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Simulation of a modified neutron detector applied in CSNS

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Abstract We simulate the response of a modified Anderson-Braun rem counter in the energy range from thermal energy to about 10 GeV using the FLUKA code. Also, we simulate the lethargy spectrum of CSNS outside the beam dump. Traditional BF_3 tube is replaced by the ^{3}He tube, a layer of 0.6 cm lead is added outside the boron doped plastic attenuator and a sphere configuration is adopted. The simulation result shows that its response is exactly fit to H*(10) in the neutron energies between 10 keV and approximately 1 GeV, although the monitor slightly underestimates H*(10) in the energy range from thermal energy to about 10 keV. According to the characteristics of the CSNS, this modified counter increases the neutron energy response by 30% compared with the traditional monitors, and it can be applied in other kinds of stray field rich of high energy neutrons.

Key words rem counter, high energy neutrons, response function, FLUKA

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1 Introduction

It is well known that the most commonly used instrument for neutron detection is the Anderson-Braun (A-B) rem counter, whose response is considered acceptable for neutron energies between thermal energy and approximately 14 MeV, although in reality the monitor underestimates H*(10)[1] in the energy range from thermal energy to about 1eV and overestimates it in the interval 1 eV—100 keV. Above 14 MeV the response falls abruptly, leading to a drastic underestimation of the ambient dose equivalent, which increases larger with increasing neutron energy. In 1990s, Birattari et al have made an improvement by adding one inch of lead to the moderator to increase high energy neutron sensitivity. Fig. 1 shows its response curve[2]. This modification is based on the traditional SONNPY, whose angular response distribution is anti-isotropy. Later in 1998, Birattari et.al also developed a modified sphere version to avoid angular dependence as the cylindrical LINUS[3].

So far in China, Li Jianping has developed a long interval neutron counter named M95-2, which adopted the parameters provided by Dr R. K. Sun (LBL)[4]. The purpose of this paper is to simulate the response of a modified A-B rem counter between 0.025 eV to 10 GeV. The design goals for the new instrument are to:

a) Obtain higher detection sensitivity than that given by a conventional rem meter, especially at high neutron energies.

b) Improve the angular dependence of response function of the modified A-B counter.

The CSNS (China Spallation Neutron Source) will be constructed in Guangdong Province in the next five years. It is a basic science research equipment. The designed beam energy is 1.6 GeV and the beam current is 200 kW. The dose equivalent outside the shielding around the accelerator is dominated by neutron component, where the energy spectrum of the neutron produced shows a wide range according to our simulations.

At last, we calculate the relative response of a modified A-B rem counter and a traditional one in the energy interval from thermal energy to 10 GeV, also we apply these two kinds of detector in the simulated CSNS neutron stray field to make a comparison.

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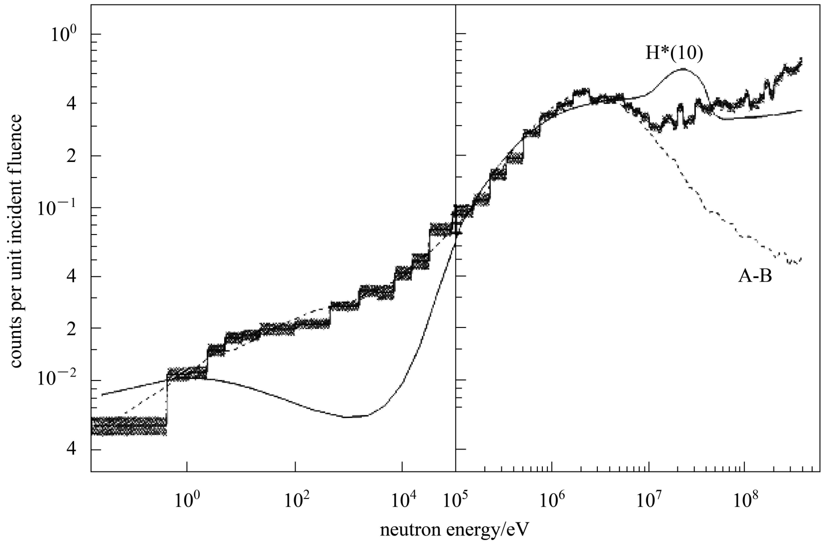

Fig. 1. Response to lateral irradiation of the A-B rem counter with 1 cm Pb around the boron plastic attenuator (From Ref. [2]).

2 M-C calculation

2.1 The configuration of the modified counter

The original design of the A-B rem counter dates back to 1963[5]. Since then the instrument has gained a widespread popularity. The standard instrument consists of a thermal neutron detector enclosed within a moderator assembly made up of an inner polyethylene moderator, a boron doped plastic attenuator and an outer polyethylene moderator. A number of holes are drilled both in the lateral and front surfaces of the plastic attenuator to allow part of the thermal neutron components to penetrate.

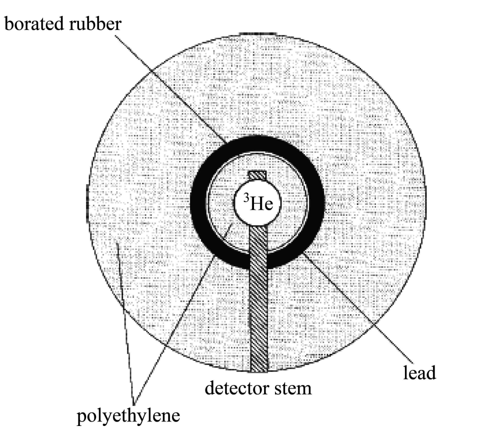

Fig. 2. Cross section of the modified A-B counter.

The modified A-B rem counter has a similar construction to that of a conventional one. Fig. 2 shows an exact cross section of our instrument as it was coded into the computer, and the different thicknesses of each composition are: from the counter outwards, 1.9 cm polyethylene, 0.6 cm boron doped plastic attenuator, 0.6 cm lead and 8.3 cm polythene.

The only three unique points are:

(1) The BF_3 tube is replaced by a new ^{3}He tube.

(2) A lead layer of 6 mm around the boron plastic attenuator is added.

(3) The cylindrical configuration is replaced by a new sphere configuration.

The reason will be discussed in Section 3.

2.2 The M-C simulation technique

Monte Carlo calculations have been carried using the last version of FLUKA code. This code is widely used in high energy physics community both for predicting energy deposition and radiation damage and for calorimetric calculations. The responses of the modified detector are calculated using a track length estimator corresponding to the volume of ^{3}He counter and the cross-sections of (n, p) reaction are obtained from Lib: JENDL 3.3 basic[6]. The neutron monitor is represented using the combinatorial geometry; much attention is paid to reproducing the detector and the surrounding attenuator as accurately as possible. There are two important techniques used in the simulation:

(1) Variance reduction techniques have been used to reduce the computing time by using a BIASING card. We set a region importance number by regions, also, we set different biases and primary particle numbers according to the incident neutron energies.

(2) Every layer is divided into thinner layers so that we can record every layer's response in order to adjust our region biases.

3 Results and discussion

3.1 Three points to explain

(1) BF_3 tube is replaced by ^{3}He tube

^{3}He has a higher (n, p) cross section than the B(n,α) cross section for all neutron energies; the ^{3}He detector is available at higher pressures (>1 atm pressure) than the BF_3 counter (<1 atm pressure). Thus, the use of ^{3}He detector will increase the overall detection efficiency.

(2) The lead layer for extending the energy range

This is the key point which distinguishes from the conventional A-B counter. The moderation effect in a conventional rem counter is not sufficient to allow high energy neutrons to be recorded by BF_3 counter, therefore the response in high energy region decreases. But when adding a lead layer, after passing through the outer polyethylene layer, the low energy neutrons interact with Pb nuclei mainly by elastic scatting. This process does not produce moderation. Therefore, this Pb layer of a modified A-B rem counter doesn't affect the correct response in the low energy region, as does the conventional A-B counter. The high energy neutrons interact with Pb nuclei by inelastic scatting and transfer a part of the initial energy to Pb nuclei and are slowed down, so they can also be detected by the inner ^{3}He proportional tube.

(3) The sphere configuration

As described in Ref. [3], the traditional cylindrical model shows a marked and increasing anisotropy with deceasing energy from 10 MeV. But the spherical geometry can remove this dependence of the monitor response on the direction of irradiation.

3.2 The simulation result

Many Monte Carlo simulations have been done to find what kind of materials can be used to modify the response function of the rem counter to make it sensitive on an extended energy range[2]. The thing we have to do is to change the thickness of the lead and the attenuator layer, so we can find the exact similar response function with the H*(10) curve.

Figure 3 shows the effect of response function when we change the thickness of the lead layer, also we compare it with the H*(10) curve. We have done the same with the plastic layer. Fig. 4 shows this situation.

The two figures confirm our analysis that the lead can improve the response function in high energy range and the plastic layer only effects the low energy range.

Finally, we choose the most suitable thickness of every layer (the exact thickness of every layer is pointed out in Section 2.1) and Fig. 5 shows the result. For contrast, the response of traditional A-B rem counter (without 0.6 cm Pb) is also shown in Fig. 5.

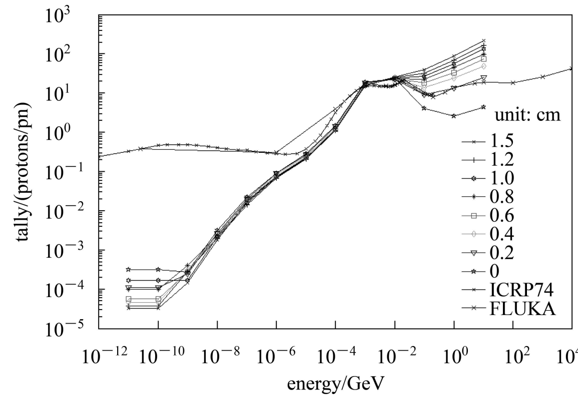

Fig. 3. Response function when we change the thickness of lead layer.

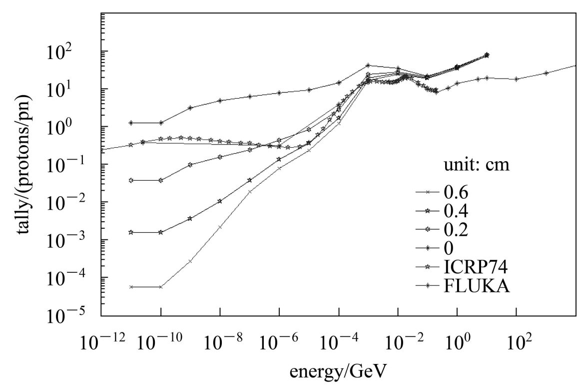

Fig. 4. Response function when we change the thickness of boron doped plastic attenuator.

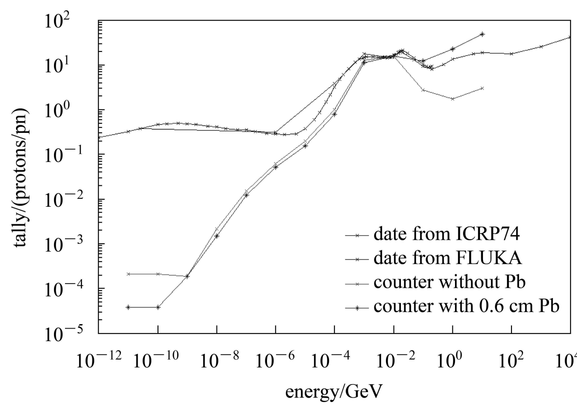

Fig. 5. Optimized response curve we have selected; response curve of the same configuration without Pb is also listed for comparison; convert coefficients from tally to ambient dose equivalent form ICRP74 and FLUKA are also listed for comparison.

The four curves are normalised at a neutron energy of 10 MeV. Table 1 shows the calculated response function of both A-B rem counters-with and without a Pb sleeve and for monoenergetic neutrons with energies in the range from thermal energy to 10 GeV. It can be seen that the response of a modified rem counter has been increased greatly.

Table 1. Calculative response function of the Sphere Counter with and without 0.6 cm Pb for monoenergetic neutrons.

neutron energy/GeV	relative efficiency A:0.6 cm Pb	relative efficiency B:0.0 cm Pb	ratio(A/B)
10	72.8	4.43	18.65
1.0	33.6	2.59	14.69
0.1	18.3	4.03	5.16
1.0×10^{-2}	23.5	23.2	1.15
1.0×10^{-3}	16.5	18.7	1.00
1.0×10^{-4}	1.2	1.49	0.91
1.0×10^{-5}	0.24	0.29	0.92
1.0×10^{-6}	7.63×10^{-2}	9.05×10^{-2}	0.95
1.0×10^{-7}	1.84×10^{-2}	2.22×10^{-2}	0.94
1.0×10^{-8}	2.21×10^{-3}	3.15×10^{-3}	0.79
1.0×10^{-9}	2.74×10^{-4}	2.72×10^{-4}	1.14
1.0×10^{-10}	5.57×10^{-5}	3.09×10^{-4}	0.20
1.0×10^{-11}	5.57×10^{-5}	3.09×10^{-4}	0.20

According to the optimized parameters of the beam dump of CSNS[7], we simulate the neutron lethargy fluence spectrum, which is shown in Fig. 6. We can see from the figure that there are two peaks, and in this interval the response function of our detector is exactly fit to the H*(10) curve. When we adopt these two kinds of counter in the CSNS,we also adopt a fictitious counter with an ideal response function, whose response curve just covers the H*(10) curve given by FLUKA. The simulative results are shown in Table 2. We can get the result that the response of the counter with 0.6 cm Pb is 30% larger than that without Pb, and its response differs from that of the ideal neutron counter only by 4%.

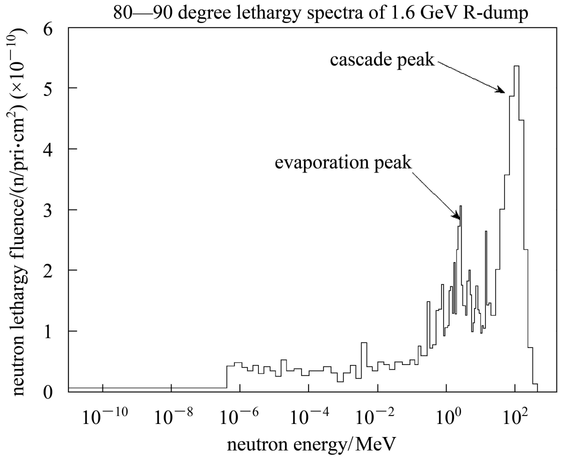

Fig. 6. Neuron lethargy fluence spectrum outside the beam dump of CSNS.

Table 2. Simulative measurement result and the ratio between them.

simulative response of lethargy neutron spectrum in CSNS		A-B counter 0.0 cm Pb(A)	A-B counter 0.6 cm Pb(B)	A-B counter ideal C
		0.19	0.25	0.26
response ratio	A/(A,B,C)	100.0%	76.0%	73.0%
	B/(A,B,C)	131.0%	100.0%	96.1%

4 Conclusion

The modified A-B rem counter described in this paper does improve the response function in high energy range that it can be considered as a valid instrument for neutron monitoring up to 1 GeV. Its angular response has been investigated through simulations with FLUKA in Ref. [3]. So it is of interest at intermediate and high energy accelerator facilities. Further work we have to do is to calibrate it in some representative energy points and to validate it in the real neutron radiation dosimetry.

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