Study on Parameters of ADS Spallation Targets for Actinides Transmutation

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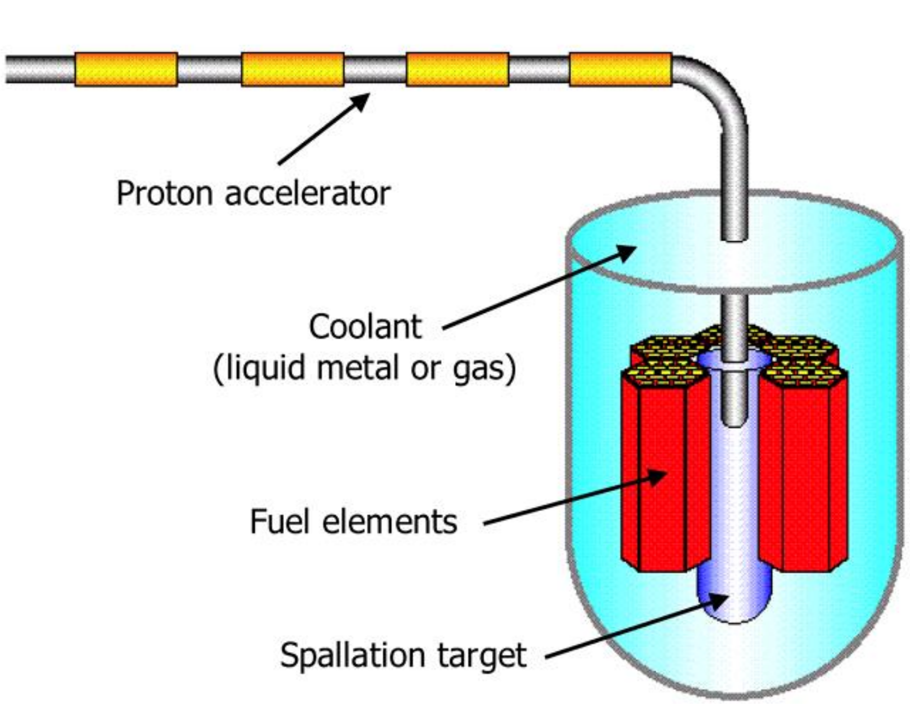
ADS

The concept of ADS (Accelerator Driven Subcritical System) consists of a proton accelerator coupled to a subcritical core by a spallation target. The proton beam collides with the spallation target producing neutrons that drive the subcritical core. Because of its subcritical core, the nuclear reaction is not self-sustaining, which makes this reactor model inherently safer, since criticality accidents have a low probability of occurring.

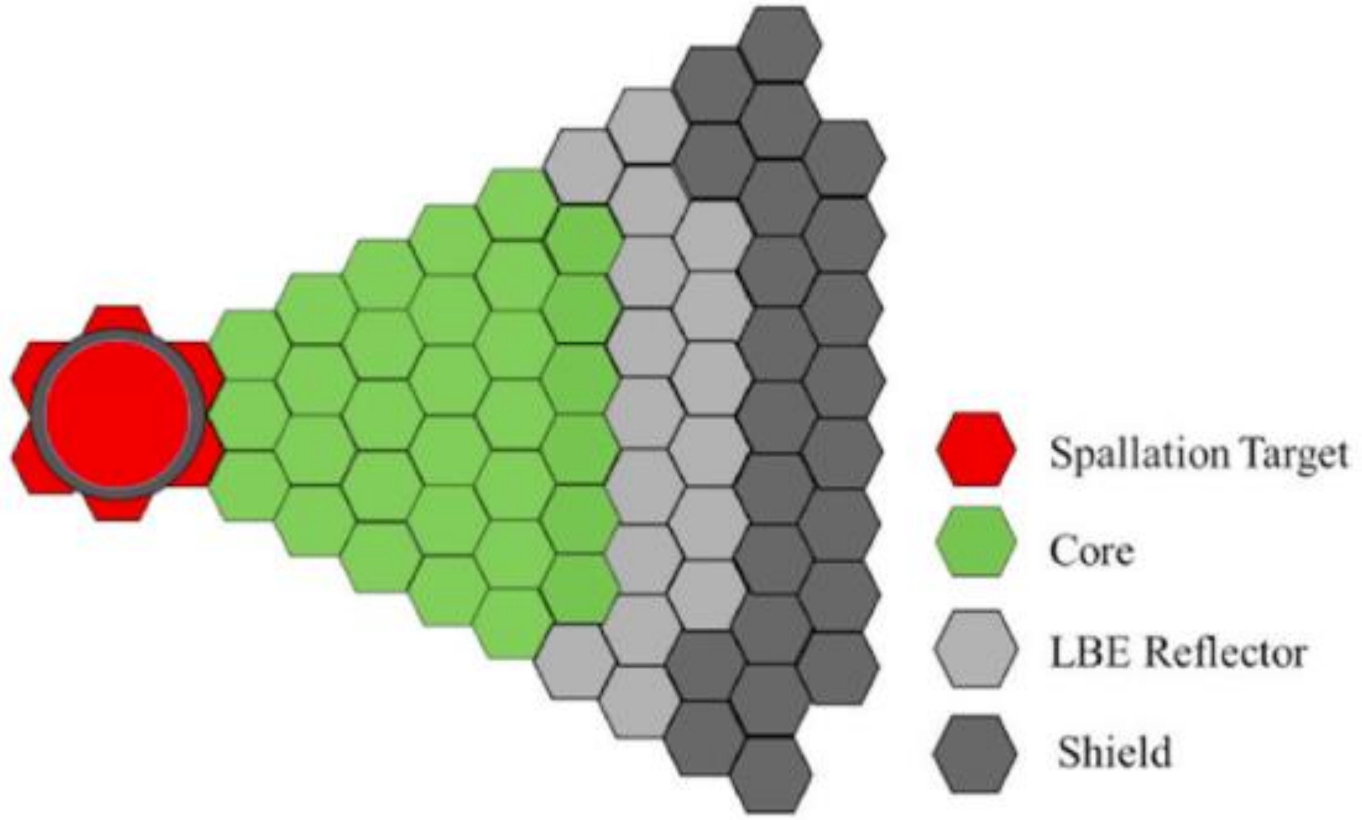
ADS

The accelerator bombards a target with high-energy protons which produces a very intense neutron source through the spallation process.

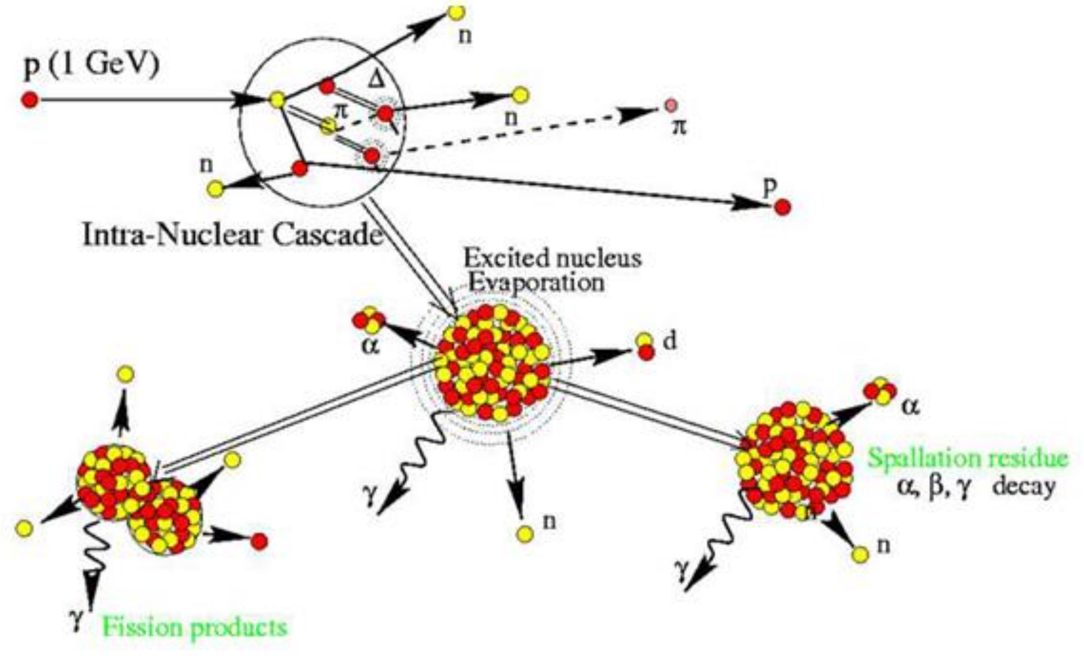
These neutrons can consequently be multiplied in the sub-critical core which surrounds the spallation target.

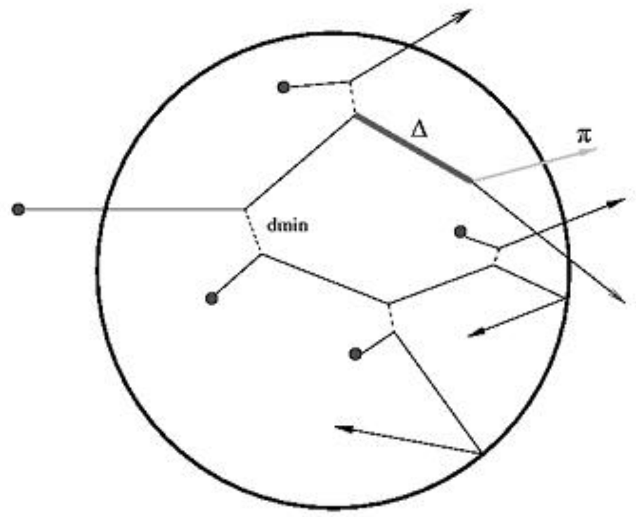


Top view of ADS model



Spallation Process





Transmutation waste

As one of the proposed uses for the ADS reactor has been the transmutation of nuclear waste.

Transmutation requires that the minor actinides be irradiated with a very intense neutron field, as can only be achieved in a high-power fission system such as a thermal reactor, fast reactor, or accelerator-driven subcritical system (ADS).

The minor actinides must be transmuted through fission reactions and these most likely take place in a hardened spectrum of neutrons, like the neutrons that are produced in spallation reactions

Methodology

The methodology for the development of this study takes into account:

(a) Choice of Materials

(b) Beam Energy

(c) Target diameter and width

(d) Neutron production

(e) Target Sensibility to temperature

Materials

Different materials have been proposed in the literature as spallation targets and suggested as possible components of ADS research. High-density heavy materials are suitable as spallation targets, although spallation reactions can also be observed in light elements such as Na or N.

The targets can be either solid or liquid.

For solid targets, the desirable characteristics are

(a) good thermal conductivity at operating temperature,

(b) small thermal expansion coefficient as it reduces thermal stress,

(c) adequate elastic properties even under irradiation,

(d) ability to resist corrosion even under irradiation,

(e) lowest possible radiotoxicity.

Materials

liquid metal targets are distinguished by the characteristics of

(a) not being susceptible to radiation damage to the target volume and

(b) allowing the heated target material to be moved away from the beam interaction zone to extract heat elsewhere

this work will study two liquid targets and a solid target their possible candidate materials:

(a) natural lead (Pb)

(b) lead-bismuth eutectic alloy (LBE)

(c)Tungsten (W).

Materials

	Material	Z	MP (K)	BP (K)	ρ (g/cm3)	κ ($Wm^{-1}K^{-1}$)
1	W	74	3 695	5 828.00	19.196 (600 K) 19.087 (900 K) 19.001 (1200 K)	174.00
2	Pb	82	600.61	2022.00	10.678 (600 K) 10.289 (900 K) 9.905 (1200 K)	35.00
3	LBE	82/83	396.00	1938.00	10.52 (600 K) 9.888 (900 K) 9.535 (1200 K)	22.85

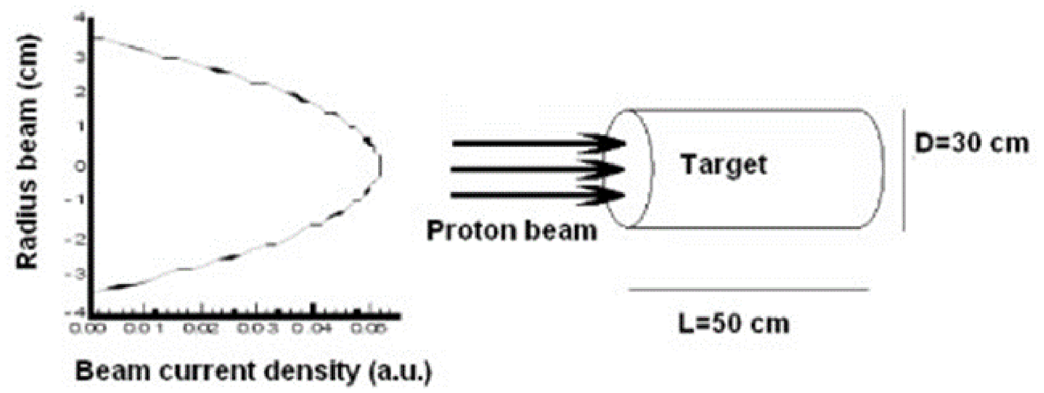
Beam Energy

The beam energy range was selected considering theoretical analyses and previous studies, including previous work done at DEN/UFMG, that point to the increase in neutron yield as an approximately linear function of energy and for higher energies, the yield is known to drop in linear correlation due to non-productive particle production and decay in 70 MeV photon pairs

The chosen targets were irradiated by proton beams with energies from 0.3 to 1.6 GeV.

Geometry

To a first approximation, the geometry consists of a simple right circular cylinder of heavy material and D cm in diameter by L cm long. A beam of 1GeV protons is launched onto the target. The beam has a 7-cm-diameter spot size, with a parabolic spatial profile.



Target diameter and width

To determine the optimum thickness, the length of the cylindrical target was varied between 10 and 80 cm with a constant diameter value (15 cm). Then, the target diameter was changed to between 10 and 40 cm at a constant length value (50 cm), respectively.

Neutron Production

- For the simulation of neutron production in spallation targets, inputs were built for the MCNPX 2.6.0 code.
- Proton transport is simulated using the physical model LAHET (The Los Alamos High Energy Transport Code) contained in MCNPX. LAHET can be used to transport a multitude of particles with high energies.
- The Cascade-Exciton Model package (CEM03.03) is also used. This package simulates the interactions between an incident particle and nucleons of the target material during the intranuclear cascade, as a sequence of binary collisions separated in space and time.
- The JEFF 3.3 (The Joint Evaluated Fission and Fusion File) cross section libraries were used for these simulations. JEFF is an international collaboration of the NEA (Nuclear Energy Agency)
- The NJOY99 code was used to generate the data libraries cross section for the respective operating temperatures in the MCNPX 2.6.0 readout format

Modeling the spallation targets in MCNPX

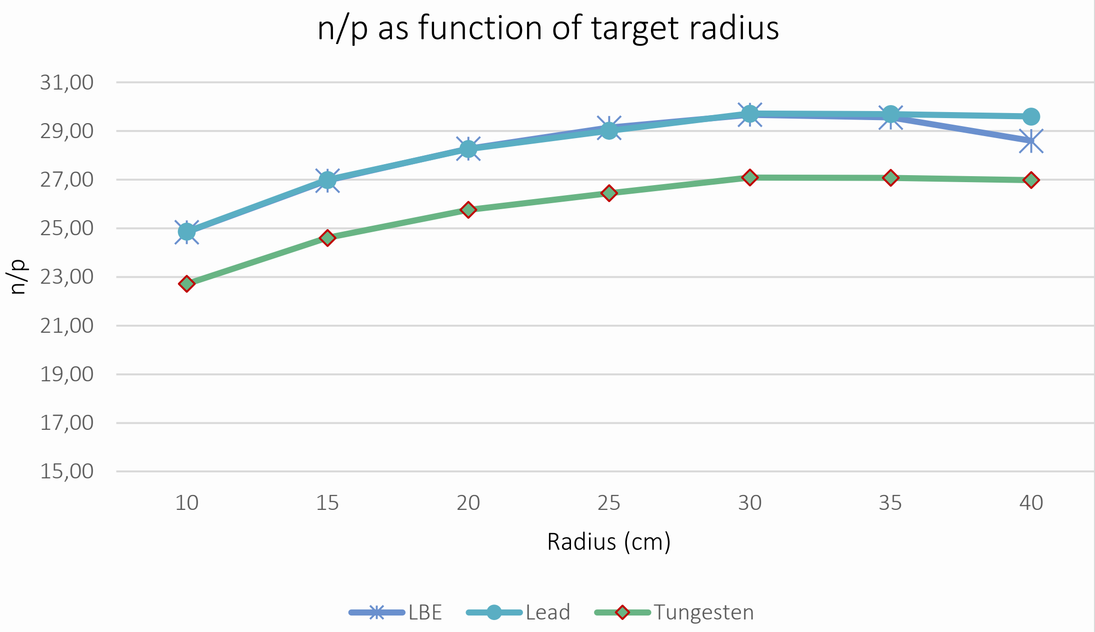
Isotopic distribution per material

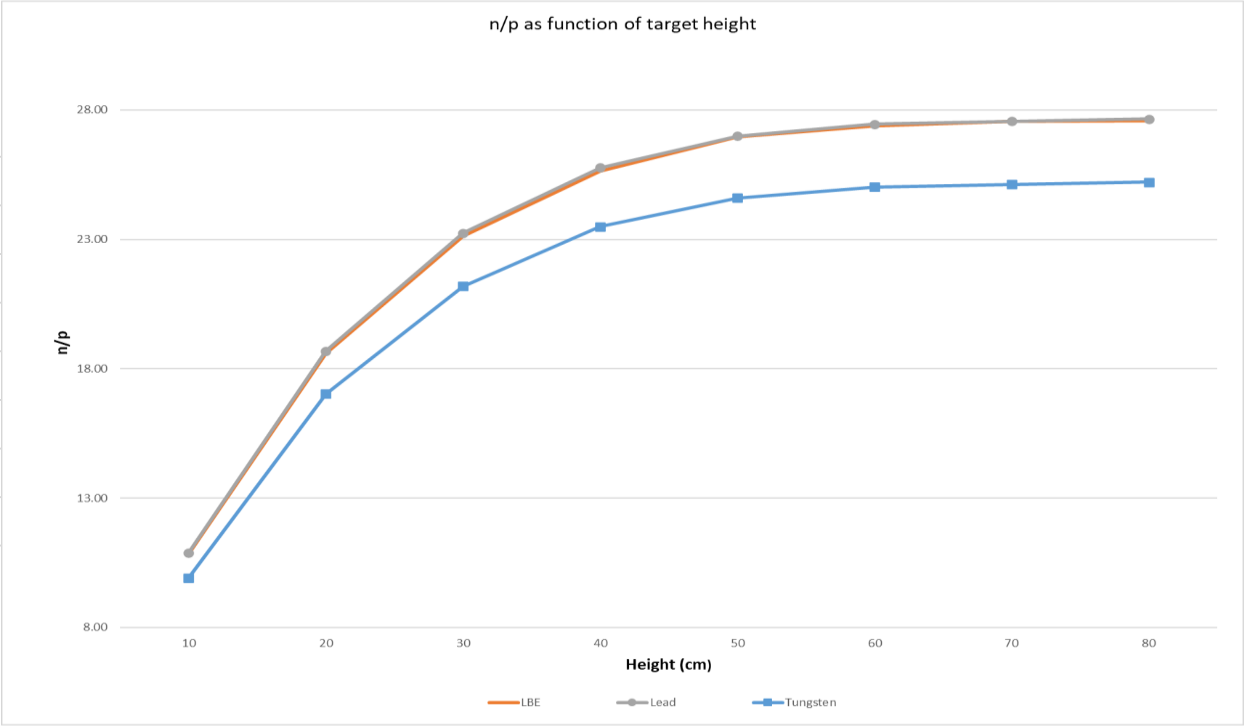
Material	Distribution (mass fraction)
Lead	^{204}Pb (0.0140) ^{206}Pb (0.2410) ^{207}Pb (0.221) ^{208}Pb (0.5240)
LBE	^{204}Pb (0.0063) ^{206}Pb (0.1085) ^{207}Pb (0.0995) ^{208}Pb (0.2358) ^{209}Bi (0.5500)
W	^{180}W (0.0012) ^{182}W (0.265) ^{183}W (0.143) ^{184}W (0.3064) ^{186}W (0.2843)

Results and discussion

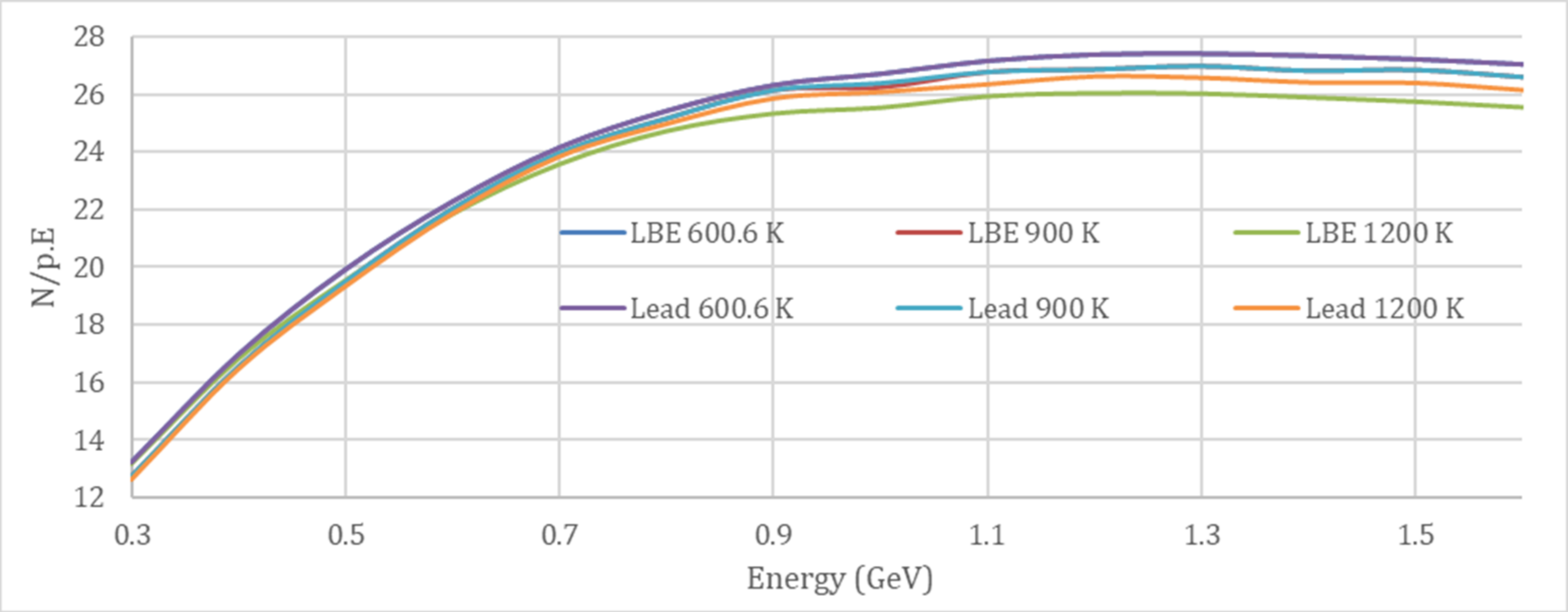
The multiplicity is a crucial parameter to study. Such importance is because the target should produce the largest neutron flux in its surroundings by being as compact as possible. Moreover, knowing how the target produces neutrons is relevant because its production will impact the nuclear transmutation parameters of the subcritical reactor

Results and discussion: Radius and Length



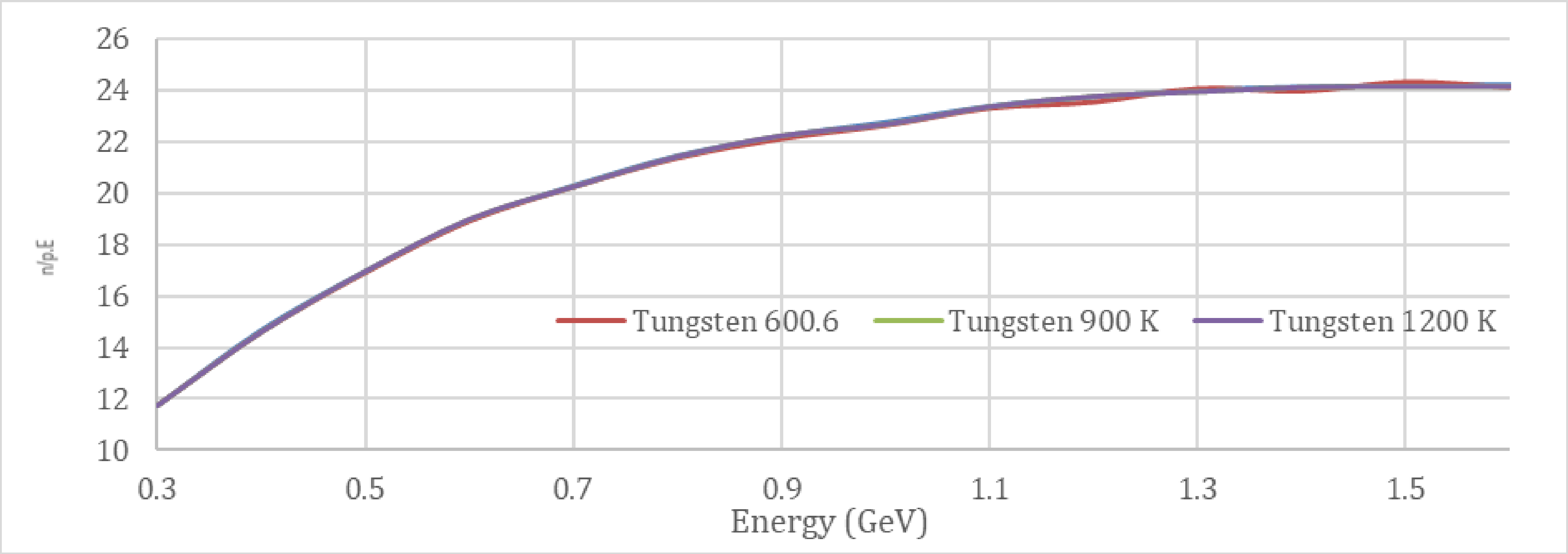


Results and discussion: Energy to Different Temperatures



(a) Multiplicity as a function of proton beam energy to natural lead and LBE

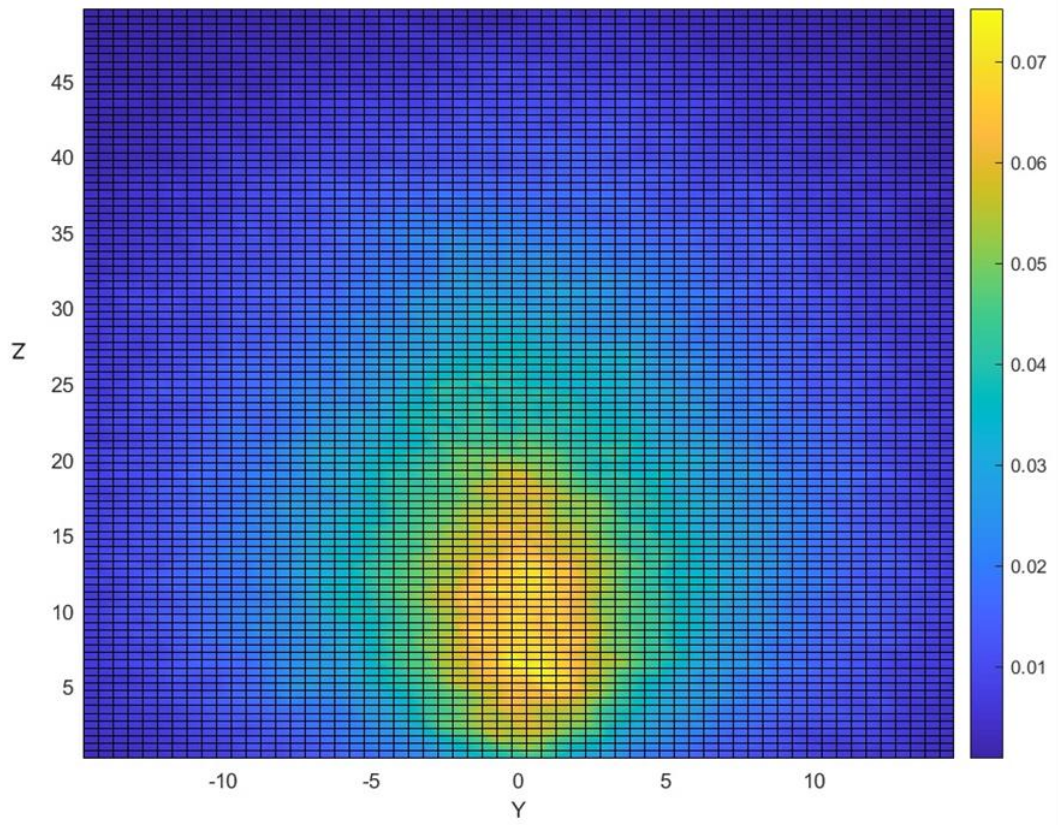
Results and discussion: Energy

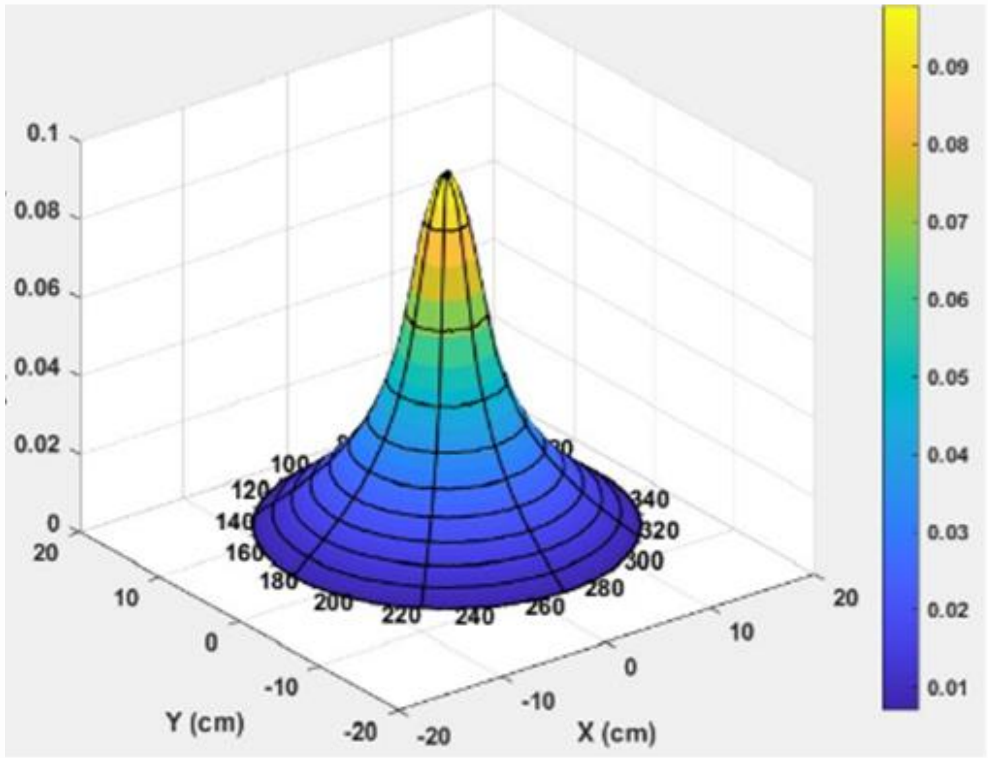


(b) Multiplicity as a function of proton beam energy to tungsten

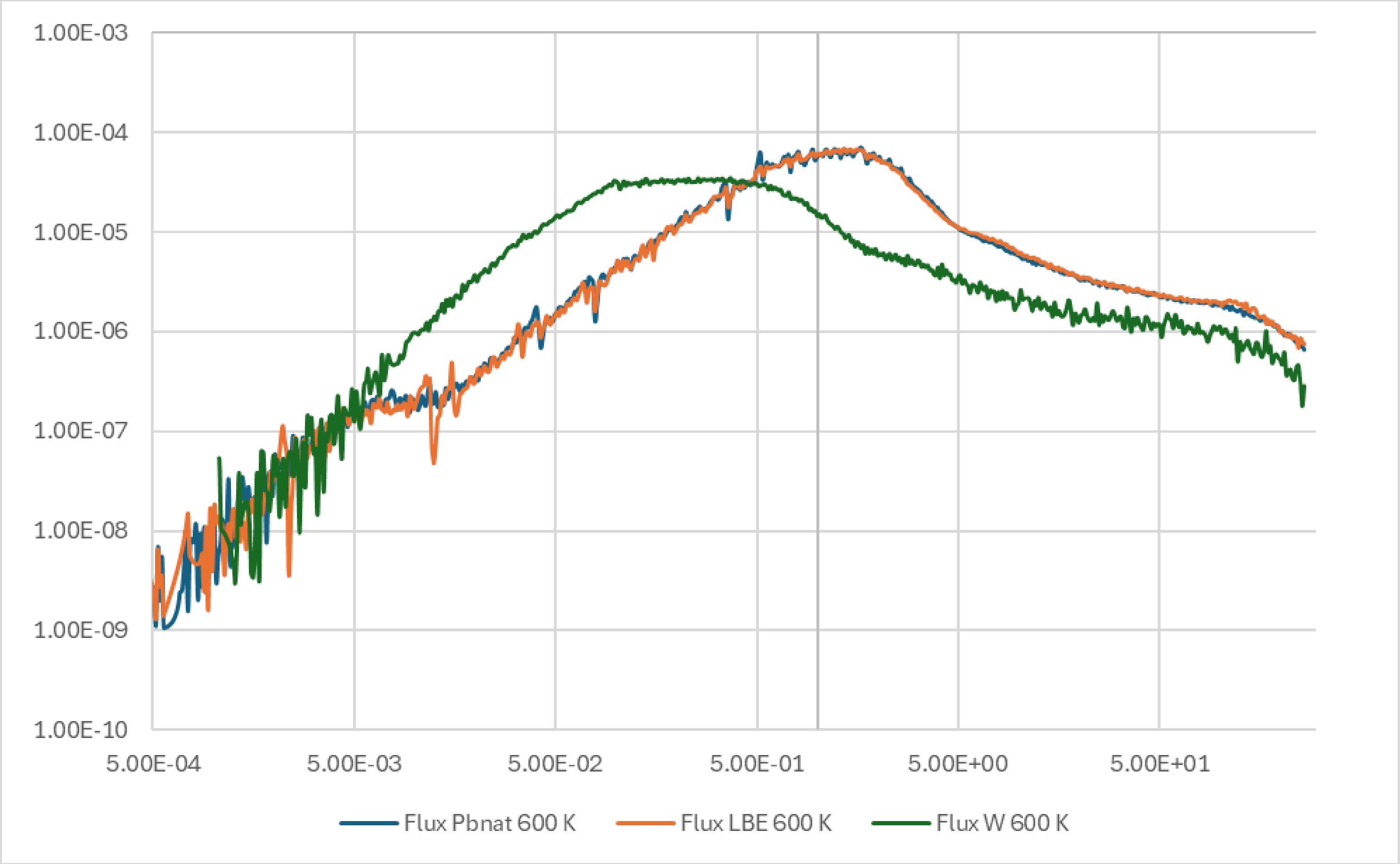
Results and discussion: Fluence

Distribution of neutron flux for a cylindrical and rectangular profile for Lead under the action of a 1 GeV beam to a cylinder of 15 cm in radius and 50 cm in diameter.



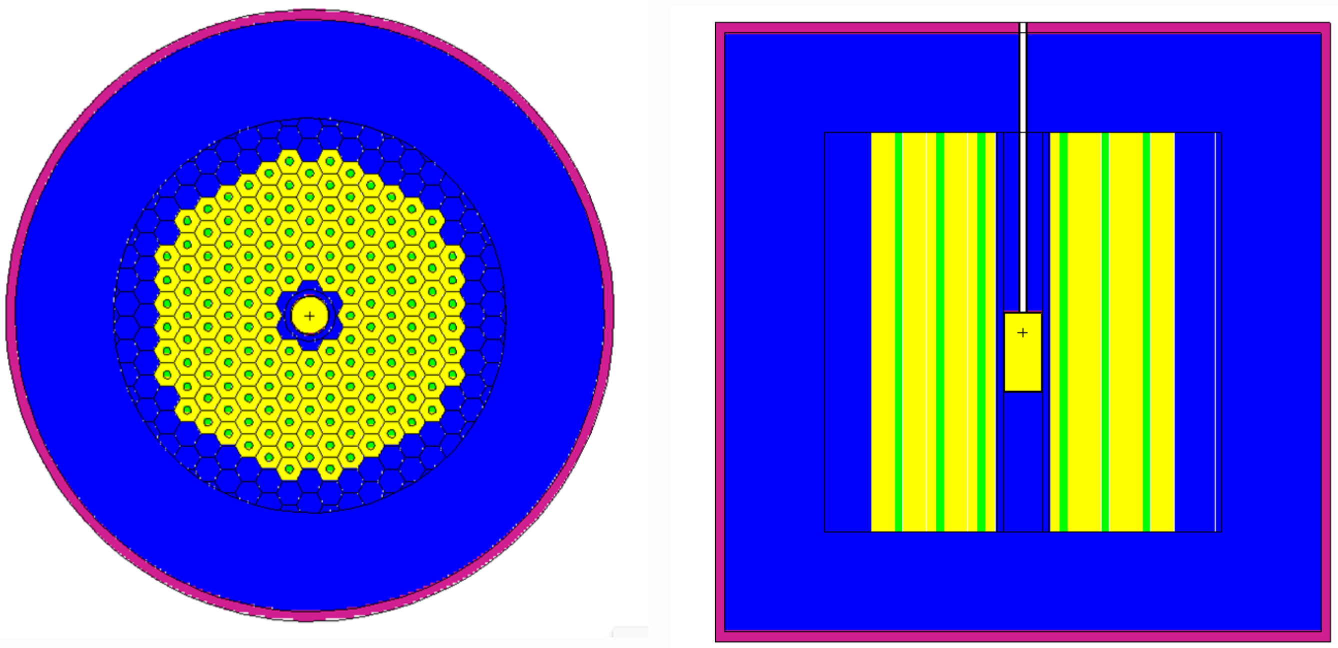


Flux in Target Surface



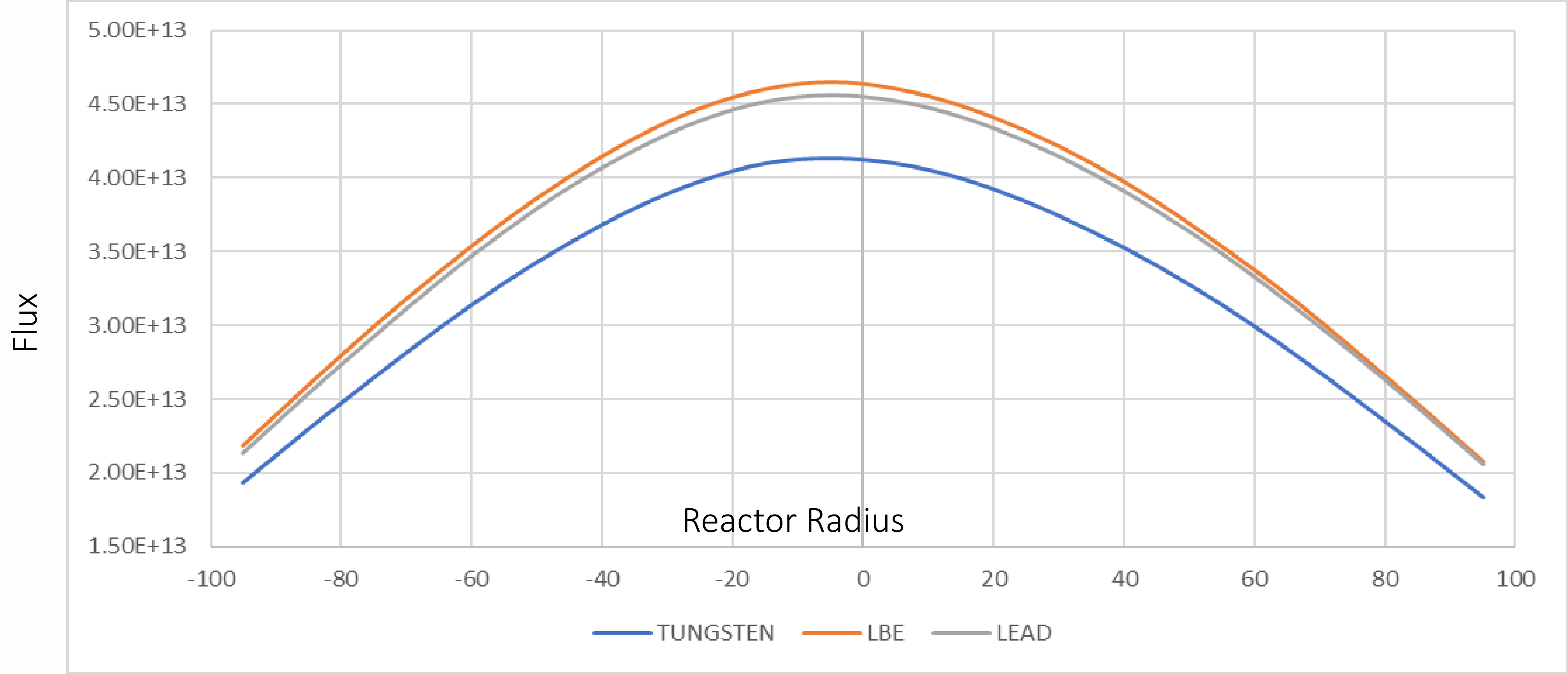
Profile of the ADS simulated

Core Volume	6.00 m^3
Initial Fuel	Th^{232} + 17%U^{233}
Initial Fuel Mass	3,92 t
Fuel Density	10.00 g/cm^3
Thermal Power	515 MW
Cylindrical Target Radius	9.00 cm
Cylindrical Target Height	38.00 cm
Coolant	Lead
Reflectors	Lead
Spallation Target	Lead/LBE/Tungsten



FUEL	Colant - Target	Reflector	Shielding

Axial Distribution in ADS with Targets Studied



Conclusions

It is shown that the specific neutron yield starts to decrease for energy values greater than 1 GeV meaning an increase in the neutron value in the ADS device.

The importance of the studied parameters is evidenced (a) the target material, (b) the influence of the geometry (radius and length), (c) the energy of the proton source and (d) target temperature control.

It was found that the three targets have similar characteristics in terms of neutron production.

Conclusions

The graphs showed that the optimal configuration is reached for a radius close to 15 cm and a length close to 50 cm.

Proton beam with energy close to 1 GeV guaranteed an optimized rate of neutrons.

Adequate temperature control is a relevant parameter to be considered in the production of neutrons by the target

Conclusions

The next stage of this work will be to use the neutron flux obtained with the different targets as an external source of neutrons in the subcritical system model to evaluate nuclear waste transmutation data with burning data in the monteburns and serpent codes.

Acknowledgments

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