FLUX AND BUILDUP FACTORS IN MULTILAYERED MEDIA

M.A. Abou Mandour, M.M. El-Afify*, M.K. Shaat** and W.A. Metwally***

* Nuclear Engineering Department, Faculty of Engineering, Alexandria University, Alexandria-21544 Egypt.
**Reactor Department, Nuclear Research Center, Atomic Energy Authority, Egypt.

ABSTRACT

The study of the neutron's behavior is an important part in various research problems such as in the construction of nuclear reactors and high energy accelerators. It is also indispensable in the packaging and storage of isotopic neutron sources. In this paper, the behavior of highly energetic neutrons while penetrating a multilayered is studied. The media consists of three slabs of different materials. The selected materials are carbon, iron, and lead. The considered neutron source is a planar monoenergetic source with initial energy up to 14 MeV. The used calculational method is the Monte Carlo Method.

Keywords: Flux, Buildup Factors, Multilayered Media, Highly Energetic Neutrons, Monte Carlo Method.

INTRODUCTION

The objective of the study of the transport of neutrons in a medium is to calculate their distribution which succeed to penetrate large thickness of dense matter and arrive to its outer regions. Only particles of exceptional energies and directional distributions have significant probabilities of achieving this. This study plays an important role in various nuclear assemblies such as in the construction of nuclear reactors and high energy accelerators. It is also indispensable in the packaging and storage of isotopic neutron sources. Recently, efforts have been concentrated on research works using 14 MeV neutron source in order to obtain good data for the verification of nuclear fusion reactor design.

Most of the methods that had been used in neutron transport are based on the transport theory. Among these methods are the Pn, Sn, and the finite element method. Another technique, based on the transport theory is the Monte Carlo method. It is a powerful method which comes very close to simulating the actual motion of the particles through the domain.

Recently, calculations were concerned with the usage of the buildup concept to enable the analytical treatment of complicated problems. The previous efforts are mainly categorized into two classes. The first class deals with the calculations and measurements of the buildup factors in a single layered medium. Dunn *et al.* [1] calculated the gamma ray and neutron dose equivalent buildup factors for six common shielding materials. The used geometries were point source, infinite slab and point detector. The technique for estimating slab buildup factors used a decomposition of the dose equivalent into single scatter and multiscatter components. A rigorous model was used for the single scatter while a Monte Carlo model is used for the multiple scatter. The neutron source energy ranged from 0.1 to 14 MeV. The used materials were aluminum, iron, lead, water, polyethylene and concrete. Another effort was made by Abou Mandour, and Hassan, [2]. They developed a Monte Carlo program to calculate the neutron buildup factors for fast (14.1 MeV) monoenergetic neutrons. Three responses were computed : flux, dose rate, and heat deposition rate buildup factors. Calculations were performed for point isotropic, monodirectional planar and isotropic planar sources in a homogeneous medium of carbon or iron.

The second class deals with the efforts made for multi-layered media. Several combinations of different materials were used to study the shielding properties of the media. Shin and Ishii, [3] calculated the neutron dose buildup factors for medium energy neutrons using the Point Kernel Method and the ANISN code. The used materials were concrete and iron. Characteristics of obtained buildup factors were tested for a double layered shield consisting of concrete with variational atomic composition and iron. Sokolinova, *et al.* [4] experimentally determined the doses of the absorbed energy in a mixed (neutron-gamma) field generated by 14 MeV neutrons which have passed through iron and lead layers of different thicknesses Ueki, and Namito, [5] calculated the neutron dose rates, using the Monte Carlo Method, to construct the optimum shielding arrangement for a shipping cask with iron-polypropylene cylindrical shielding system. Abou Mandour, and Hassan, In a second work [6], the problem of a double layered medium carbon-iron or iron-carbon irradiated with a planar monodirectional source was treated. They showed that the buildup factors are strongly affected by the presence of the two layers and are very different from those calculated for a homogeneous medium.

Calculations or measurements for a multilayered medium consisting of three different materials are scarce. The main objective of the present work is to perform a parametric study, using the Monte Carlo Method, of the flux and flux buildup factors for a three layered medium consisting of carbon, iron and lead with different thicknesses and arrangements.

COMPUTATIONAL METHOD

The basic idea of Monte Carlo is to create a series of life histories of the source particles by using random sampling techniques to sample the probability laws that describe the real particle's behavior, and to trace out step by step the particle's random walk through the medium. This history of the particle is followed. The life history is then terminated, if the particle is absorbed, escaped the medium or emerged the emergy class of study. Then a "new" particle is started from the source. By running off a large number of such case histories, their results can be averaged to obtain estimates of the expected behavior of the particle population. Particle transport processes are quite amenable to such a treatment, since the individual interaction events (collisions) are usually described in terms of statistical characteristics (mean free paths or cross sections).

The main advantage of the Monte Carlo method for radiation computations is that the interactions of an individual particle may be simulated by machine computation, the energy and direction of the particle after such successive interactions being governed by the cross sectional data used in the computation. The method is best suited for the analysis of geometrically complex systems for which analytical approaches are virtually impossible and numerical schemes are extremely time consuming. Another advantage of the method is its usefulness for a class of problems such that the fine structure of cross sections is important and/or such that a detailed simulation of the physics of the interactions is needed. This class of problems is often the driving motivation for using Monte Carlo even though the geometries may be simple.

PROGRAM VERIFICATION

Due to the lack of experimental or theoretical results applicable for the considered three layered medium, the developed program was verified by comparing its results with some pre-published results but for different configurations; such as the case of the double layered medium, [6].

Another verification was made by comparing the uncollided flux calculated from the Monte Carlo program with the value obtained from the analytical formula. Both comparisons showed good agreement.

FLUX AND BUILDUP FACTORS

The main objective of this work is to study the behavior of the highly energetic neutrons while penetrating a multilayered media consisting of three slabs of different materials. This behavior is described through the calculations of the flux, forward and backward, the flux buildup factor, and the energy spectra especially at the interfaces between the three materials.

This study provides numerical values for the buildup factor which are valuable to enable many neutron transport calculations to be carried out analytically using the point kernel technique. Among these fields are the design of neutron radiotherapy systems, the design of fusion reactors, and the assurance of personnel safety near high energy neutron generators.

The considered neutron source in the calculations is a planar monoenergetic source with initial energy of 14 MeV. The chosen materials are carbon, iron, and lead as an example of light, intermediate, and heavy materials respectively.

The main parameters affecting the neutron transport through the three layered medium are the arrangement of the three slabs, the thickness of each slab and the initial energy of the incident neutrons. A parametric study is carried out to show the effect of each of these parameters separately.

Effect of Arrangement

The effect of the order of arrangement is studied by considering all the possible arrangements of the carbon, iron and lead slabs. Any arrangement is marked as : X-Y-Z where X, Y, and Z refer to the symbol of the material used in sequence. In the calculations, the other two factors, slab thickness and neutron initial energy, are kept constant.

As can be seen from Figure 1, if lead is placed as a first layer the neutron flux decreases monotonically in the second and third layers. By interchanging the second and third layers and keeping the lead as a first layer, the neutron flux decreases in case of carbon as a second layer due to the relative smaller fraction of backscattered flux in carbon and because of the larger scattering angles with which the forward neutrons are scattered in iron. To estimate the alteration in the numerical value of the flux due to the presence of the three layers, the flux in an infinite homogeneous medium is calculated and plotted on the same figure.

To determine the contribution of the backscattered neutrons in altering the neutron flux, the Monte Carlo program is modified to separately calculate the neutron forward and the backward flux at any depth in the medium. The calculations are given in Figure 2. It can be noticed that the backscattered neutrons in the lead layer is much greater than that in the carbon layer.

The drop in the flux in the third layer is due to the increase in the flux of lower energy neutrons entering the third layer. To confirm this fact numerically, the program is also extended to calculate the neutron spectrum at each interface between the layers. The results are given in Figure 3. The number of neutrons suffering inelastic collisions in the third layer is increased leading to the flux decrease.

By placing iron as a first material, the behavior of the flux is approximately the same except that the flux in the three layers is lower than that in the case of placing lead as the first layer because of the smaller scattering power of iron. When the first layer is the lightest one, see Figure 4, its flux is enhanced by a greater factor if lead is the second layer than the case when iron is the second layer. This is due to the multiplication effect of the lead material.

The flux buildup factor is calculated for each of the above mentioned configurations and plotted in Figures 5 to 7. The effect of the order of arrangement on the numerical values of the buildup factor is noticed in these figures. For comparison, the case of a homogeneous medium of the same material is also calculated and plotted on the same figures.

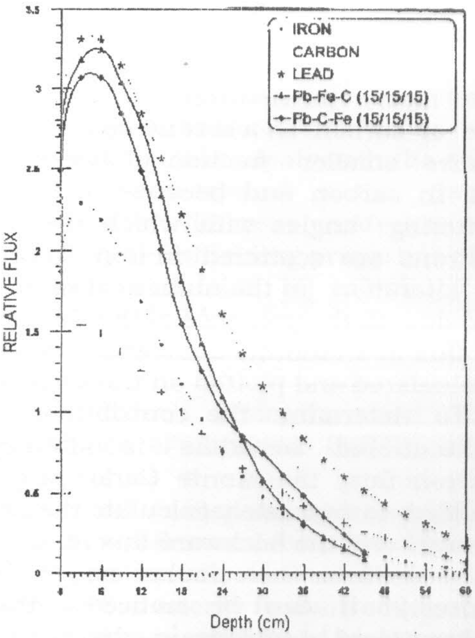

Figure 1 Relative flux behavior in a three layered medium, irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement order Pb-Fe-C and Pb-C-Fe.

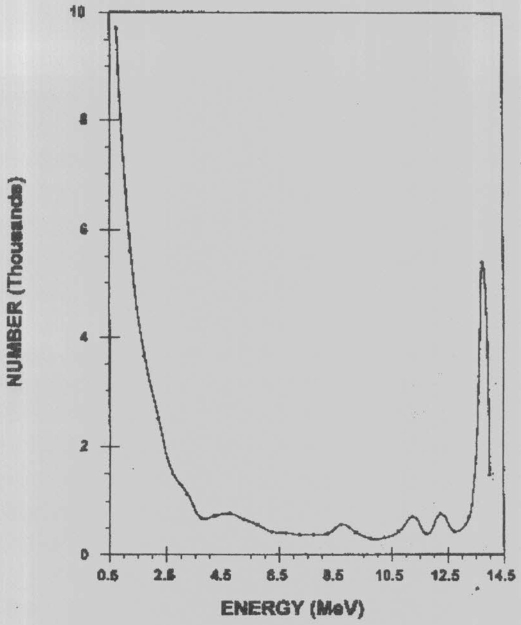

Figure 3 Neutron energy spectrum at the C-Fe interface of the Pb-C-Fe arrangement and slab thickness of 15 cm each.

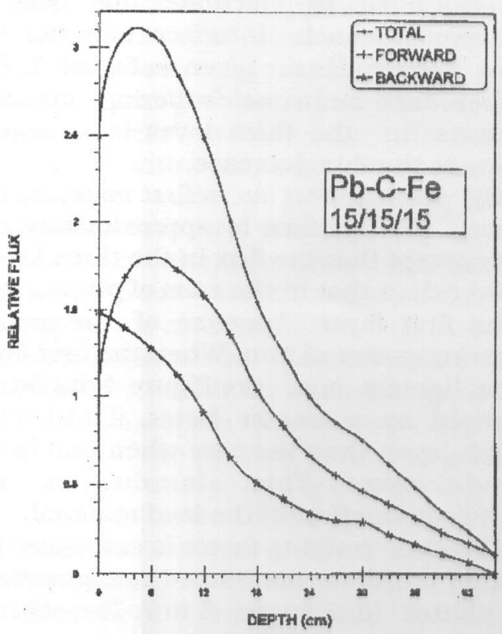

Figure 2 Total, forward, and backward relative flux behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement order Pb-C-Fe.

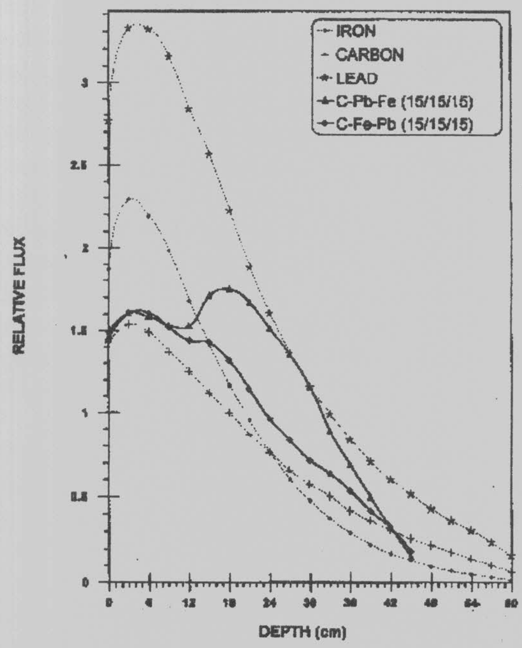

Figure 4 Relative flux behavior in a three layered medium, irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement order C-Pb-Fe and C-Pb-Fe.

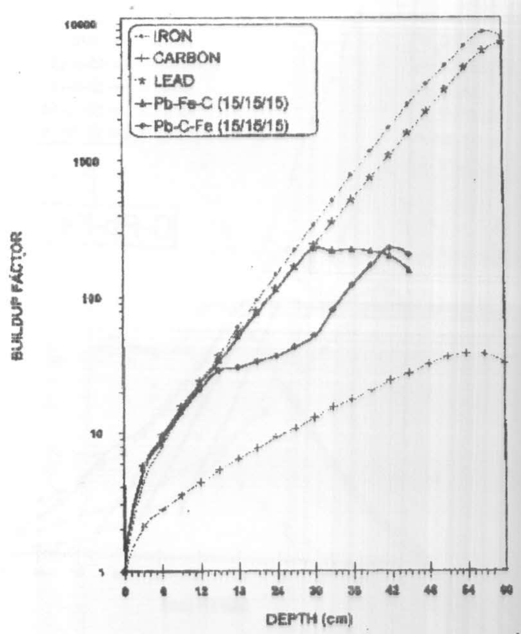

Figure 5 Flux buildup factor behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement order Pb-Fe-C and Pb-C-Fe.

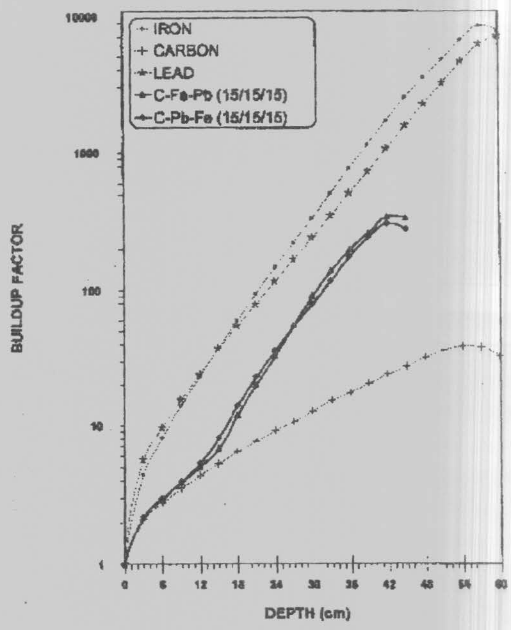

Figure 7 Flux buildup factor behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement order C-Fe-Pb and C-Pb-Fe.

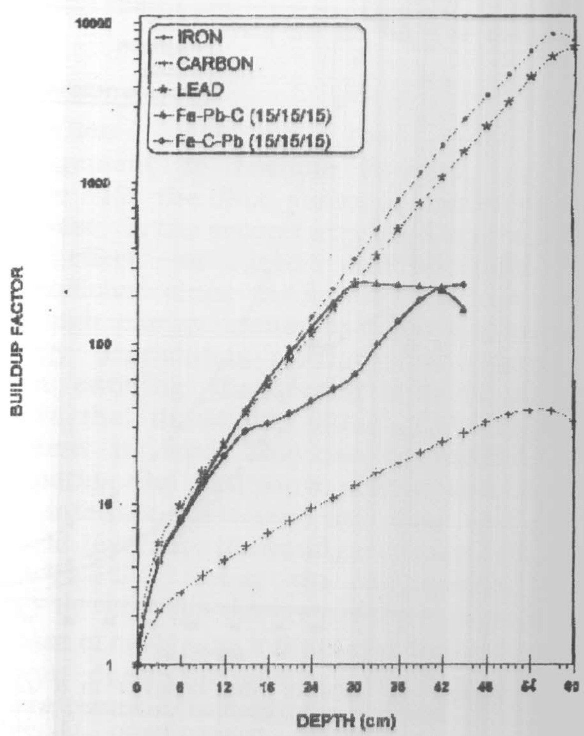

Figure 6 Flux buildup factor behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement order Fe-Pb--C and Fe-C-Pb.

Effect of Slab Thickness

To show the effect of slab thickness on both the flux behavior and the numerical values of the buildup factor, three arrangements , C-Pb-Fe, C-Fe-Pb and Fe-Pb-C are selected. In the calculations the first and third layers are of the same thickness, 15 cm, while the intermediate layer is set to 3, 9, 15 and 30 cm.

The thicknesses and the kind of material of the second layer have a great effect on the flux behavior in the whole three layered medium. If the arrangement is C-Pb-Fe, the flux distribution shows a second maximum in the second layer. The amount of flux enhancement at the maxima is dependent on the second slab thickness, increasing the thickness, the maximum increases, (see Figure 8). The cause of this enhancement in the flux is attributed to two reasons : the first is the effect of the greater fraction of the backscattered neutrons in the lead layer when compared with the iron layer and the second is the effect of the neutron multiplication in lead since the spectrum of the neutrons entering the lead layer have a relatively great fraction of neutrons near the peak energy. This explanation can be verified by considering iron as a second layer. The results of this configuration are plotted in Figure 9. The figure shows that , the second maximum in the flux distribution has disappeared because of the lack of multiplication in iron. To emphasis this phenomena, the thickness of the first layer is varied while the thickness of the other two layers are kept constant. It can be noticed that when the thickness of the first layer becomes smaller the two maxima coincide and vice versa, as seen in Figure 10. On the other hand, when varying the thickness of the third layer, a smaller influence is recorded in both orders of arrangements as can be noted from the examples given in Figure 11.

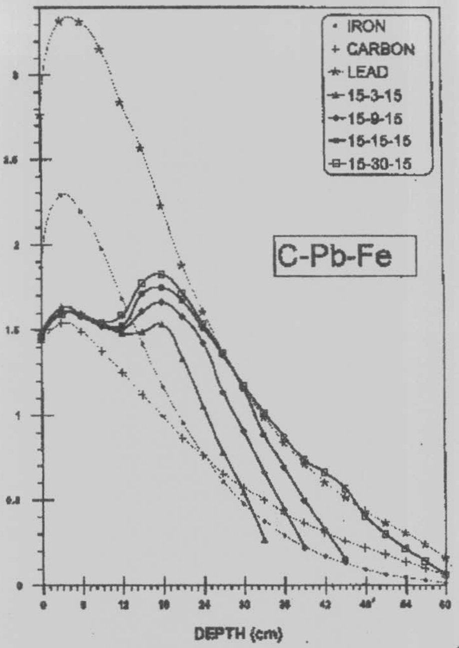

Figure 9 Relative flux behavior in a three layered medium, irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement C-Fe-Pb.

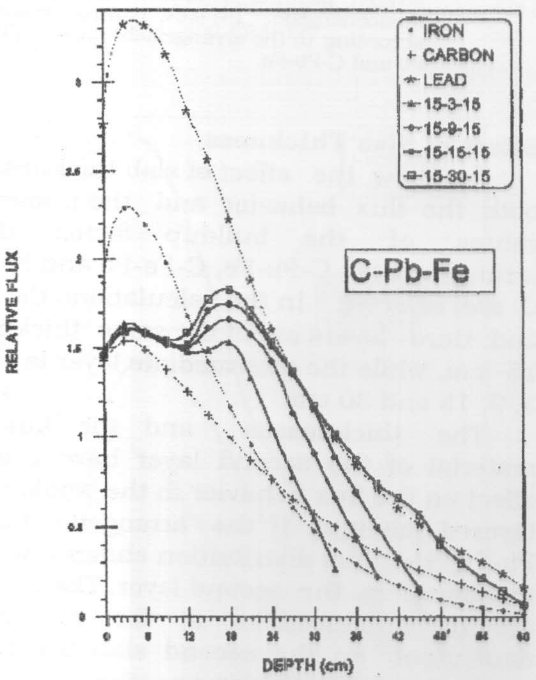

Figure 8 Relative flux behavior in a three layered medium, irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement C-Pb-Fe and varying the thickness of the intermediate layer.

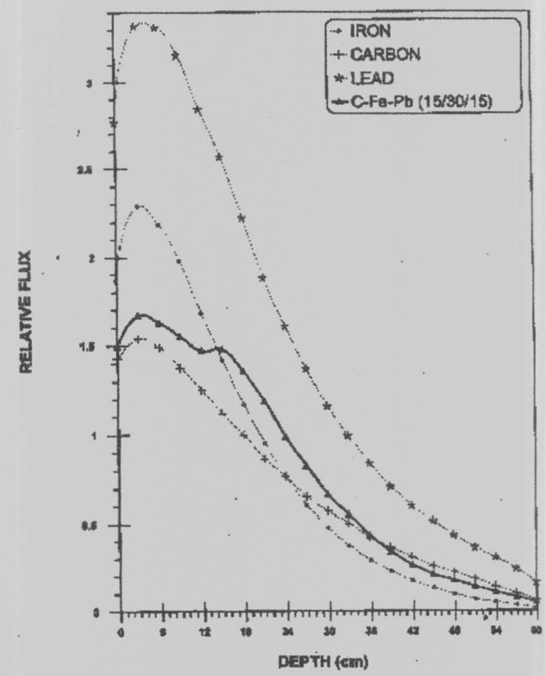

Figure 10 Relative flux behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement C-Pb-Fe and varying the thickness of the first layer.

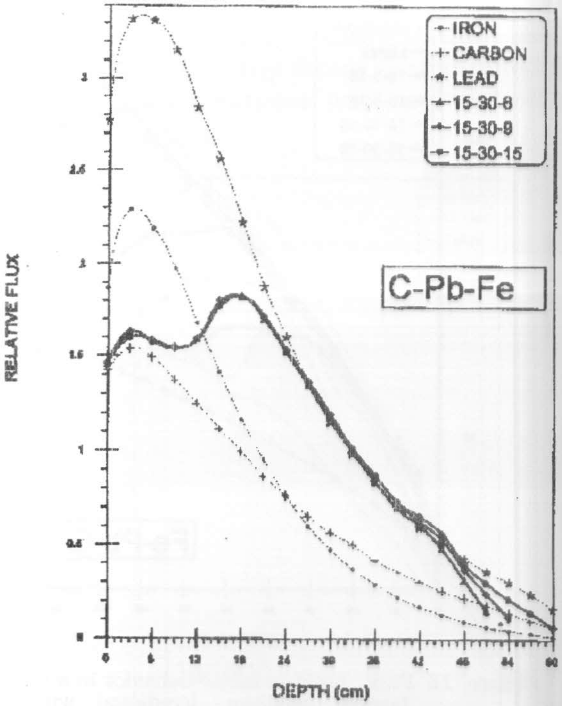

Figure 11 Relative flux behavior in a three layered medium, irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement C-Pb-Fe and varying the thickness of the last layer.

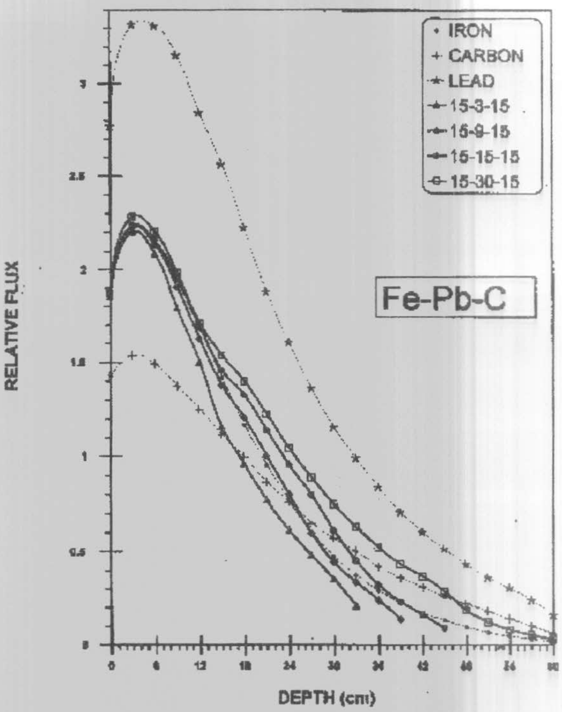

Figure 12 Relative flux behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement Fe-Pb-C and varying the thickness of the intermediate layer.

When reversing the order of arrangement to become Fe-Pb-C, as in Figure 12, the flux shows a monotonical decrease in the second and third layers and the effect of lead multiplication is insignificant since the first layer is iron and the high energy neutrons suffer a stronger energy degradation so that their energies upon entering the second layer is much below the threshold value of the (n,2n) reaction in lead. This can be verified by comparing the neutron's energy spectra at the interface between the first and the second layers for the configurations C-Pb-Fe and Fe-Pb-C. From the comparison, the peak of the high energy neutrons is greater in case of carbon as a first layer than in case of iron due to the smaller mean free path of the neutrons in iron than in carbon.

Again for the previous examples the buildup factors are calculated and presented in the set of curves of Figures 13 to 16.

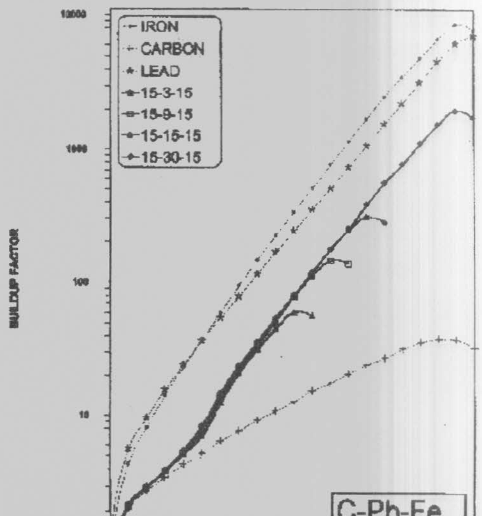

Figure 13 Flux buildup factor behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement C-Pb-Fe and varying the intermediate layer.

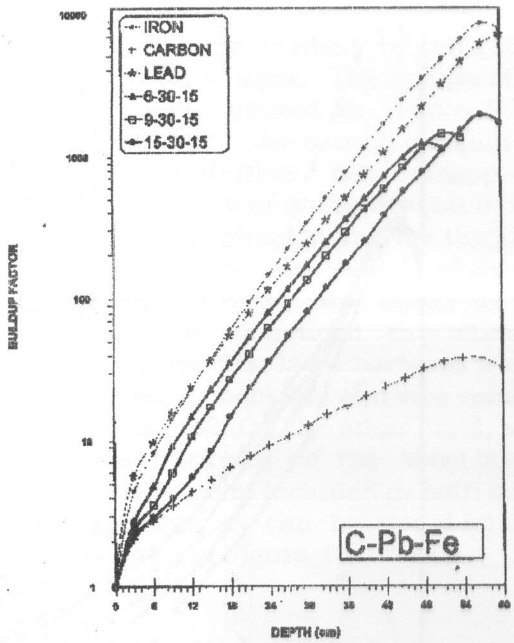

Figure 14 Flux buildup factor behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement C-Pb-Fe and varying the thickness of the first layer.

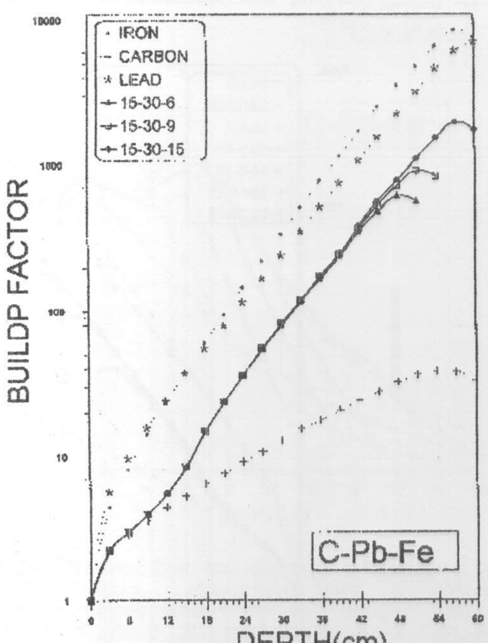

Figure 15 Flux buildup factor behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement C-Pb-Fe and varying the thickness of the third layer.

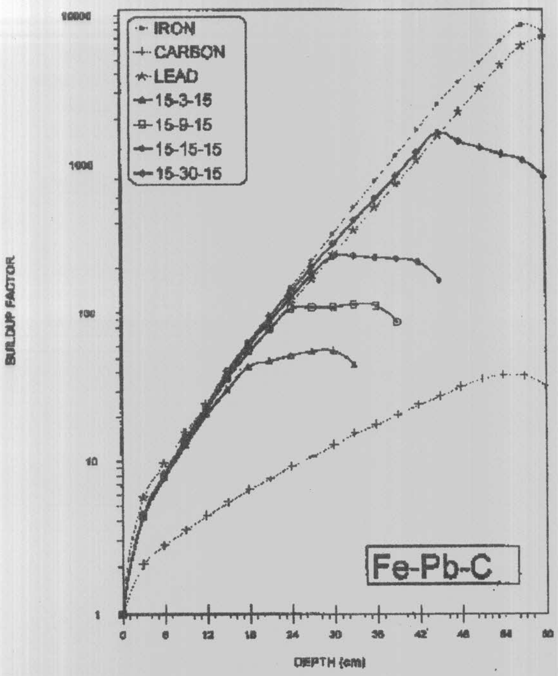

Figure 16 Flux buildup factor behavior in a three layered medium ,irradiated with a planar monoenergetic 14 MeV neutron beam, according to the arrangement Fe-Pb-C and varying the thickness of the intermediate layer.

Effect of Initial Energy

To investigate the variation of the neutron flux distribution and buildup factor while changing the neutron's initial energy, the thickness of the three slabs are being set to 15 cm each. The curve parameter is the initial energy of the source neutrons and so the calculations are carried out for energies of 5, 7, 9, 11 and 14 MeV.

In the C-Pb-Fe arrangement, large angle back scattering and neutron multiplication in lead are again the main factors behind the enhancement and the alteration of the neutron flux. The effect of back scattering is dominant at the low source energies while the neutron multiplication is dominant at the high source energies. This can be noticed especially when comparing the curves in Figure 17 giving the neutron fluxes for 5 MeV and 14 MeV respectively. The study is continued by considering the other arrangement of Fe-Pb-C, and the same values of the neutron's initial energies. The relative contribution of the two factors stated above is less significant in this case.

The flux buildup factor is calculated for the two configurations and are plotted in Figures 18 and 19.

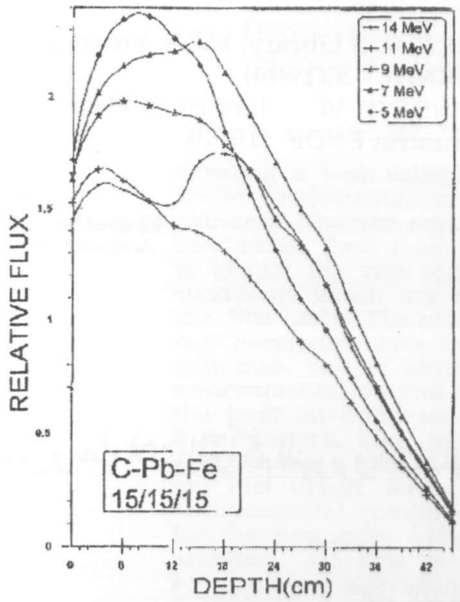

Figure 17 Relative flux behavior in a three layered medium, irradiated with a planar monoenergetic neutron beam, according to the arrangement C-Pb-Fe and varying the energy of the incident neutrons.

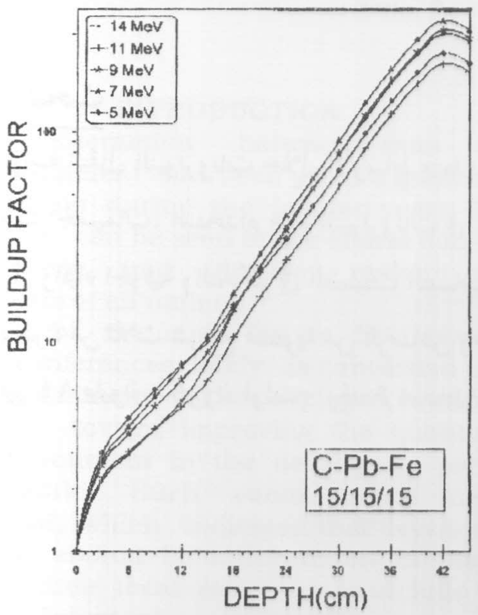

Figure 18 Flux buildup factor behavior in a three layered medium, irradiated with a planar monoenergetic neutron beam, according to the arrangement C-Pb-Fe and varying the energy of the incident neutrons.

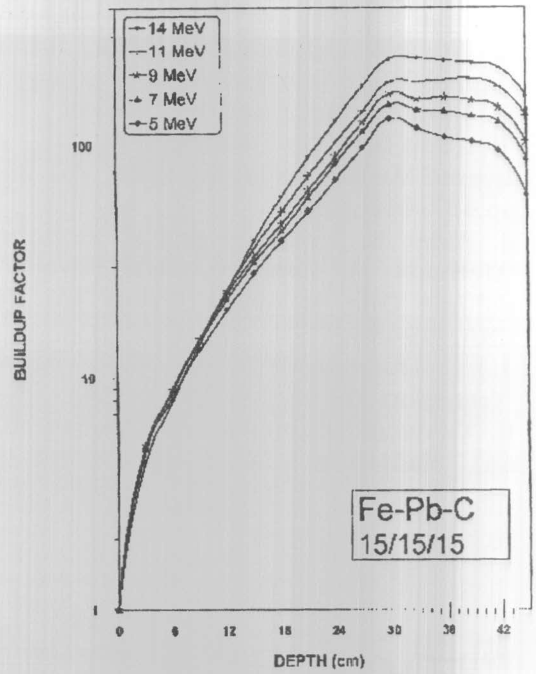

Figure 19 Flux buildup factor behavior in a three layered medium ,irradiated with a planar monoenergetic neutron beam, according to the arrangement Fe-Pb-C and varying the energy of incident neutrons.

REFERENCES

1. W. L. Dunn A.M. Yacout and F. O'Foglalualha, "Gamma Ray and Neutron Dose Equivalent Buildup Factors for Infinite Slabs", Nucl. Sci. & Eng., Vol. 110, pp. 134-156, (1992).
2 M. Abou Mandour and M. Hassan "Neutron Buildup Factors for Different Irradiation Environments", Isotopenpraxis, Vol. 23, pp.429-437, (1987).
3. K. Shin and Y. Ishii, "Build-up Factors for Medium Energy Neutrons up to 400 MeV", Radiation Protection Dosimetry, Vol. 40, pp. 185-194, (1992).
4 N.K., Sokolinova, V.I., Gadzhokov, T.E. Petkov, K.D. Ilieva, J.D., Jordanova, O.J. Penchev, T.M. Troshev, V.J. Khristov "Dose Determination in a Mixed Field of 14 MeV Neutrons Passing Through Shielding Layers" , Yad.-Energ., Vol. 22, pp. 16-22, (1985).
5. K. Ueki and Y. Namito, "Monte Carlo Simulation to Construct the Optimum Shielding Arrangement", 1st Inter-

national Conference on Supercomputing in Nuclear Applications, Mito, Ibaraki (Japan), 12-16 March, (1990).
6. M. Abou Mandour and M. Hassan "Neutron Buildup Factors for Multi-layered Media", Isotopenpraxis, Vol. 23, pp.437-442, (1987).
7. B. Alder S. Fernbach and M. Rotenberg "Methods in Computational Physics", Volume One, Academic Press Inc., NY, USA, (1963).
8 J.J. Duderstadt and W.R. Martin "Transport Theory", Wiley (1979).
9. R. G. Jaeger Engineering ,"Compendium on Radiation Shielding", Vol. 1, Shielding Fundamentals and Methods, Springer - Verlag, Berlin, (1968).
10. J. Wood, "Computational Methods in Reactor Shielding", Pergamon Press, Oxford, (1982).
11. JEF-2 Library, IAEA, Vienna, Austria. Jef 2, (1993)
12. JENDL-3 Library, IAEA, Vienna, Austria. JENDL - 3,(1994)
13 ENDF/B-VI Library, IAEA, Vienna, Austria ENDF (1993).

Received December, 14 1997
Accepted February 26, 1998

الفيض ومعاملات التراكم للنيوترونات ذات الطاقة العالية عند سقوطها على وسط ثلاثي الشرائح

محسن ابو مندور * ، محمد العفيفى *

*قسم الهندسة النووية -جامعة الاسكندرية

محمد كمال شعت **، وليد عبد المحسن متولى **

**قسم المفاعلات -مركز البحوث النووية هيئة الطاقة الذرية

ملخص البحث

إن دراسة انتقال النيوترونات خلال الأوساط متعددة الشرائح من الموضوعات الهامه فى مجالات كثيرة منها المفاعلات الذرية ، معجلات الجسيمات، استخدام حزم النيوترونات فى المعالجة والعلاج فى للأورام ، استخدام حزم النيوترونات فى الكشف عن آبار البترول والمياه الجوفية والتحكم فى العمليات الصناعية. يقوم البحث على حساب الفيض النيوتروني ومعاملات التراكم لوسط يتكون من ثلاث شرائح مستوية من الرصاص والحديد والكربون عند سقوط حزمه متوازية من النيوترونات ذات الطاقة العالية (حتى ١٤ مليون إلكترون فولت) وقد تم استخدام طريقة مونت كارلو فى العمليات الحسابيه.