On the neutron transparency of various materials proposed for the AIDA enclosure

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The AIDA implantation setup to be built for the DESPEC experiment will be encapsulated into a chamber at a low gas pressure. Both the AIDA setup and the chamber should be as transparent as possible to the β-delayed neutrons emitted by the implanted atoms and lead to a low neutron-induced background.

The neutron transparency of the alternative materials proposed for its construction has been investigated by Monte Carlo simulation with the GEANT4 code [1]. In addition, the γ-ray background produced by the interaction of neutrons with the material has been calculated as well.

The materials considered are:

- Pure aluminum. It has a low atomic number (Z) and a low neutron cross section.
- An aluminum alloy. The 1050 is one of the purest alloys available.
- Carbon fiber. Lower average Z than aluminum and smooth neutron cross sections.
- Stainless steel. Higher average Z and larger neutron cross sections than the previous materials.

The compositions (percentage by weight) of the various materials are:

Pure aluminum (2.7 g/cm^3): 100% ^{27}Al

Aluminum 1050 (2.7 g/cm^3):

Fe	Si	Zn	Ti	Mg	Mn	Cu	Al
0.40	0.25	0.0	0.05	0.05	0.05	0.05	remain

Carbon fiber (1.92 g/cm^3):

C	O	N	Ca	H
84.2687	8.3750	6.7003	0.5025	0.1300

Stainless Steel (7.7 g/cm^3):

C	Mn	S	P	Fe
0.55	0.90	0.05	0.04	98.46

The natural isotopic abundances have been considered in all the cases.

I. Neutron transmission through the different materials

The interaction of a neutron beam perpendicular to plates of various materials and thicknesses has been simulated with the GEANT4 Monte Carlo simulation kit. The standard G4NDL data library was used. The transmission through the plates was computed for neutron energies ranging from 0 to 10 MeV. Table 1 shows the transmission integrated over all energies for the various materials and plate thicknesses.

Thickness(mm)	Aluminium pure	Aluminium 1050	Steel	Carbon fibre
0.5	0.9934(1)	0.9934(1)	0.9880(1)	0.9921(1)
1	0.9869(1)	0.9869(1)	0.9861(1)	0.9843(1)
2	0.9739(1)	0.9739(1)	0.9823(1)	0.9689(1)
3	0.9611(1)	0.9612(1)	0.9301(1)	0.954(1)

Table 1. Transmission probabilities for different materials and wall thickness.

The transmission probabilities as a function of the neutron energy corresponding to pure Al, the 1050 Al alloy, carbon fiber and stainless steel are shown in Figures 1, 2, 3 and 4, respectively.

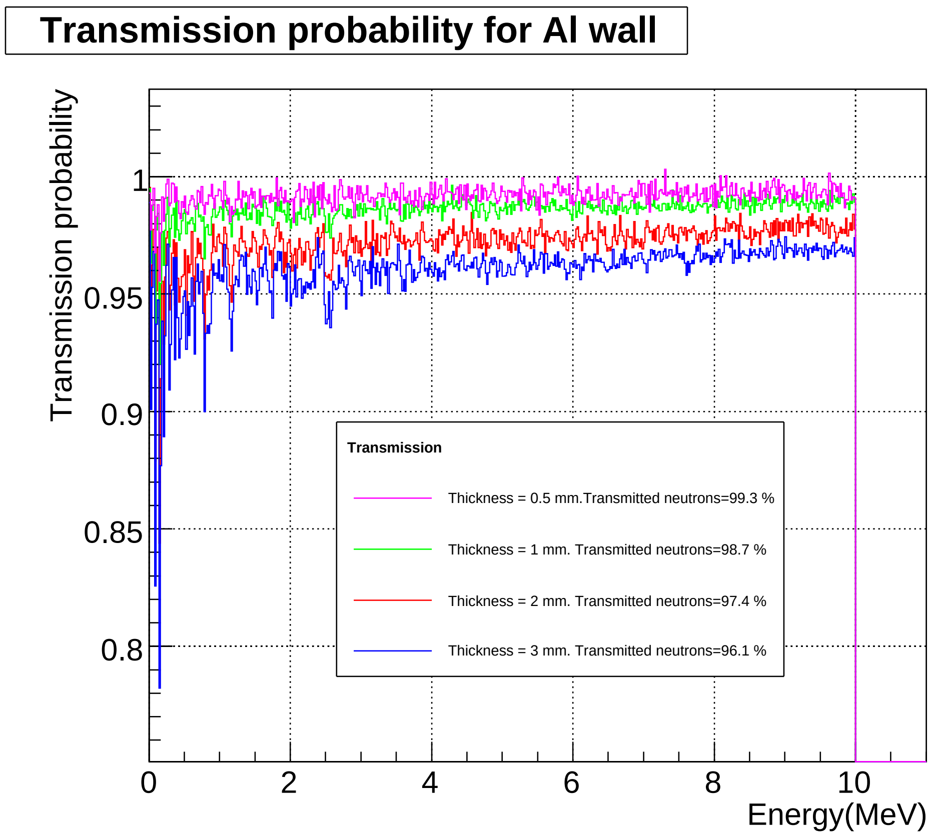

Figure 1. Neutron transmission as a function of the neutron energy for pure Al. Four different thicknesses have been considered.

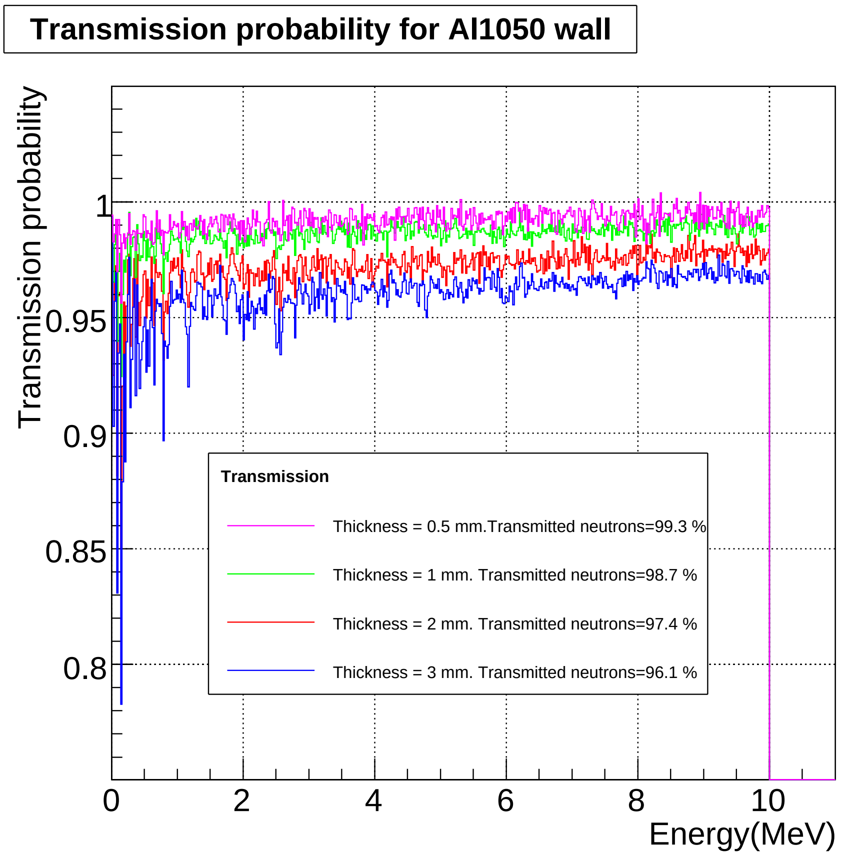

Figure 2. Neutron transmission as a function of the neutron energy for an 1050 Al alloy. Four different thicknesses have been considered.

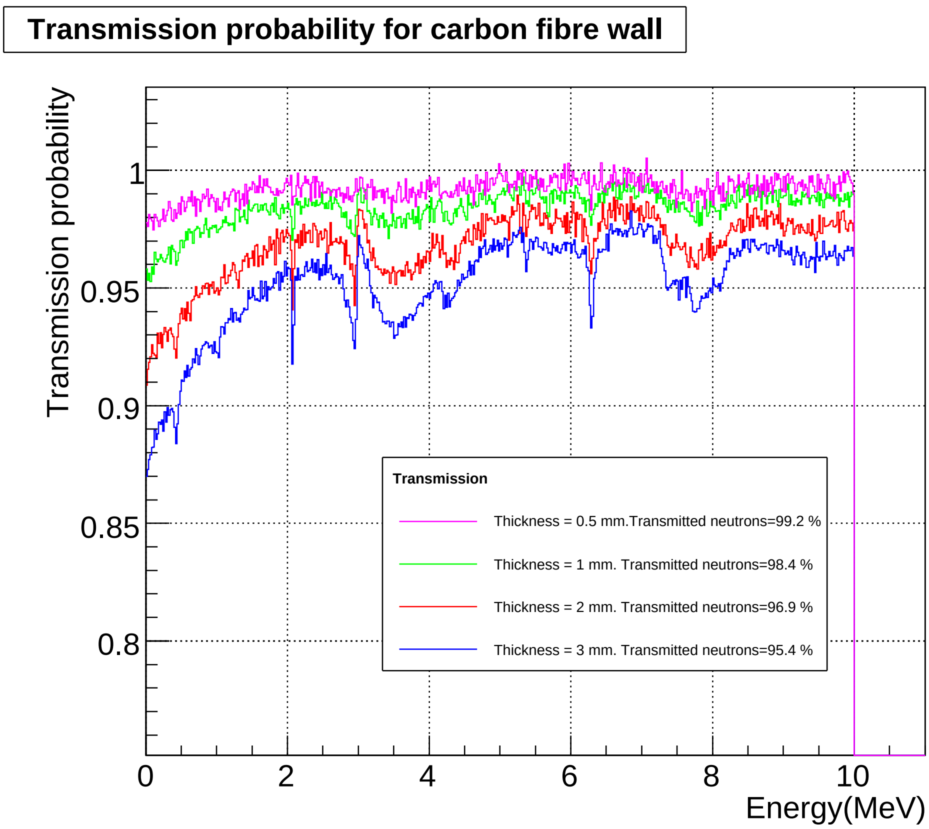

Figure 3. Neutron transmission as a function of the neutron energy for carbon fiber. Four different thicknesses have been considered.

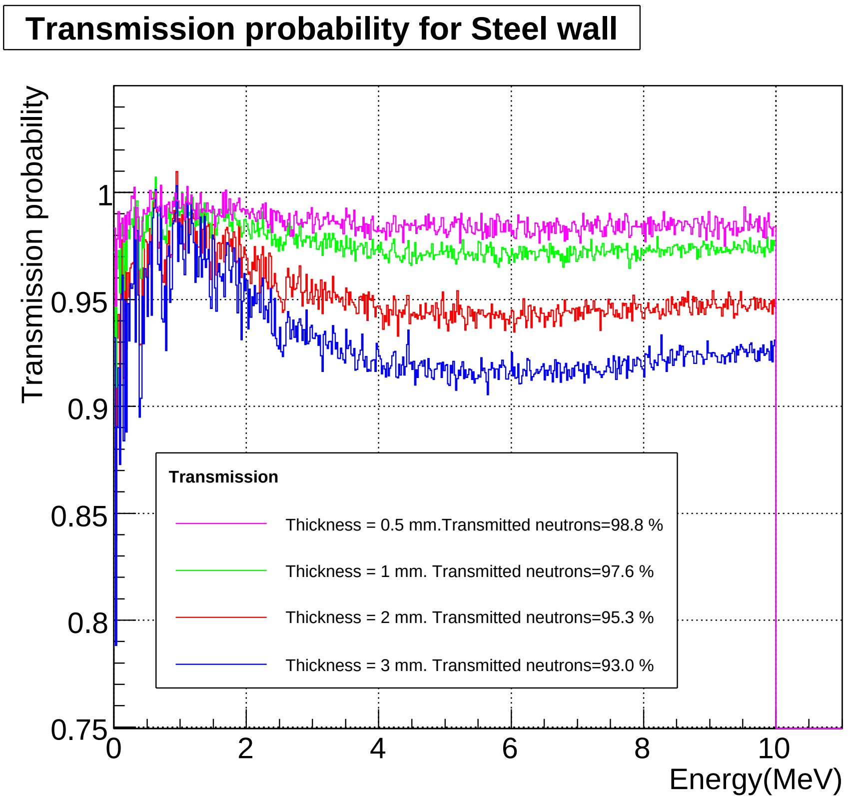

Figure 4. Neutron transmission as a function of the neutron energy for stainless steel. Four different thicknesses have been considered.

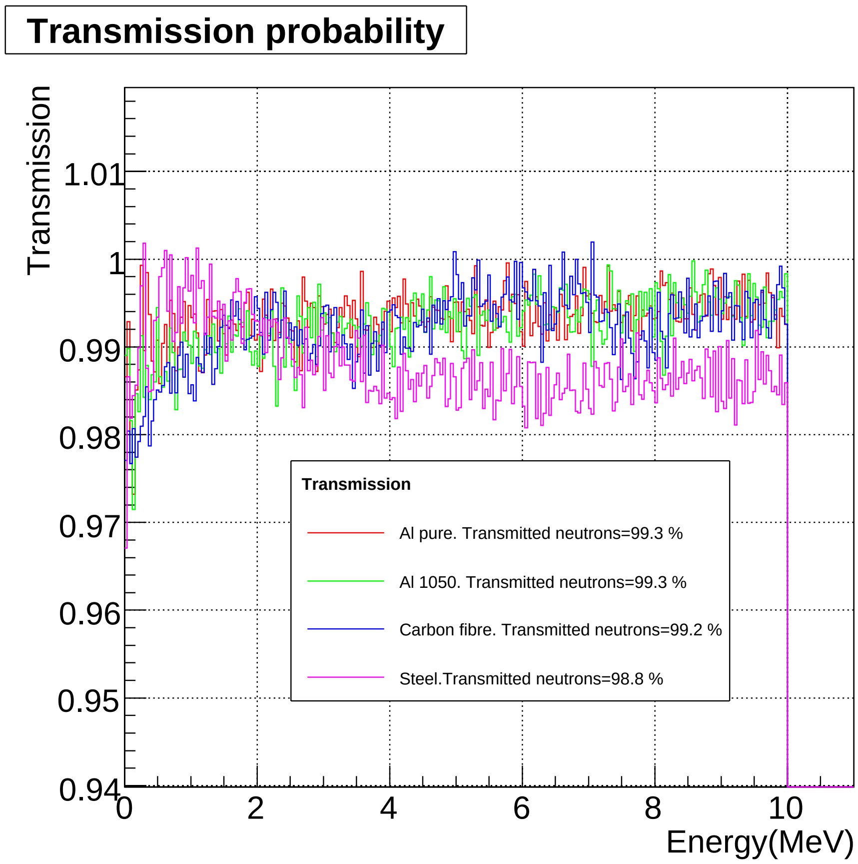

Figure 5. Comparison of the neutron transmission through 0.5 mm thick plates of the various materials in the range between 0 and 10 MeV.

The best overall transmission corresponds to the aluminum, but in the energy region below 1 MeV it is decreased due to the presence of resonances in the neutron cross sections. Figures 5 and 6 show a comparison between the different materials in two neutron energy ranges.

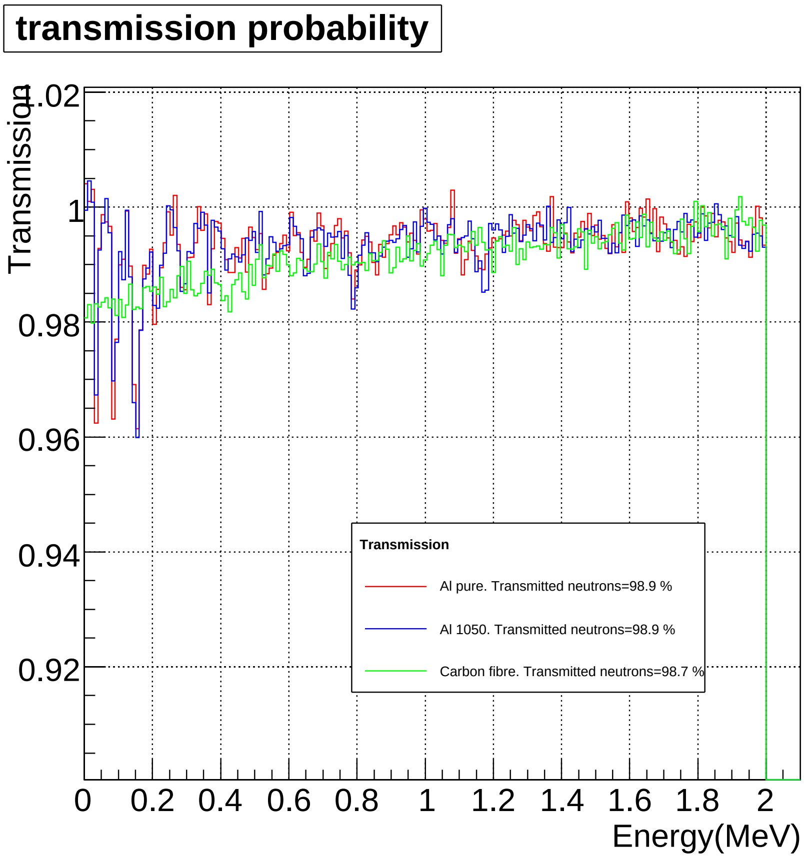

Figure 6. Comparison of the neutron transmission through 0.5 mm thick plates of the various materials in the range between 0 and 2 MeV.

In a second simulation, an isotropic neutron source was considered at the center of a box with 0.5mm thick walls. The purpose was to investigate the influence of the real effect on neutrons crossing the plates at all possible angles. The integrated transmission probabilities are 0.9896(1) and 0.9899(1) for aluminum pure and aluminum 1050. The transmissions has been reduced a 0.38% and a 0.35% respectively.

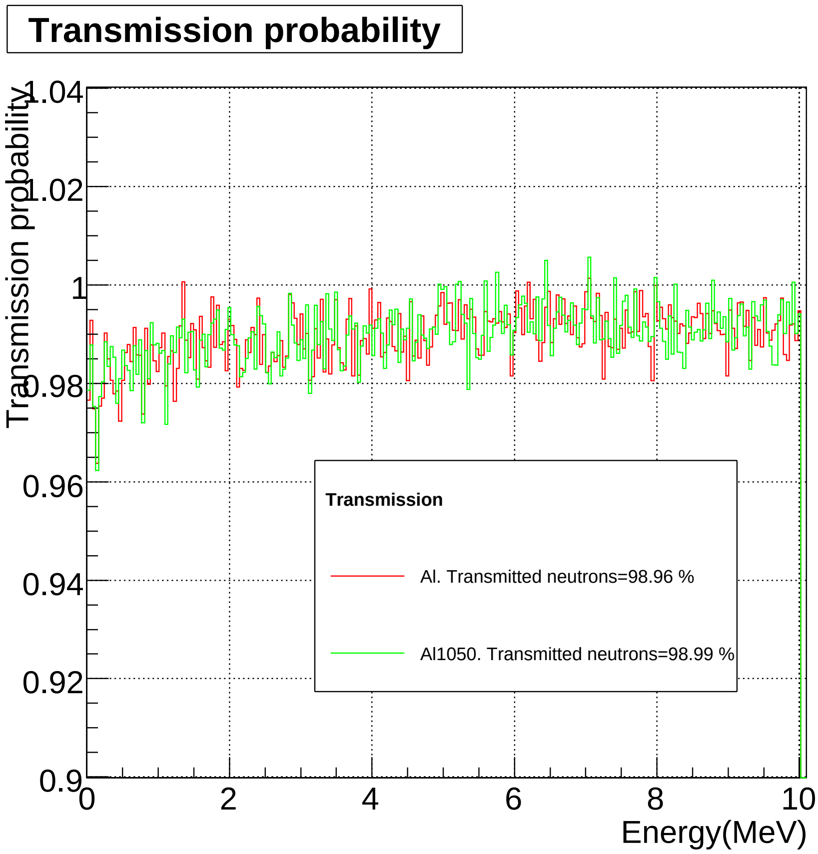

Figure 7. Neutron transmission for an isotropic source placed inside a box with 0.5 mm thick Al walls.

II. The gamma background

Neutrons interacting with the material of the implantation setup can produce a γ-ray background which is coincident in time with the neutron signals. Such a background source should be minimized as much as possible, and this can be achieved by an appropriate election of materials with low γ-ray production cross sections: neutron capture, neutron inelastic a(n,γ), (n,*x*γ)… The effect of the various materials proposed for the chamber has been investigated by Monte Carlo simulation. The secondary γ-rays produced in the neutron interactions of a white neutron beam impinging perpendicularly on the material plates were recorded. The total number of γ-rays per neutron integrated over the entire neutron energy range is shown in Table 2.

Thickness(mm)	Aluminium pure	Aluminium 1050	Steel	Carbon fibre
0.5	$1.3579\cdot10^{-3}$	$1.348\cdot10^{-3}$	$0.0525\cdot10^{-3}$	$2.61382\cdot10^{-3}$
1	$2.734\cdot10^{-4}$	$2.734\cdot10^{-4}$	$5.228\cdot10^{-3}$	$1.060\cdot10^{-4}$
2	$5.4854\cdot10^{-3}$	5.4930210^{-3}	$10.41228\cdot10^{-3}$	$0.2132\cdot10^{-3}$
3	$8.2414\cdot10^{-3}$	$8.2414\cdot10^{-3}$	$15.63254\cdot10^{-3}$	0.334810^{-4}

Table 2. γ-rays per neutron for different materials and wall thickness.

Figure 8 shows the energy spectrum of the γ-rays produced in the neutron interactions.

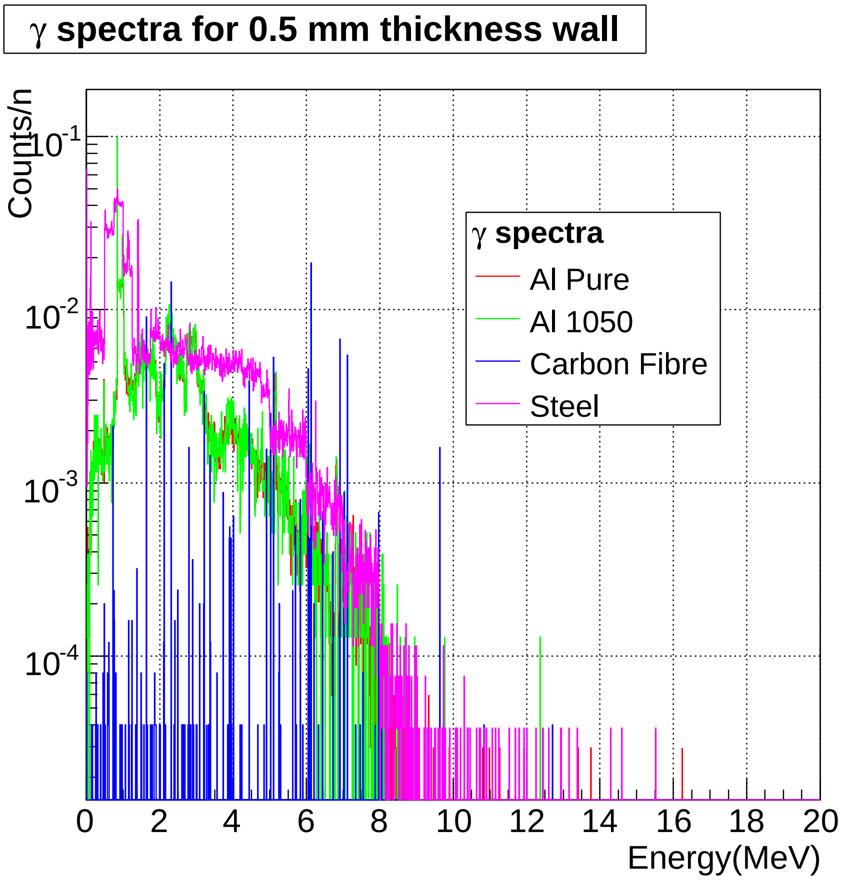

Figure 8. Energy distribution of the γ-rays per neutron for the different materials integrated over all the neutron energies.

III. Conclusions

The following conclusions can be reached:

- Aluminum is the best option for the AIDA chamber. Its neutron transmission integrated over all the energy range is the largest of all the materials considered. However, at neutron energies below 200 keV, the presence of resonances in the Al neutron cross sections enhances the interaction probability. The transmission through a 0.5 mm Al plate is reduced to 96%, a few percent below the 98% computed for the carbon fiber.
- As it can be seen in Figures 1 and 2, the transmission through the Al plates shows a smooth behavior. On the contrary, it can be observed in Figure 3 that the transmission through the carbon fiber plates has a structure as a function of the neutron energy.
- The carbon fiber shows the lowest gamma/neutron production because of its low capture cross section. In any case, the values for all the materials seem to be well below 1% in the range of thicknesses considered and therefore γ-ray production should not be an issue. The contribution from other materials present in the setup could be however much larger. Therefore, the detailed list materials should be investigated in detail.
- Taking into account the previous considerations, we conclude that the best material for the AIDA chamber is aluminum. The thickness of the walls should be lower than 0.5 mm. As it can be seen in the figures 5 and 6, the pure aluminum and the 1050 aluminum alloy show a nearly identical behavior.