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A Preliminary Design of Neutron Beam Shaping Assembly for AB-BNCT

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Accelerator-Based Boron Neutron Capture Therapy (AB-BNCT) is more and more popular for its convenience and good compatibility with hospitals. In this work, we assume an accelerator neutron source that generates neutrons by the ^{7}Li(p,n)^{7}Be reaction and the incident proton energy is 2.8 MeV. The neutron yield and spectrum was simulated by PHITS code and the ENDF/B-VII nuclear data library was used. To moderate the neutrons to the range from 0.5 eV to 10 keV, a neutron beam shaping assembly (BSA) was designed. The different materials, dimensions and shapes of BSA was compared. The parameters were evaluated according to the recommended ones of the IAEA-TECDOC-1223 report.

Tab.1 IAEA recommended BNCT neutron beam parameters at the BSA beam port.

BNCT beam port parameters	Recommended value
$\Phi_{epithermal}$ (cm^{-2} s^{-1})	$\sim 10^9$
$\Phi_{epithermal}/\Phi_{fast}$	>20
$\Phi_{epithermal}/\Phi_{thermal}$	>100
$\dot{D}_{fast}/\Phi_{epithermal}$ (Gy cm^2)	$<2\times10^{-13}$
$\dot{D}_{\gamma}/\Phi_{epithermal}$ (Gy cm^2)	$<2\times10^{-13}$
Fast energy group (Φ_{fast})	$E>10$ keV
Epithermal energy group ($\Phi_{epithermal}$)	1 eV $\leq E \leq$ 10 keV
Thermal energy group ($\Phi_{thermal}$)	$E<1$ eV

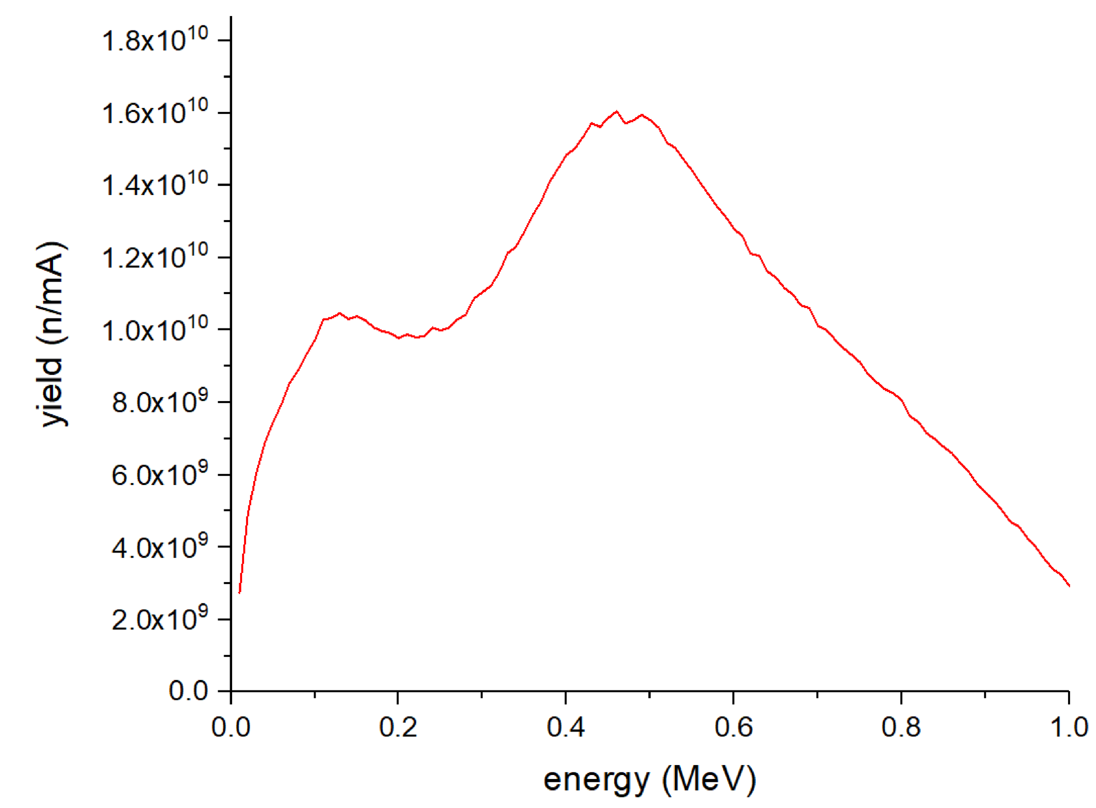


Fig.1 The neutron yield of the ^{7}Li(p,n)^{7}Be reaction.

The neutron yield of the ^{7}Li(p,n)^{7}Be reaction with 2.8 MeV proton hitting 140 μm lithium target. The calculated yield is 1.02E+12 n/cm^{-2}/mA. It was also calculated by MCNP6 code with the same settings, and the yield is 20% greater than that. In consideration of making allowance, the former one was selected for the calculation below.

Tab.2 Neutron flux at the beam port with different moderator diameters.

Number	Moderator diameter (cm)	Total neutron flux (n/cm^{-2}/s)	Thermal neutron flux (n/cm^{-2}/s)	Epithermal neutron flux (n/cm^{-2}/s)	Fast neutron flux (n/cm^{-2}/s)	The ratio of fast/epithermal
1	15	3.5603E+07	4.5830E+05	3.3212E+07	0.2391E+07	0.0720
2	25	5.1750E+07	1.4173E+06	4.9134E+07	0.1199E+07	0.0244
3	30	5.3391E+07	1.6487E+06	5.2261E+07	0.1130E+07	0.0216
4	35	5.3721E+07	1.7495E+06	5.0857E+07	0.1114E+07	0.0219
5	45	5.3520E+07	1.7813E+06	5.0628E+07	0.1111E+07	0.0219
6	55	5.3415E+07	1.7735E+06	5.0530E+07	0.1112E+07	0.0220
7	75	5.3392E+07	1.7716E+06	5.0509E+07	0.1111E+07	0.0220

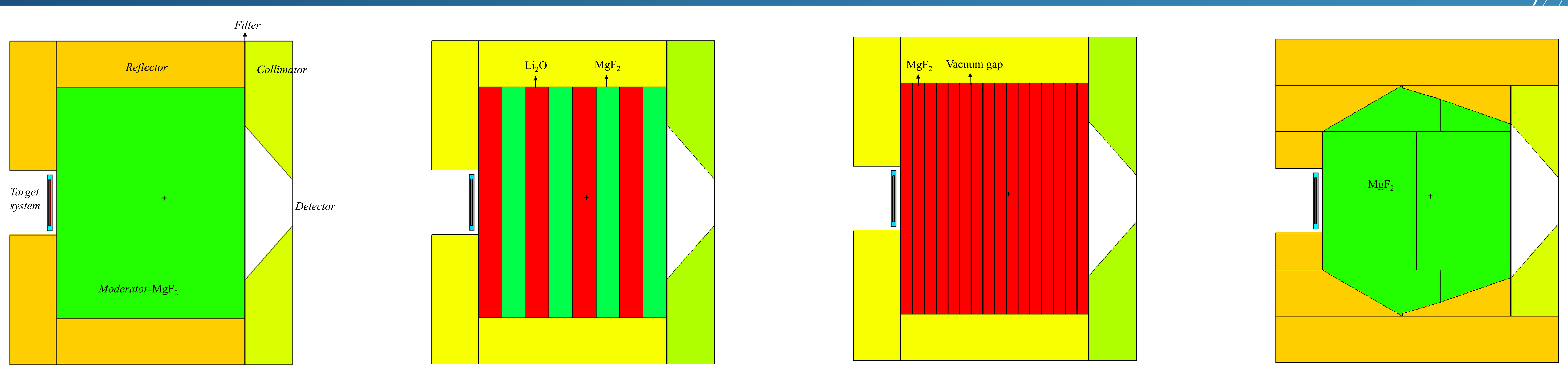
Tab.3 Neutron flux at the beam port with different moderator lengths.

Number	Moderator lengths (cm)	Total neutron flux (n/cm^{-2}/s)	Thermal neutron flux (n/cm^{-2}/s)	Epithermal neutron flux (n/cm^{-2}/s)	Fast neutron flux (n/cm^{-2}/s)	The ratio of fast/epithermal
1	20	2.6427E+08	2.7676E+06	1.9650E+08	0.6501E+08	0.3308
2	30	1.1920E+08	2.3598E+06	1.0753E+08	0.0931E+08	0.0865
3	35	8.0092E+07	2.0142E+06	7.6791E+07	0.3301E+07	0.0430
4	40	5.3391E+07	1.6487E+06	5.2261E+07	0.1130E+07	0.0216
5	45	3.5304E+07	1.3044E+06	3.3623E+07	0.0377E+07	0.0112
6	50	2.3039E+07	1.0026E+06	2.1913E+07	0.0123E+07	0.0056

By a cylinder shape of the moderator with magnesium fluoride, which shows in Fig. 2(a), the neutron flux at the beam port of different moderator diameters and lengths was calculated and the results show in the Tab.2 and Tab.3. It could be found that the diameter of 30 cm and the length of 40 cm have the best performance. Based on these results, different shapes of the moderator were compared.

As for the moderator materials, we compared with magnesium fluoride and lithium-7 oxide by a cylinder shape with same dimensions. It was found that Li2O could get 20% more epithermal neutrons at the beam port. It's interesting, but it deliquesces easily and need to be further considered.

Fig. 2 shows the beam shaping assembly with different shapes of the moderator. The reflector is lead. The filter is a cadmium layer and a bismuth layer. The bipyramid shape gave a best performance of epithermal neutrons, which is 20-30% higher than others.



(a) (b) (c) (d)

Fig.2 The beam shaping assembly with different shapes of the moderator. (a) is a cylinder shape, (b) is a spaced arrangement with different moderation materials, (c) is a spaced shape with vacuum gaps and (d) is a bipyramid shape.

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