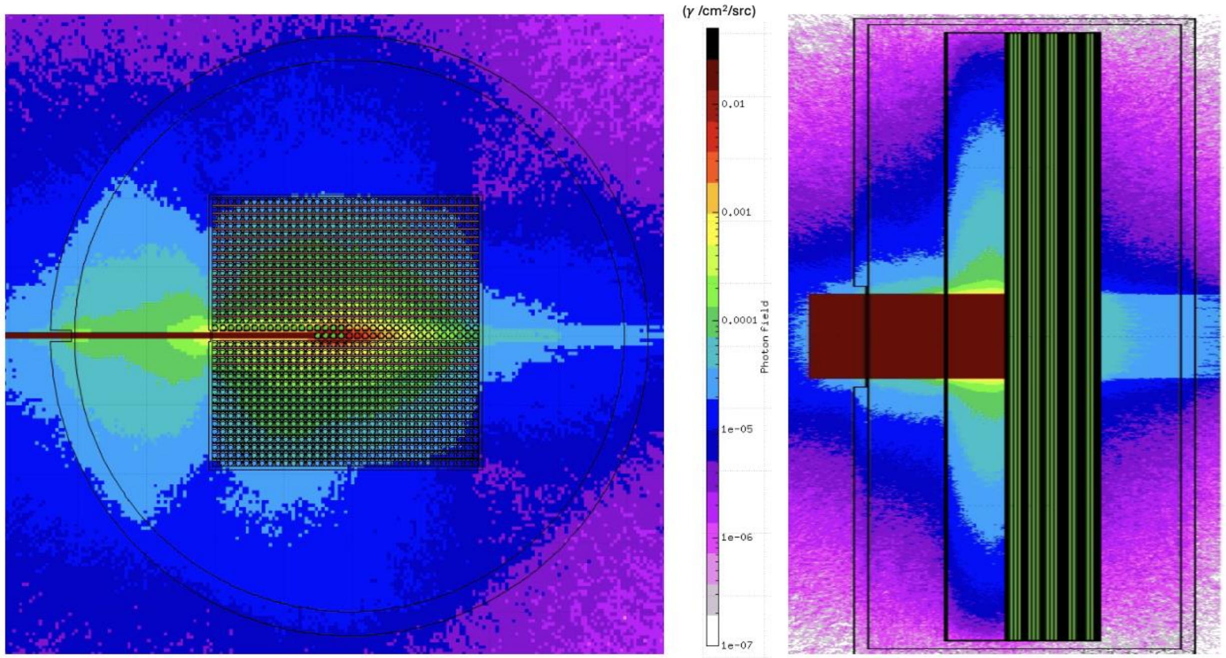


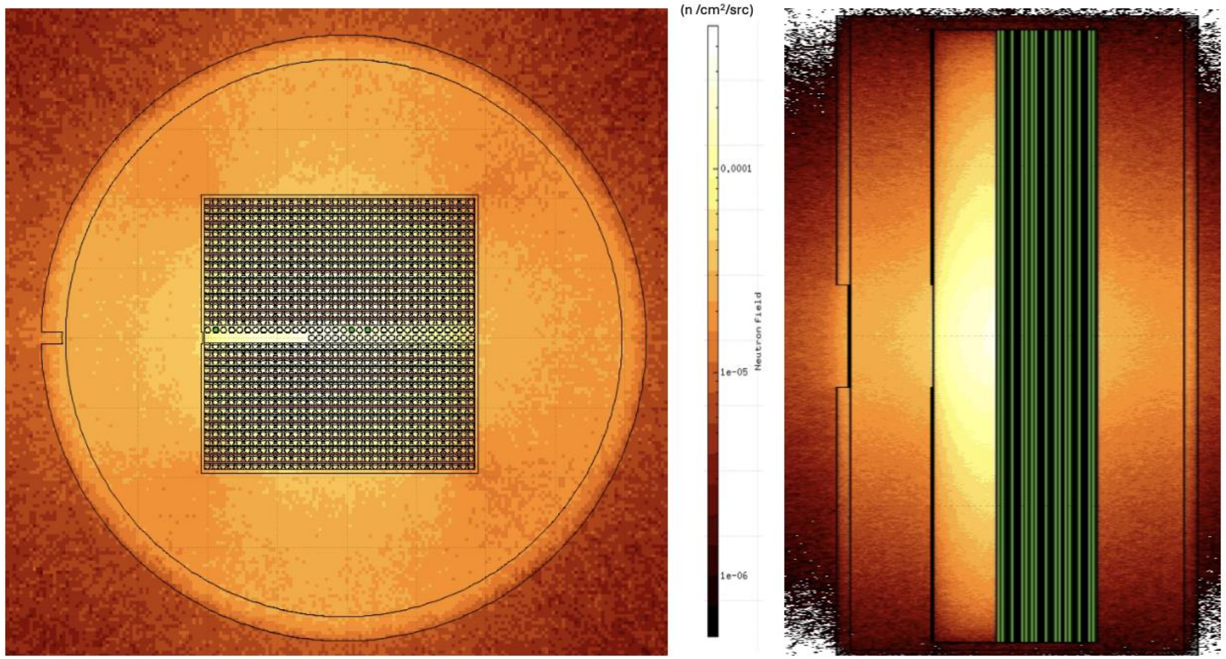
Case 1: PWR spent fuel
(33.7 GWd/ton)



Case 2: PWR fresh fuel

Test cases (2)

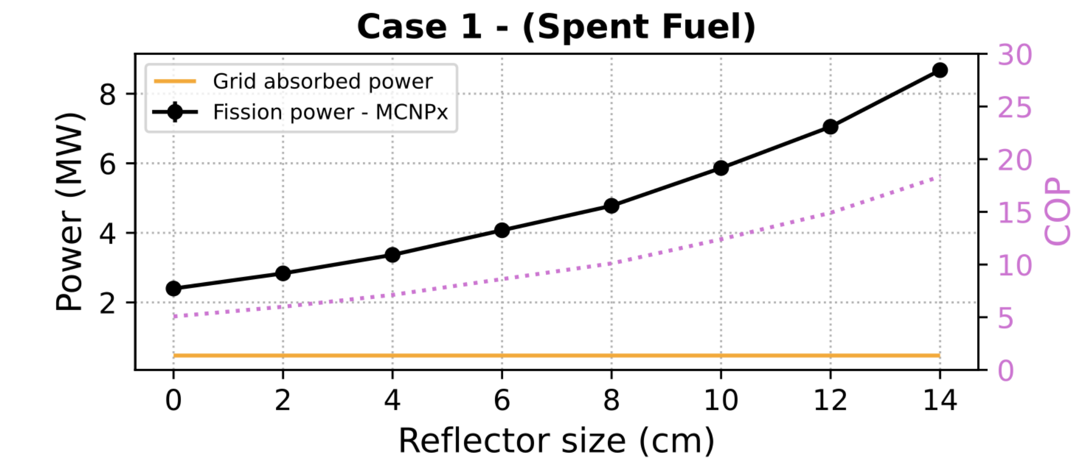


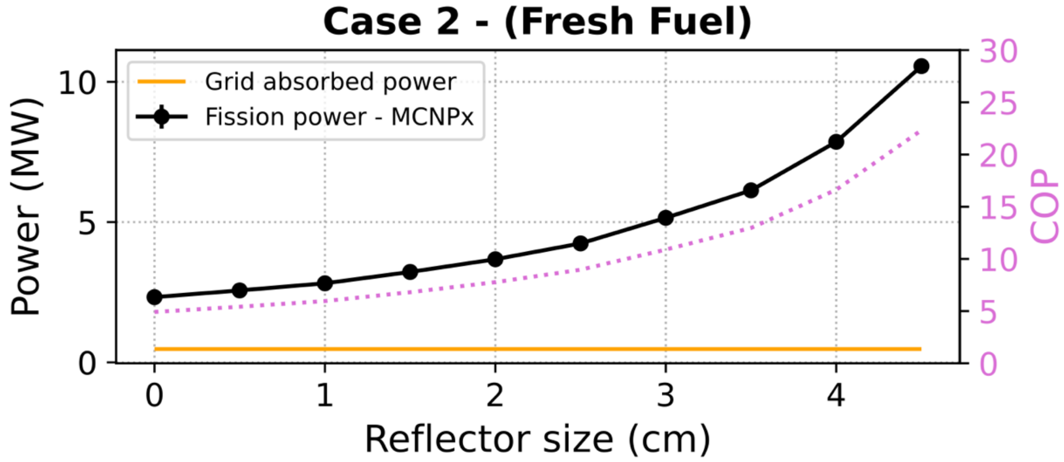


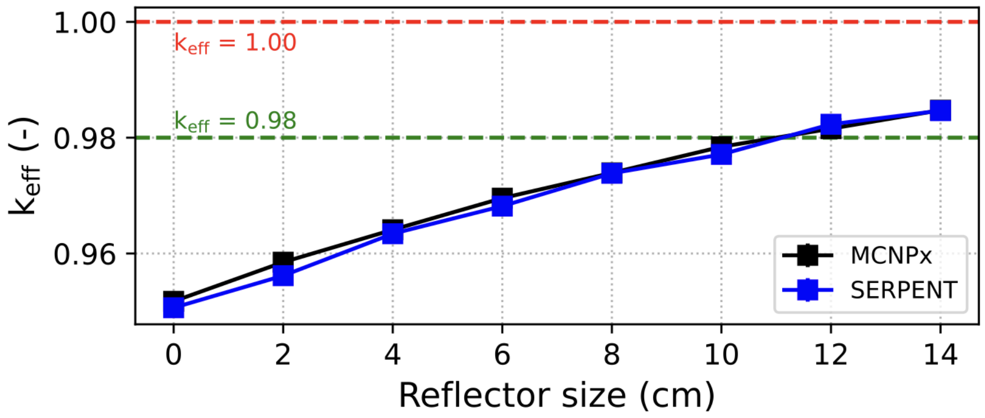
Photons distribution

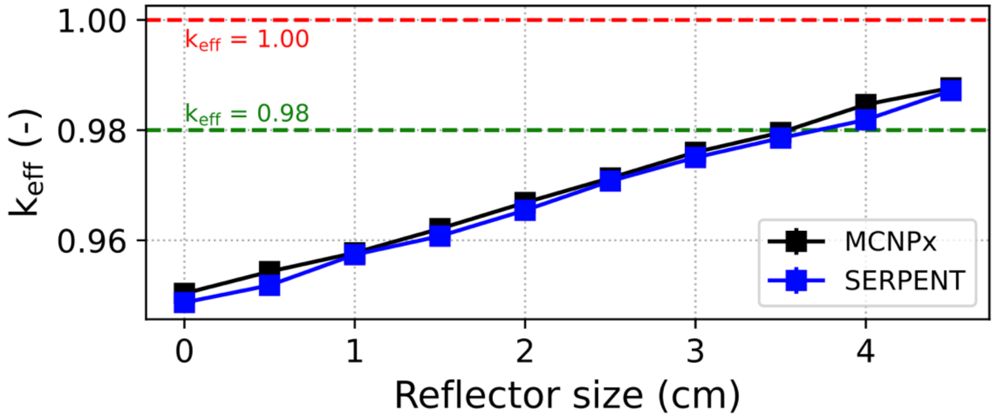
Neutrons distribution

Preliminary results









$$\boxed{\mathrm{COP} = \frac{\text{Thermal power produced by the system}}{\text{Electrical power absorbed by the system}}}$$

Thank you for your attention!