Alex. Eng.J., Alex. Univ., Volume 28 No. 4, pp 511 - 519 (1989)

Neutron Build-Up Factors for Double-Layered Media

by

M. Ghabashy* and M. Abou Mandour**
*Department of Engineering Mathematics and Physics
Faculty of Engineering, Alexandria University, Egypt.
**Department of Nuclear Engineering
Faculty of Engineering, Alexandria University, Egypt.

Abstract

The concept of the neutron build-up factor is recently used in the analysis of various practical applications in the fields of radiation protection, design of fusion devices, neutron therapy, neutron diagnostics, study of heating in a shield and neutron-radiogauging. The use of the build-up factors can simplify the calculations in most of these applications. A systematic investigation of the effect of the different parameters (the thicknesses, the type of material of each layer of the slab, the order of arranging the two media in the slab, the type of scattering inside each layer, and the irradiation geometry) generally characterizing the build-up factor has been carried out using the S_n-method. It is found that the build-up factor in a double-layered slab is strongly dependent on the c-values of the two media and on the order of arranging the two layers in the slab.

1. Introduction

In many practical applications in the fields of radiation shielding, radiation protection, design of fusion devices, neutron therapy, neutron diagnostics, the study of heating in a shield and radiogauging, multi-region systems are encountered quite often. In the calculations concerning these practical applications, treating the multi-layered problem, with the given interface and boundary conditions, is a tedious and a complicated problem. The most accurate methods commonly used are the S_n and the Monte Carlo method. Both methods are numerical methods and need large memory computing machines and also need much computing times.

An alternative method, which is much simpler and in the same time possesses high accuracy for treating these calculations is carried out using the build-up concept [1-17]. The build-up factor for neutrons at a certain point is defined as the ratio of the total flux to the uncollided flux at this point [18, 19, 20]. Knowing the build-up factor data, the stationary flux at any point in the multi-layered slab can be determined and thus the succeeding calculations which are mainly dependent on the flux in the above mentioned fields can be completed.

The objective of this study is to give numerical values for the build-up factors for a large number of different double-layered media that are most important in the practical applications and present them in a suitable form. The S_n-method is selected for solving the neutron transport in the double-layered medium. This is because the S_n-method has two main advantages: first, it can treat different media in a simpler way than the other alternative method (the Monte Carlo method); and second, it needs less computing time relative to the other method.

2. Computational Method

2.1, Build-up Concept

The build-up factor at a certain point (r) is defined as the ratio between the total flux to the uncollided flux at that point, mathematically,

$$B(r) = q(r)/\{q_o \cdot \exp[-(w_{t1}\ x_1 + w_{t2}\ x_2)/u_o]\}$$

where

q_o = total flux at point (r=0).
$q(r)$ = total flux at point (r).
x_1 = thickness of the first layer compared to the meam free path.
w_{t1} = total cross-section of the first layer
x_2 = thickness of the second layer
w_{t2} = total cross-section of the second layer
u_o = the cosine of the angle of incidence of the neutron source

The above equation is valid in case of anisotropic planar source. If the source of neutron at x=0 is an isotropic planar source, the exponential function in the above equation is replaced by

$$E_1\ (w_{t1}\ x_1 + w_{t2}\ x_2)$$

where E_1 is the known E_1-function.

2.2. Build-up Factor Computations

Previous calculations or measurements of the buildup factors in a double-layered medium are scarce [1,2]. The Monte Carlo calculations and the experimental techniques carried out give results that are only useful for the materials and geometries considered. The present results can be used for a variety of materials.

The dependence of the build-up factor on the penetration depth, in multi-layered media is more complex than that in homogeneous media. In multi-layered systems the build-up effect of the incident neutrons depends not only on the previously penetrated layers and the layer under consideration, but also on the subsequent layers. The order in which the layers are arranged is of great importance.

The different parameters that affect the values of the build-up factor are the types of the two media specified by the parameter "c"which is defined as the ratio between the microscopic scattering cross-section to the microscopic total cross-section, the thicknesses of the two layers, and the order of arranging the two layers. The effect of each of these parameters is studied separately.

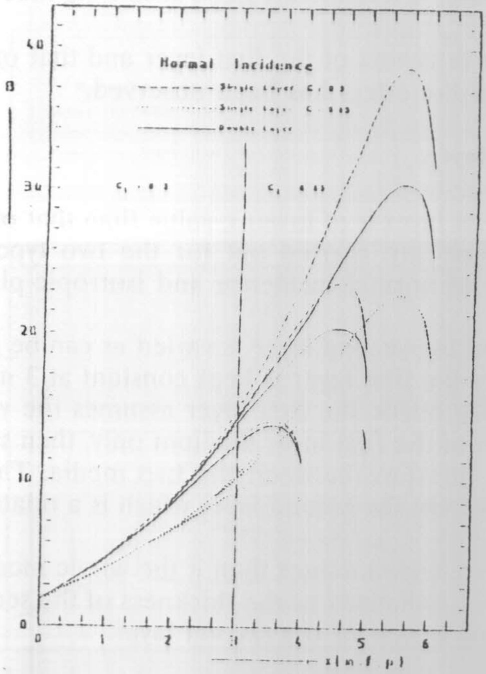

figure (1)

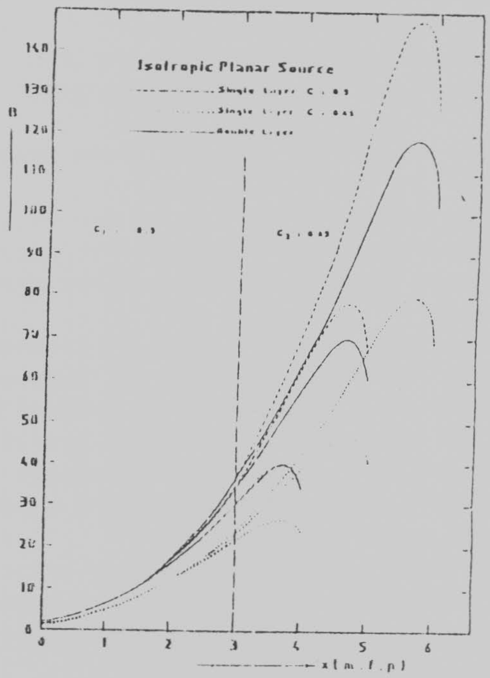

figure (2)

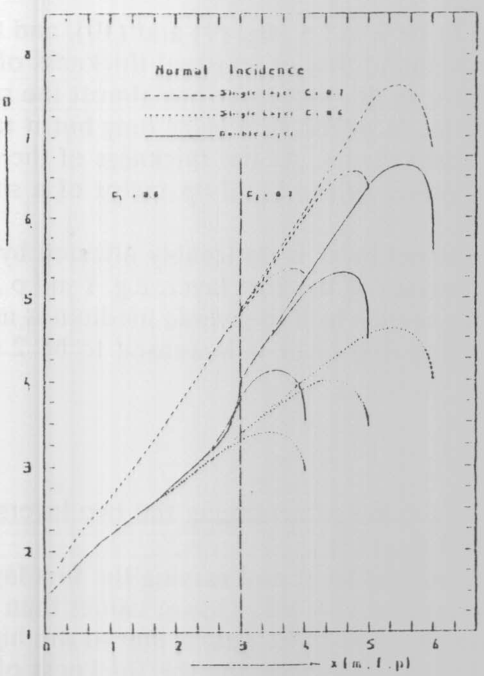

figure (3)

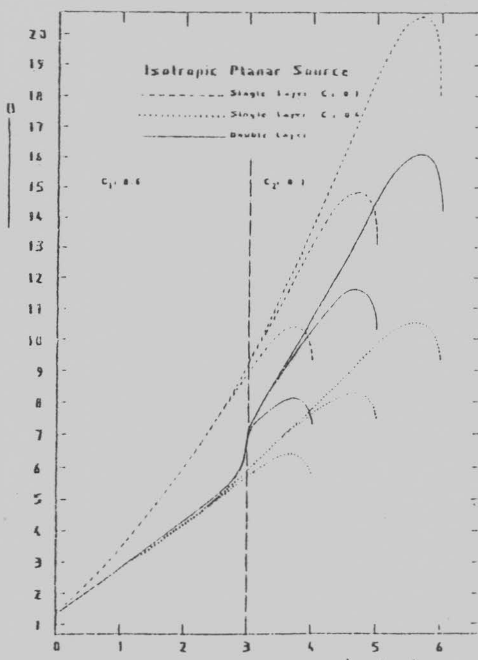

figure (4)

Three cases of combinations of different media have been investigated. The first case is that when the two layers are relatively good scattering media (high c-value), fig. (1) and (2), the second case is that when the two layers are relatively good absorbing media (low c-value), fig. (3) and (4), and the third case is that when one layer is a relatively good scattering medium and the other is a relatively good absorbing medium, fig. (5) and (6).

In each arrangement of the two layers the thickness of the first layer and that of the second layer are varied interchangeably and the effect has been observed.

The effect of the thickness of the second layer:

The case of a double-layered slab whose first layer is of lower c-value than that of the second layer is first studied. The calculations are carried out for the two types of neutron sources: anisotropic planar source of normal incidence and isotropic planar source.

As a first step in this study, the thickness of the second layer is varied as can be seen in fig. (7) and fig. (8), while the thickness of the first layer is kept constant at 3 m.f.p. It can be concluded that the build-up factor inside the first layer assumes the value of the build-up factor of a single layer made of the first layer medium only, then starts to take higher values as it approaches the interface between the two media. This is expected due to the back-scattered neutrons from the second layer which is a relatively good scattering medium.

In the second layer, the build-up factor takes higher values than if the whole medium is made of the first layer only. This increase is enhanced as the thickness of the second layer is increased due to the lower absorbing power of the second layer.

The effect of the thicknesses of the first layer:

The thickness of the first layer is decreased to be 2 m.f.p., fig. (9) and (10), and then to be 1 m.f.p., fig. (11) and (12). It can be concluded that at constant thickness of the second layer, the behavior of the build-up factor in the first layer has almost the same depth dependence as if the whole medium is made of the first layer only but it takes higher values near the interface between the two media. As the thickness of the first layer decreases, the build-up factor assumes values of the build-up factor of a single layer made of the second layer medium only.

The behavior of the build-up factor in the second layer is noticeably affected by the thickness of the first layer. At very small thicknesses of the first layer, e.g. 1 m.f.p., the build-up factor has almost the same depth dependence as if the whole medium is made of the second layer only. As the thickness of the first layer is increased to be 2 or 3 m.f.p., the build-up factor takes lower values.

Order of arrangement:

The above calculations are repeated when the order of arranging the two layers are reversed. The results are given in fig. (13) and fig. (14).

In the first layer, at constant thickness of the second layer and varying the first layer's thicknesses, the build-up factor of the double-layered slab takes lower values than that if the whole medium is made of the first layer medium only. This is due to the higher absorbing power of the second layer which has lower c-value. As the thickness of the

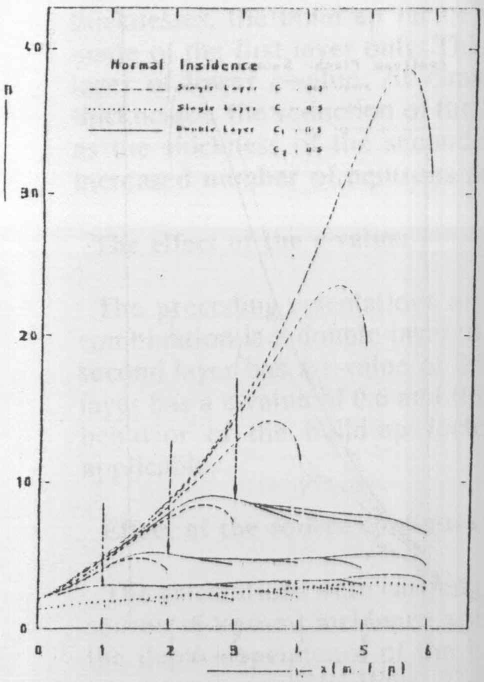

figure (5)

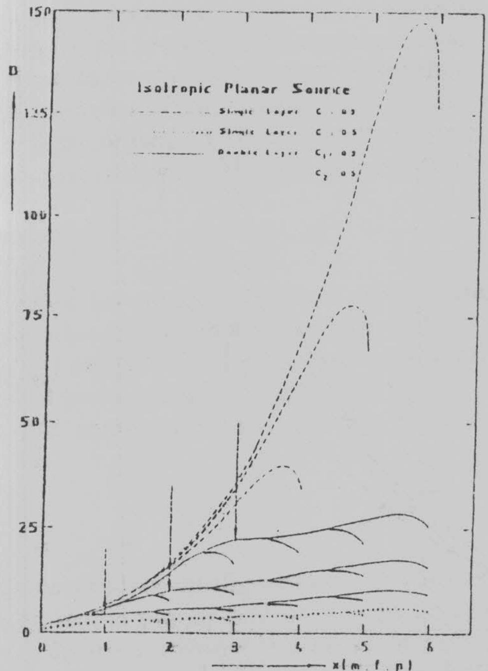

figure (6)

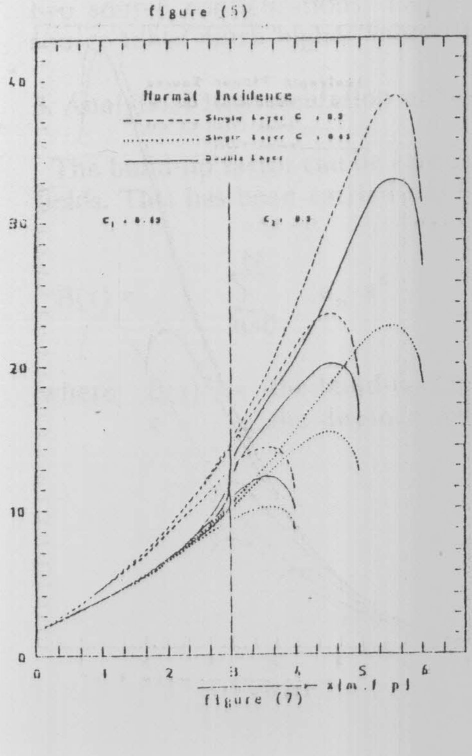

figure (7)

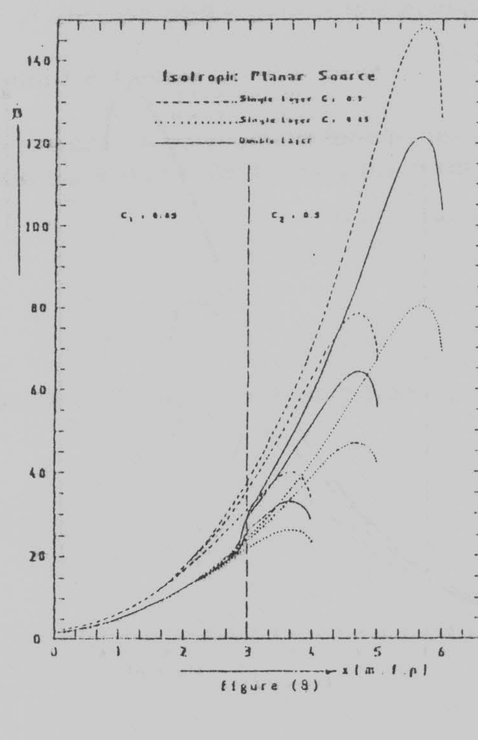

figure (8)

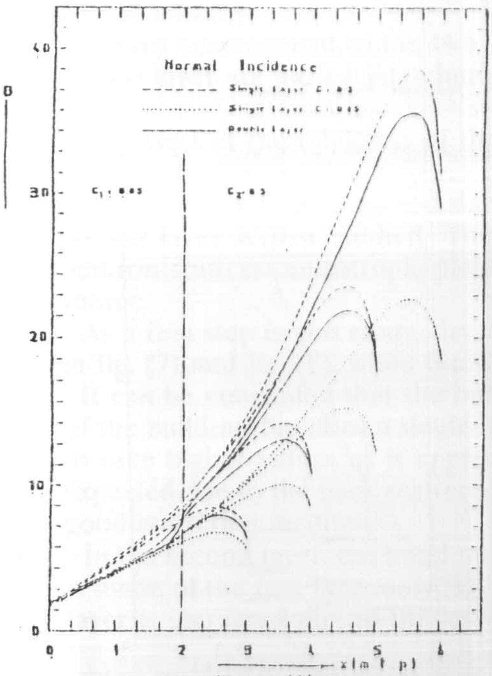

figure (9)

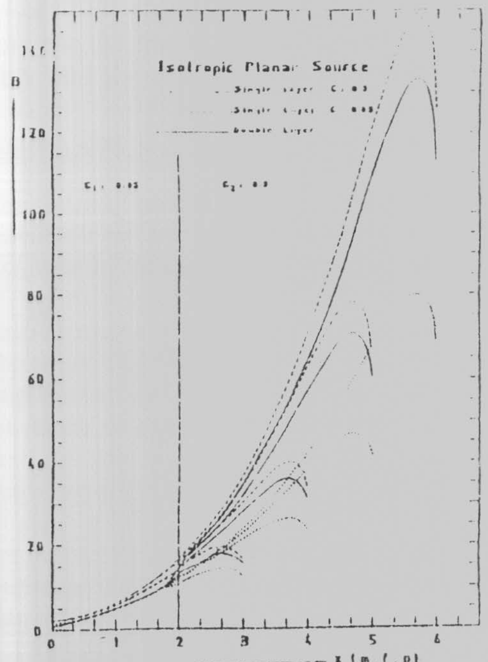

figure (10)

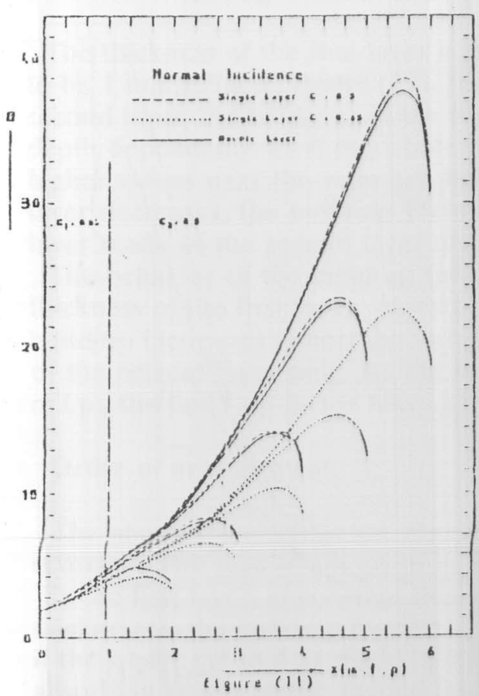

figure (11)

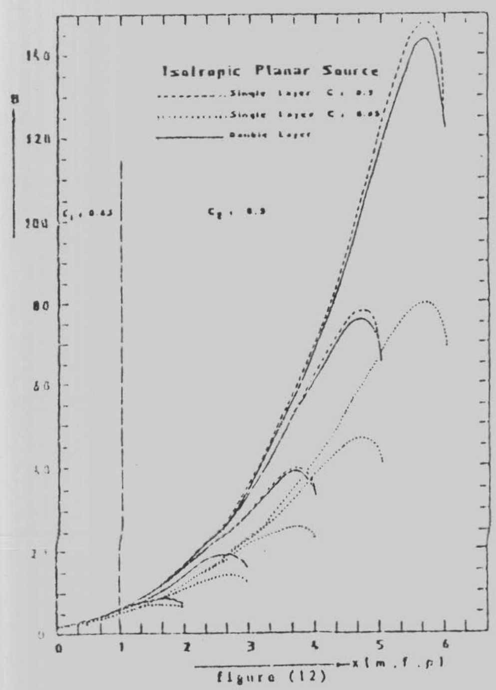

figure (12)

first layer increases, the lowerness of the build-up factor values decreases.

In the second layer, at constant second layer thickness and varying the first layer thicknesses, the build-up factor takes lower values than that if the whole medium is made of the first layer only. This is due to the increased absorption inside the second layer of lower c-value. At constant first layer thickness and different second layer thicknesses, the reduction of the build-up factor of the double-layered slab is increased as the thickness of the second layer is increased. This is also expected due to the increased number of neutrons absorbed with increased second layer thickness.

The effect of the c-value:

The preceding calculations are repeated for another level of the c-values. The first combination is a double-layered slab whose first layer has a c-value of 0.85 and whose second layer has a c-value of 0.9, fig. (7) and (8). In the second combination, the first layer has a c-value of 0.6 and the second layer has a c-value of 0.7, fig. (3) and (4). The behavior of the build-up factor is the same and the above conclusions are also applicable.

Effect of the source configuration:

The calculations were carried out for two source configurations: the anisotropic planar source of normal incidence and the isotropic planar source. It can be concluded that the depth-dependence of the build-up factor is almost the same in both cases of the two source configurations. The build-up factors in the case of the isotropic planar source takes much higher values than in the case of the anisotropic planar source.

3. Analytical Representation of the Build-Up Factors

The build-up factor can be expressed as a sum of polynomials for easy use in different fields. This has been carried out by using a fitting code. It takes the form

$$B(x) = \sum_{n=0}^{N} a_n x^n$$

where $B(x)$ = the build-up factor
x = the distance compared to the mean free path (m.f.p.).

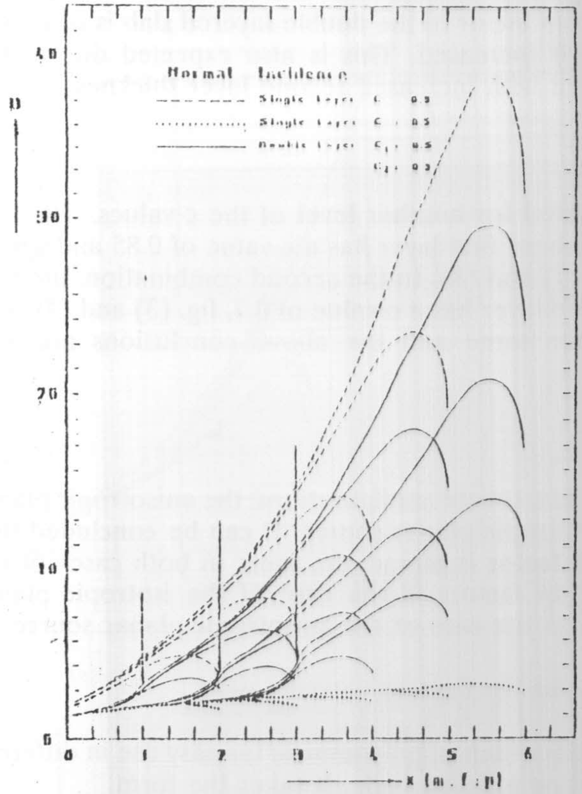

Fig.(13) Flux-build up factors calculated for x-m.f.p. single-layered slab of c=0.5 or 0.9 and a double-layered slab of "x-m.f.p. first layer of c=0.5 + x-m.f.p second layer of c=0.9". Case of anisotropic planar source and normal incidence.

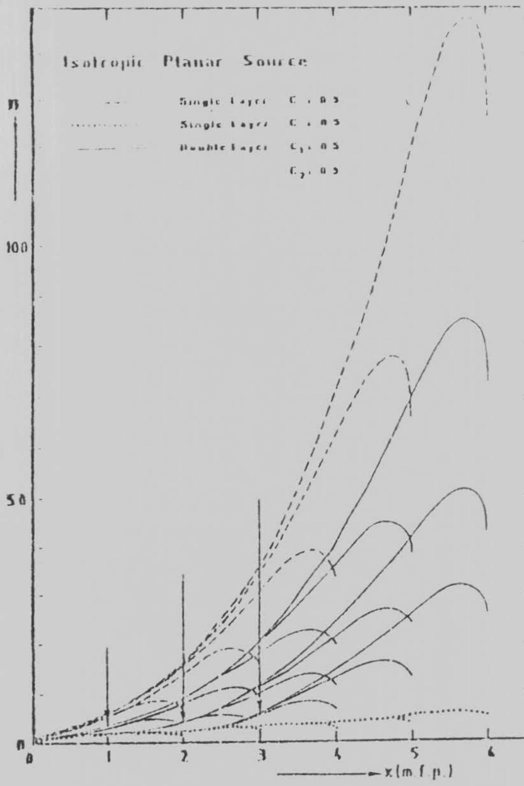

Fig.(14) Flux-build-up factors calculated for x-m.f.p. single-layered slab of c=0.5 or 0.9 and a double-layered slab of "x-m.f.p. first layer of c=0.5 + x-m.f.p second layer of c=0.9". Case of isotropic planar source.

References

[1] Abou Mandour M. and Hassan M., "Fast Neutron Number Albedo Characteristics for Double-Layered Slabs", *Alexandria Engineering Journal*, vol. 27, No. 2, 1988.

[2] Shin K., Hakana H. and Hyoda T., *Nucl. Sci. Eng*, vol. 85, p. 280, 1983.

[3] Wells M.B. and Marchall J.D., *Radiation Research Associates*, RRR-T97-a, 1969.

[4] Atten F.J., Futtere A. and Wright W., *Ballistics Research Laboratory*, BRL-1189, Aberdeen, Provlong Grounds, Maryland, 1963.

[5] Ban S., Shin K. and Hyoda T., *Memoirs*, Faculty of Engineering, Kyoto University, vol. 41, p. 137, 1979.

[6] Coleman W.A., Maeker R.E., Muckenthaler F.J. and Stevens P.N., *Nucl. Sci. Eng*, vol. 27, p.411, 1967.

[7] Durling G., *Ark. Phys.*, vol. 26, p. 293, 1963.

[8] French R.L. and Wells M.B., *Nucl. Sci. Eng*, vol. 19, p. 441, 1964.

[9] Maeker R.E. and Muckenthaler F.J., *Nucl. Sci. Eng*, vol. 22, p. 455, 1964.

[10] Meaker R.E. and Muckenthaler F.J., *Nucl. Sci. Eng*, vol. 26, p. 339, 1966.

[11] Meyer W., Leighty J.W. and Thiesing J.W., *Nucl. Sci. Eng*, vol. 60, p. 405, 1976.

[12] Micklich B.J., *Trans. Am. Nucl. Soc.*, vol. 44, p. 144, 1983.

[13] Micklich B.J., *Trans. Am. Nucl. Soc.*, vol. 46, p. 628, 1984.

[14] Micklich B.J., *Trans. Am. Nucl. Soc.*, vol. 52, p. 304, 1986.

[15] Miller W.H. and Meyer W., *Nucl. Sci. Eng*, vol. 64, p. 886, 1977.

[16] Segal Y., German U. and Notea A., *Nucl. Sci. Eng*, vol. 51, p. 223, 1973.

[17] Shin K. Hasegawa T. Nakano H. and Hyodo T., *Nucl. Sci. Eng*, vol. 17, p. 668, 1980.

[18] Song Y.T., Huddleston C.M. and Chilton A.B., *Nucl. Sci. Eng*, vol. 35, p. 401, 1969.

[19] Job P.K. and Sriniransan M., *Nucl. Sci.*, vol. 28, p. 422, 1983.

[20] Duderstadt J. and Hamilton J., *Nuclear Reactor Analysis*, John Wiley & Sons, 1976.

[21] Bell S. and Glasstone S., *Nuclear Reactor Theory*, Van Nostrand Reinhold Comp., New York, 1970.

[22] DuDerstadt J. and Martin W.R., *Transport Theory*, A Wiley International Publication, New York, 1979.

[23] Yuan Y.L., Gardner R.P. and Verghese K., "A Monte Carlo Model for On-line Neutron Capture Prompt Gamma-Ray Analysis of Coal in Transmission Geometry", *Nucl. Tech.*, vol. 77, p. 97, 1987.