A study of 14 MeV neutrons buildup factor in paraffin wax, graphite and lead.

دراسة عامل التراكم لنيوترونات ذات الطاقة 14 مليون إلكترون فولت في شمع البرافين , الكرافيت والرصاص.

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Abstract

The 14 MeV neutrons buildup factor in paraffin wax, graphite and lead have been experimentally determined using the BF_3 counter up to a thickness of 2.5 mean free path (mfp).The dependence of the secondary neutrons spectrum transmitted from all selected materials on the thickness at the fixed incident neutron energy has also been studied using a liquid organic scintillation detector type NE 213. Results indicate that, the value of buildup factor remains close to unity up to penetration depths of 0.4 mfp and then increases when sample thickness increased. The neutron spectra obtained in this research depends on the material type and thickness. In general, the neutron spectra decrease with increasing sample thickness. Comparison of the experimental results obtained with the previously calculated neutron buildup factor shows a good agreement.

الخلاصة

تم تحديد عامل التراكم لنيوترونات ذات الطاقة 14 مليون إلكترون فولت عمليا في كل من شمع البرافين , الكرافيت والرصاص وبأسماك مختلفة تصل إلى 2.5 متوسط مسار حر, باستعمال العداد BF_3 .
كذلك تمت دراسة اعتماد طيف النيوترونات الثانوية النافذة من العينات على سمك العينة باستخدم الكاشف ألوميضي العضوي السائل نوع NE 213 .
أظهرت النتائج الحاصلة في هذا البحث إن عامل التراكم يساوي واحد تقريبا لسمك يصل الى متوسط مسار حرمقداره 0.4 ثم يزداد بزيادة سمك المادة. كذلك وجدنا أن طيف النيوترونات النافذة من العينات تعتمد على نوع المادة وسمكها. عموما إن شدة النيوترونات الأولية النافذ من مادة الدرع تقل بزيادة سمك الدرع. النتائج العملية الحاصلة لعامل التراكم كانت متقاربة مع النتائج النظرية السابقة.

1. Introduction

It has been found that neutron generators are widely used in physical, chemical and biological researches. The attenuation of 14 MeV neutrons in various materials attracts the attention of biological, agriculture, industrial and medical researchers. The concept of buildup factor is useful to describe the attenuation of gamma rays and neutrons in shielding materials. The values of neutron buildup factors are usually determined theoretically by neutron transport calculation and Monte Carlo method [1-3]. A detailed historical review on calculation of buildup factor and its use are given by Arthur et al.[4] and Harima [5] .

Neutron attenuation is a accomplished mainly through elastic and inelastic scattering reactions, which reduce the neutrons energy until they can be absorbed (captured) by the shielding materials. The neutron capture cross section is large only for thermal neutron energies. Therefore, the neutrons slowing down by scattering is important before capture.

Light elements are best for slowing down neutrons by elastic scattering . So materials with a high hydrogen content e.g. water and plastic are used. Inelastic scattering occur when the incoming neutrons impart some of their energy to the scattering material which excite the target nuclei [6, 7]. The scattered neutrons may reach the detector and get counted a part of uncollided neutrons beam. The intensity of transmitted neutrons beam (I) is represented by [4, 6]:

$$I = I_0 \, B \, e^{-\Sigma_{rem} .x} \qquad ---------(1)$$

Where I_0 is the incident neutrons intensity in the absence of the slab between source and detector, B is the neutron buildup factor, $\sum_{rem}$ is the macroscopic removal cross section of the slab material and x is the slab thickness.
Usually the product ($\sum_{rem} .x$) is called the optical thickness which represents the number of neutron mean free path (mfp).
This study was carried out to measure the neutron buildup factor in light elements like paraffin wax and graphite as well as in heavy element like lead at different thicknesses. The fast neutrons spectra (in MeV region) resulting from 14 MeV neutrons after slowing down in those samples were also investigated.

2. Experimentation

2.1 Experimental setup

The geometrical arrangement for the present measurements is shown in Fig.1. Neutrons were produced in ${}^{3}_{1}H\,(d,n)\,{}^{4}_{2}He$ fusion reactions. The Neutron Generator type T- 400 was obtained from Iraqi Atomic Energy Commission. This generator accelerates deutrons beam D^+ of 100 KeV energy.
The energy of emitted neutrons in the zero direction to the D^+ (in forward direction) was 14 ± 0.1 MeV with the source strength 10^7neutron /s.
Samples of paraffin wax (ρ=0.96 g. cm^{-3}), graphite (ρ=1.54 g. cm^{-3}) and lead were put in the form of rectangular plates with dimensions 80 cm × 80 cm.
BF_3 counter containing an assembly of BF_3 gas tube (43 cm long and 2.5 cm diameter manufactured by Centronic), pre-amplifier (Canberra 1406), amplifier (Silena 7601), high voltage power supply (Tennelec 950), Scalar and timer (Tennelec 535) was used to count the transmitted neutron beam intensities.
The combination of BF_3 tube and cylindrical moderator was suggested as a flat response neutron detector by Mc Taggart [8].The counter designed to be sensitive only to neutrons incident on the front face parallel to the cylindrical axis of the counter. Those incidents from either directions tend to be moderated by the outer annulus of paraffin and are subsequently captured in the boron layer without giving rise to a count.
The neutron spectrometer containing NE213 liquid organic scintillation detector (5 cm radius, 5 cm length manufactured by Nuclear Enterprise Ltd.), amplifier (Tennelec 244), high voltage power supply (Canberra 1406) and computerized multichannel analyzer (MCA) was used to detect the fast neutron spectrum transmission from the samples. NE213 detector was placed inside a paraffin cylindrical collimator to avoid the effect of scattered neutrons from reaching the detector.
The other NE213 detector was used as a primary neutron monitoring (at 90^O direction of incident neutrons) to check the source strength.
Calibration of the system for full scale on the MCA of 14 MeV was determined by using 4.97Ci of ${}^{241}Am - Be$ and 0.45Ci of ${}^{252}Cf$ neutron sources.
Each spectrum was recorded for a period of 30 min. to reduce the statistical error. Background spectra were recorded for the same time period and subtracted from each spectrum.

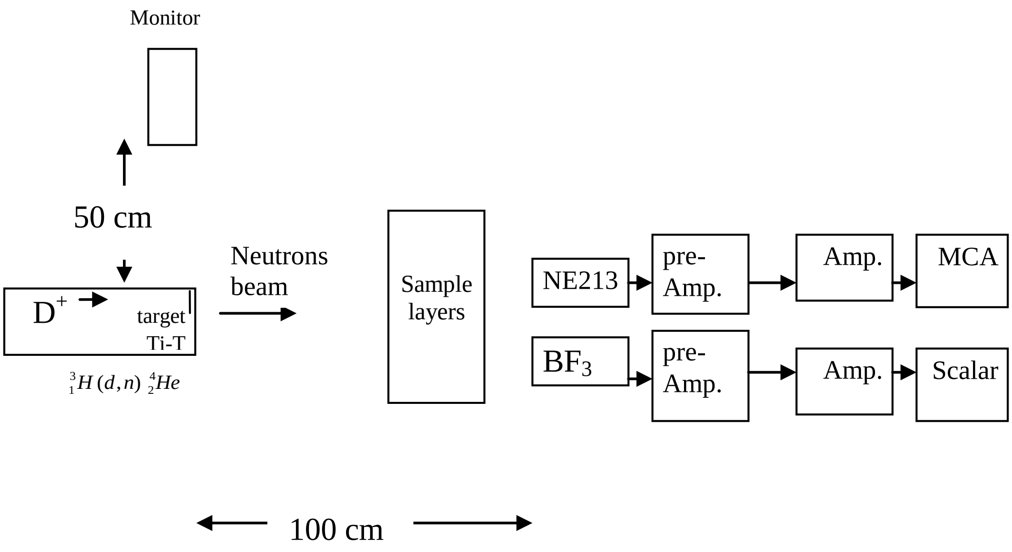

Fig. 1. Geometrical arrangement of the experimental measurements

2.2 Buildup factor measurements

The incident neutrons intensity in the absence of any sample (I_0) and transmitted ($I_{measured}$) from the sample were recorded for various thicknesses using the BF_3 counter.

The value of the $I_0 e^{-\Sigma_{rem}.x}$ is called calculated intensity ($I_{calculated}$) was obtained by substituting

value of $\sum_{rem}$ (0.071 cm^{-1} for paraffin wax , 0.0785 cm^{-1} for graphite and 0.088 cm^{-1} for lead) at 14 MeV neutron energy [6].

It is observed that the value of neutron buildup factor according to equation (1) is:

$$B = \frac{I_{measured}}{I_{caculated}} \qquad ----------(2)$$

2.3 Fast neutron energy distribution

Using neutron spectrometer, the fast neutron portion of the secondary neutrons has been measured for different thicknesses of the samples. It was then divided this region into ten groups from 1.2 MeV up to 14 MeV. The simplest multi group method was used for the evaluation of the data [9].

3. Results and discussion

The measured values of buildup factor for neutrons (B) in paraffin wax, graphite and lead for various sample thicknesses were given in table1 and plot in Fig. 2.

It can be seen that the value of buildup factor remains close to unity up to thickness of 0.4 mfp, whereas for thickness > 0.4 mfp the value of buildup factor increases with increasing sample thickness. Thus, it is obvious the multiple scattering of neutrons are produced with increase sample thickness.
It is also interested from fig.2 to note that for thicknesses > 0.4 mfp , the value of neutron buildup factor in lead is larger than that in graphite and paraffin wax. This can be explained by the effective of inelastic scattering and (n, 2n) in lead.
Fig.3 shows the comparison of experimental results with theoretical values obtained from ref.3. It can be seen that, the buildup factors in lead obtained by present work agree well with the theoretical values in most cases, except for some cases where a small disagreements is seen with the fractional difference less than 5% , this difference come from the data which have been used and the method of calculations.
Figs. (4-6) show the measured neutrons spectra distribution transmitted from investigation materials. It can be seen that the intensity of neutrons spectrum decreases with the increase of sample thickness. These spectra also show that, most of the scattered neutrons have energies below 5 MeV. This can be explained by the presence of neutron inelastic scattering reactions with the samples.
The energy group 9-14 MeV have least intensity in lead slabs. This is due to the fact that lead in this energy region have inelastic scattering cross section higher than that in graphite and paraffin wax.

4. Conclusions

The obtained results give the following conclusions:

- The value of 14 MeV neutron buildup factor for selected materials remains close to unity up to optical thickness of 0.4 mfp, whereas for optical thickness > 0.4 mfp the value of buildup factor increases with increasing sample thickness.
- The value of 14 MeV neutron buildup factor in lead is larger than that in graphite and paraffin wax.
- Most of the transmitted neutrons from selected materials have energies below 5 MeV.

Table 1. Neutron buildup factor in paraffin wax, graphite and lead for various absorber thicknesses.

Sample thickness (cm)	Paraffin wax (ρ=0.96 g. cm^{-3})		Graphite (ρ=1.54 g. cm^{-3})		Lead (ρ=11.34 g. cm^{-3})	
	Optical thickness (mfp)	Buildup factor	Optical thickness (mfp)	Buildup factor	Optical thickness (mfp)	Buildup factor
2	0.142	1.020±0.001	0.157	1.023±0.002	0.176	1.053±0.006
5	0.355	1.009±0.001	0.392	1.054±0.003	0.440	1.195±0.005
10	0.710	1.207±0.002	0.785	1.162±0.005	0.880	1.526±0.007
15	1.065	1.366±0.003	1.177	1.399±0.002	1.320	1.902±0.009
20	1.420	2.013±0.004	1.570	2.233±0.005	1.760	2.612±0.013
25	1.775	2.375±0.005	1.962	2.862±0.004	2.200	3.982±0.018

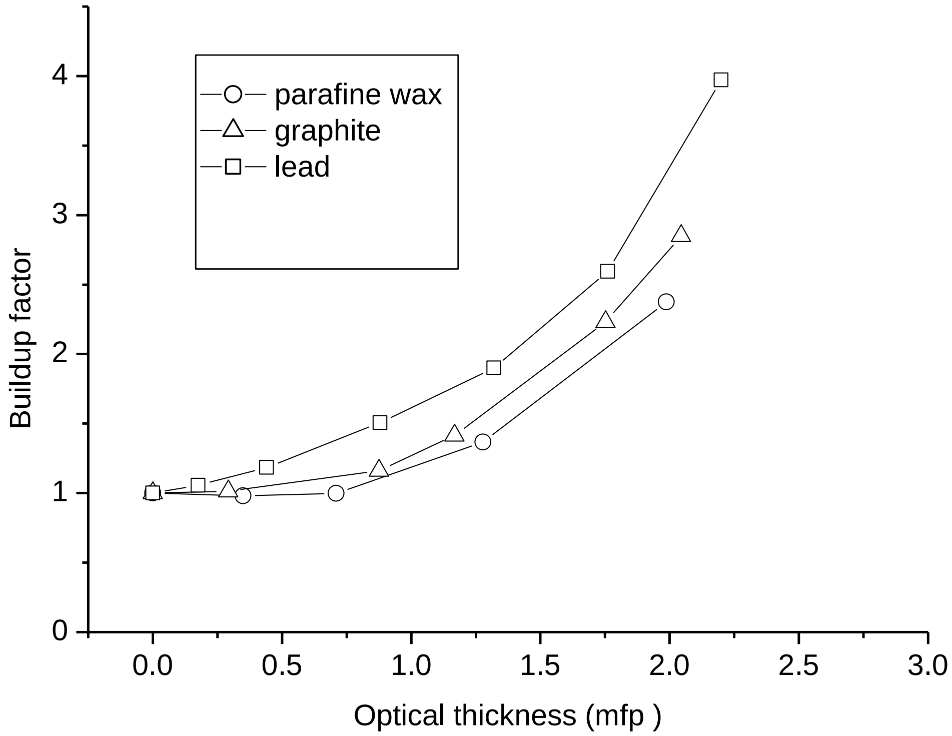

Fig.2 :Variation of 14 MeV neutron buildup factors with optical thickness in paraffin wax, graphite and lead.

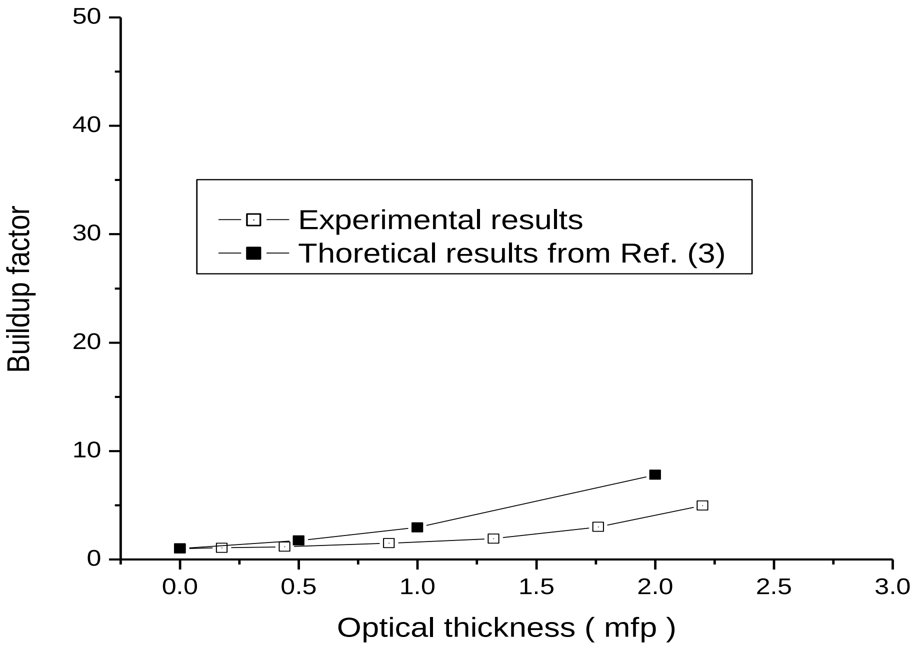

Fig.3 :Comparition of 14MeV neutron buildup factors in lead with those of reference 3 for lead.

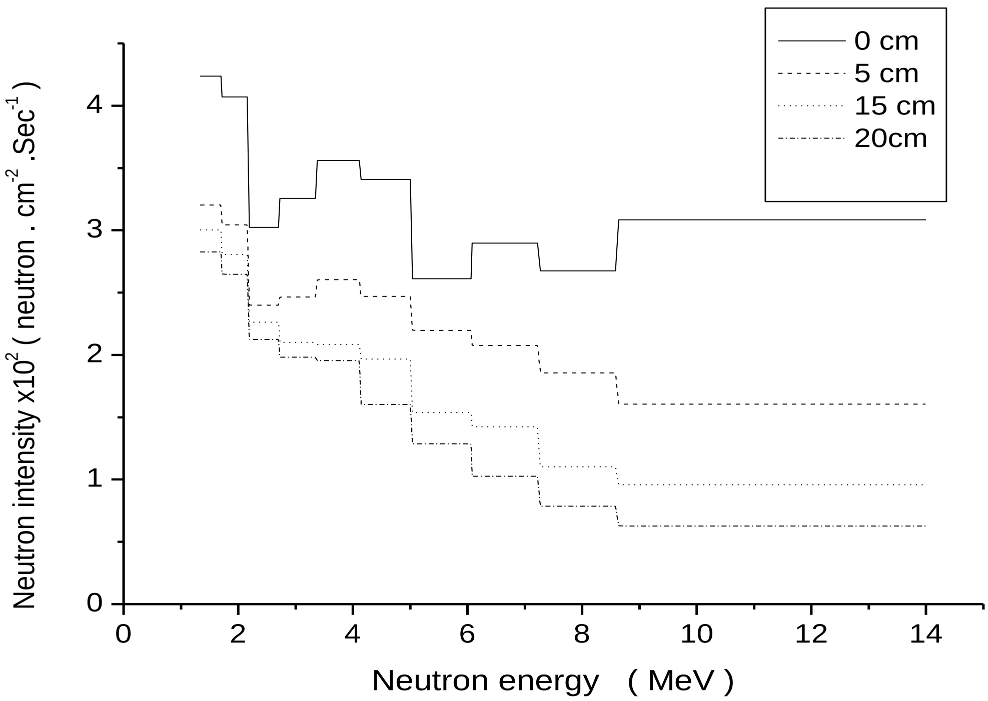

Fig. 4 : Neutron spectrum in paraffin wax for different values of layer thickness.

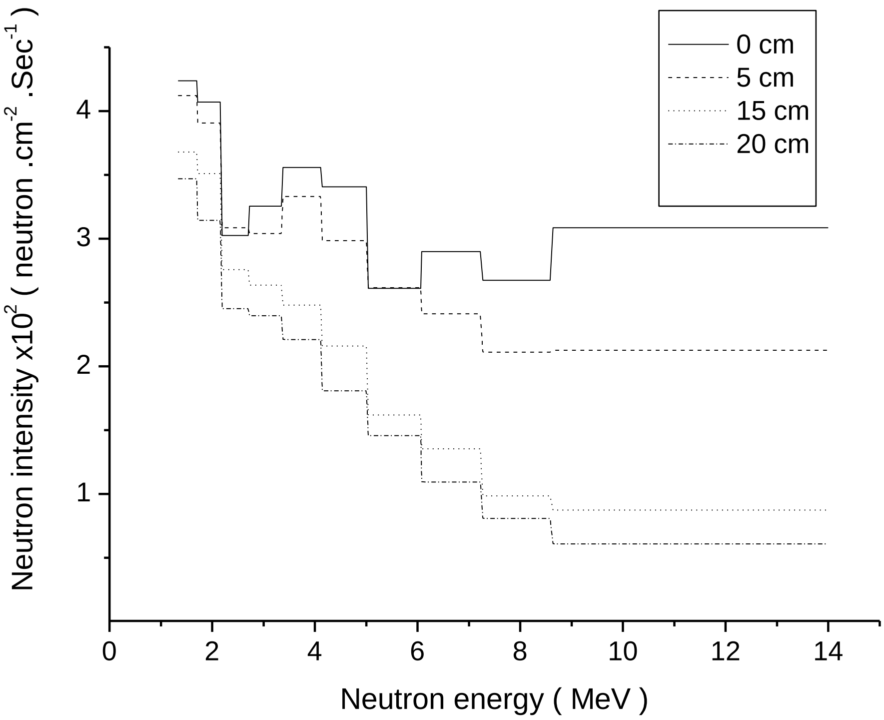

Fig. 5 : Neutron spectrum in graphite for different values of layer thickness.

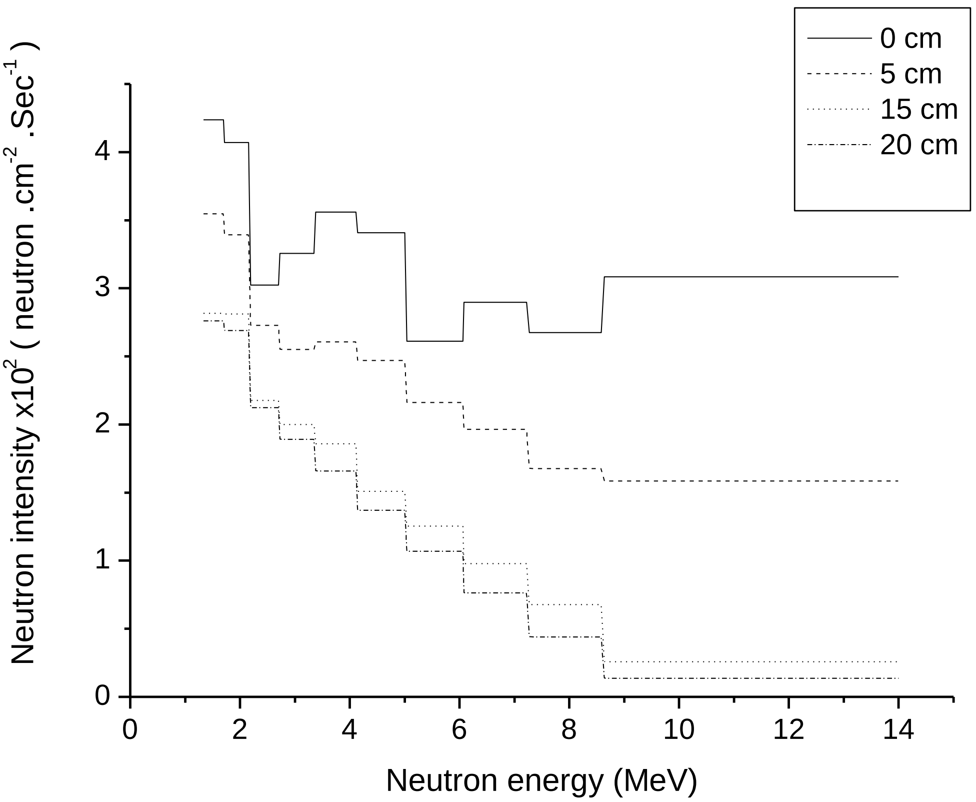

Fig. 6 : Neutron spectrum in lead for different values of layer thickness.

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