GAMMA-RAY BUILD-UP FACTORS FOR DOUBLE-LAYERED MEDIUM

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ABSTRACT

Build-up factors for monoenergetic Gamma rays having energies between 1 and 10 MeV have been studied in a double-layered media using the Monte Carlo method. All secondary photons and charged particles produced inside the medium were taken into account. The study gave special attention to the contribution of Bremsstrahlung radiation, and handled it in a precise way, as a single collision process. The calculations were carried out for Lead-Iron, and Iron-Lead absorbers. The contributions of Bremsstrahlung is pronounced specially for heavy materials.

1. INTRODUCTION

The study of the transport of photons through materials serves a number of fields as Radiation Protection, Shielding Calculations, design of Fusion-devices, Radiogauging, Radiation therapy and Diagnostics. To keep the simple mathematical exponential form of the flux in a medium irradiated by a monoenergetic beam of gamma-rays the build-up factor concept is introduced.

The purpose of this study is to calculate the build-up factors more precisely, considering the secondary radiations emitted in the medium as a result of the interactions of the photons with the medium atoms. The most important of these radiations is the bremsstrahlung radiation emitted by the electrons and positrons created in the pair production process and by the electrons scattered in the coemption process. The study is carried out using the Monte Carlo method as the unique method for handling precisely the build-up factors in multi-layered medium.

Many computations [4,7,1,15,13,20] were carried to determine the values of the build - up factors, and tables containing their values are constructed. In most of these computations the build-up factors were evaluated for single-layered media using either the moments method or the Monte Carlo method by considering only the coemption scattering. The contribution from annihilation gamma rays and Bremsstrahlung radiations were neglected even for high photon energies. Recently revised computation are done by approximately treating the Bremsstrahlung radiations [7,10,16,17,18]. Many efforts (2,8,10,11) were made to include the effect of annihilation radiations. The build-up factor for gamma photons incident on finite double layered shields using the Monte - Carlo technique was considered in [14,15]. The number and energy build-up factors for photons of 1 MeV are given as a function of lamination thickness for Al - Pb, Pb - Al, and Fe - Al. The treatment was based on taking the photoelectric effect and coemption scattering only into account.

Kuspa and Tsoulfanidis [9] handled the gamma ray build-up factor by Monte - Carlo method, and took into account the effect of Bremsstrahlung radiation. In their treatment, the Bremsstrahlung effect was handled in an approximate manner by assuming that all the energy radiated by the electron is given off as a single photon at the beginning of the electron path and in the same direction of the parent electron. They considered the case of single- material shields, and the case of double - material shields. Tanaka and Takeuchi [16,17,18] used the discrete ordinate Sn- method to handle the calculations. They applied the model of continuous electron slowing down to obtain the bremsstrahlung spectrum from which the overall average effect is calculated.

More recently , better estimation to the contribution of the Bremstrahlung was developed by Abou Mandour and Ghanem [9]. They obtained the build-up factors for planar source and for photon energy ranging between 1.0 and 10.0 MeV for Lead or Iron as a one-layered medium.

2. COMPUTATIONAL METHOD

The Monte Carlo Method is used to simulate a large number of photon histories in the considered irradiation geometry. One photon history includes the birth of photon at its source, its random walk through the medium, various interactions which it undergoes namely the photoelectric absorption, the coemption scattering and the pair production. The history of the photon is terminated when it is absorbed in the medium or when its energy decreases below the cut off limit which is chosen to be 0.01 MeV since below this energy limit the photoelectric absorption cross section is dominant and the photon is locally absorbed.

The photoelectric cross section is obtained from tables prepared by Hubbel [5,6]. The coemption scattering cross section is obtained using the Klein-Nisihina formula [3,7].

The pair production cross-section is obtained from the tables prepared by Hubbel [5,6]. The annihilation radiation is Considered in the simulation of the photons histories. In the simulation, the Bremsstrahlung process is treated as a single collision process. The treatment is based on the Bethe- Heitler theory [12]. The path of the electron or the positron is divided into a large number of bins where the probability of occurrence of the Bremsstrahlung process is examined and in case of its occurrence the photon's energy is selected according to the Bethe- Heitler theory .

In the present systematic study, the calculations are carried out for infinite perpendicular planar source in an absorbing medium. The incident beam is monoenergetic beam with energy in the range 1.0 to 10.0 MeV.

The present work includes the calculation of the Number Build-up factor which represents the contribution of the secondary photons to the uncollided photons.

The developed code was first verified by comparing its results for a specific example with published experimental results. The calculations are carried o for a planar normal source of monoenerge gamma-ray with 6 MeV energy incident upon infinite medium taking the effect of Bremsstrahlu into account and then, are recalculated when t Bremsstrahlung is neglected. The absorbing med considered are Lead and iron. The results are given Figure (1a), (1b). The ordinate represents the do build-up factor B. The absicca gives the shie thickness in mean free paths. The figures show a go agreement with the experimental results [8]. In t same figures, the results are given when t Bremsstrahlung radiations are neglected. It can concluded that neglect of Bremsstrahlung radiation c lead to inaccurate results specially for media of hi atomic numbers.

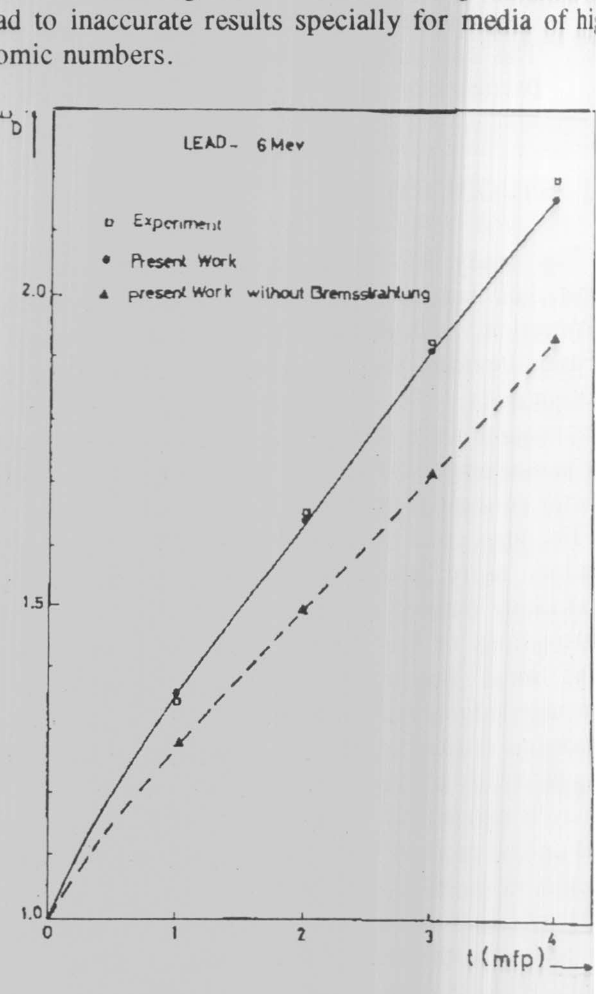

Figure 1-a. Comparison between the thesis results a the experimental results [13] inside an infinite slab lead due to a planar normal source. Ordinate is t does build-up factor, absicca is the penetration depth mfp.

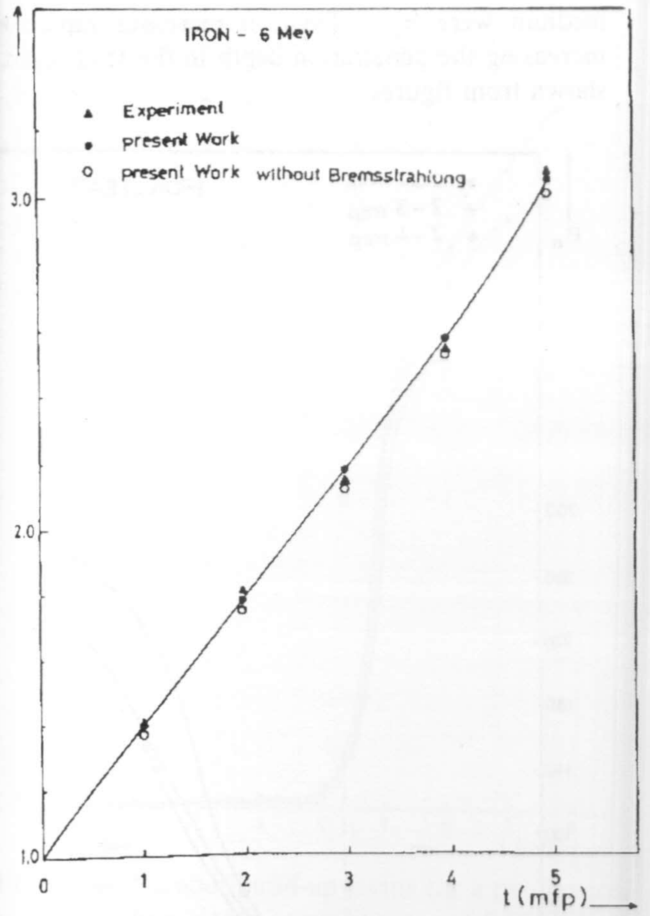

Figure 1-b. Comparison between the thesis results and the experimental results [13] inside an infinite slab of iron due to a planar normal source. Ordinate is the dose build-up factor, absicca is the penetration depth in mfp.

3. RESULTS

The dependence of the build-up factor on the penetration depth in multi-layered media is more complex than that in homogenous media. In addition to the factors affecting the build-up factor in single layered medium (medium thickness, source energy, medium material), it depends on the order of the arrangement of the layers, and the thickness of each layer.

The build-up factors are calculated and studied in double-layered media such as Lead-Iron and Iron-Lead to describe a combination between a high and an intermediate atomic weight media.

The thickness of the first and of the second layers are varied interchangeable a double-layered medium. The behaviour of the number build-up factor is shown in figures (2a), (2b) for the case of Lead-Iron medium and Figure (3a), (3b) for the case of Iron- Lead medium.

In the Figures, the ordinate represents the number build-up factor, the absicca gives the penetration depth in mean free paths, curve parameter in each figures is the thickness of the second layer in mean free paths. The effect of varying the thickness of the first layer is illustrated in Figure (2), (3).

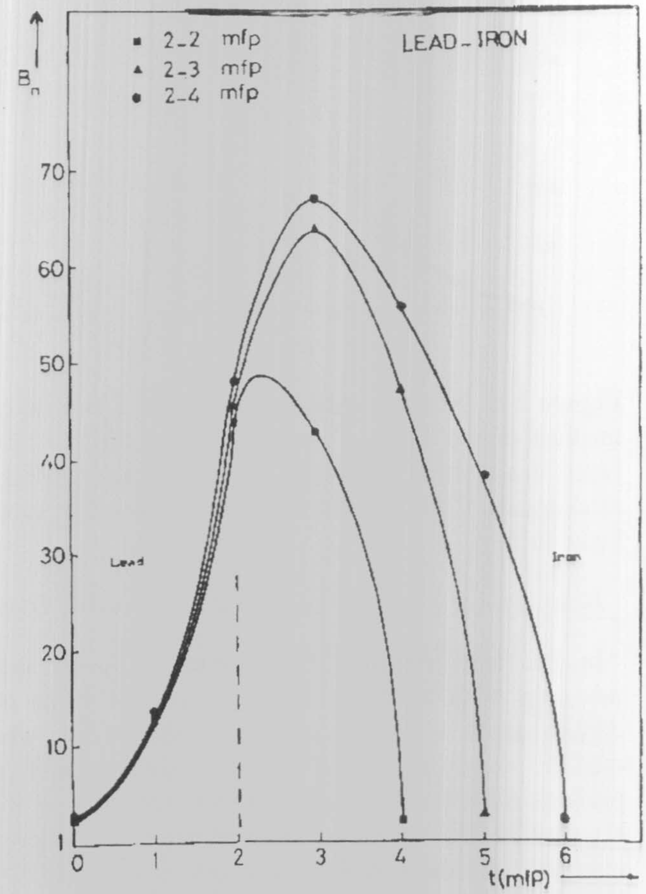

Figure 2-b. Number build-up factor for a two layered medium due to a planar normal source of 6 Mev. First layer: lead, 2mfp. Second layer: iron with different thicknesses. Curve parameter is the thickness of second layer in mfp.

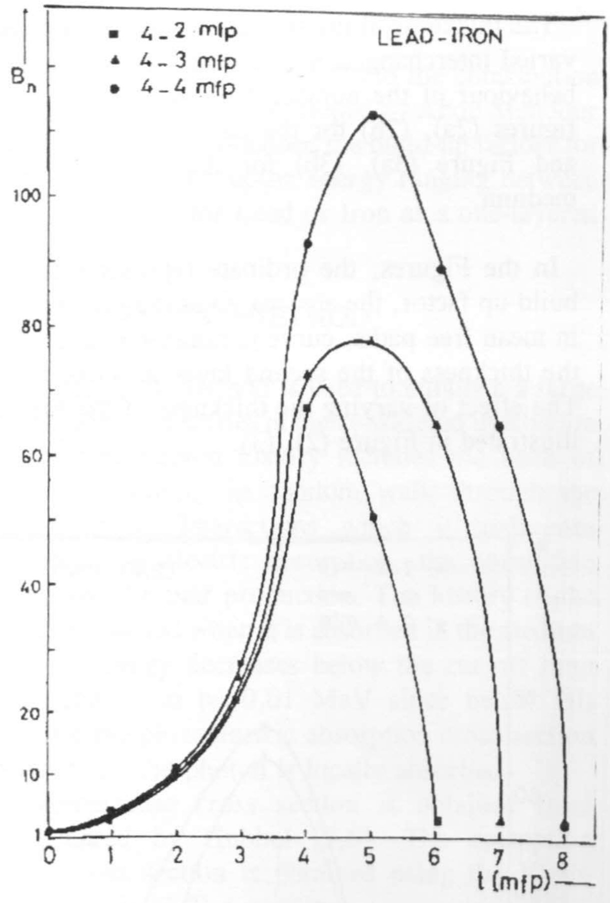

Figure 2-b. Number build-up factor for a two layered medium due to a planar normal source of 6 Mev. First layer: lead, 4mfp. Second layer: iron with different thicknesses. Curve parameter is the thickness of second layer in mfp.

Behaviour of number build-up factor in Lead-Iron:

In the lead region, the number build-up factor increases with penetration depth, and its value at a certain depth is greater than its value if the whole medium were lead. This is due to the backscattered photons from the iron-layer. It is observed also from Figures (2a,2b) that the build-up enhancement increases near the interface as the thickness of the iron layer increases because the number of the backscattered photons increase with the increase in the thickness of the second layer .In the iron region, the number build-up factor decreases rapidly with penetration depth

Behaviour of number build-up factor in Iron-Lead

In the iron region, the behaviour of the number build-up factor is the same as in the case if the whole medium were iron. Then, it increases rapidly increasing the penetration depth in the lead regi shown from figures.

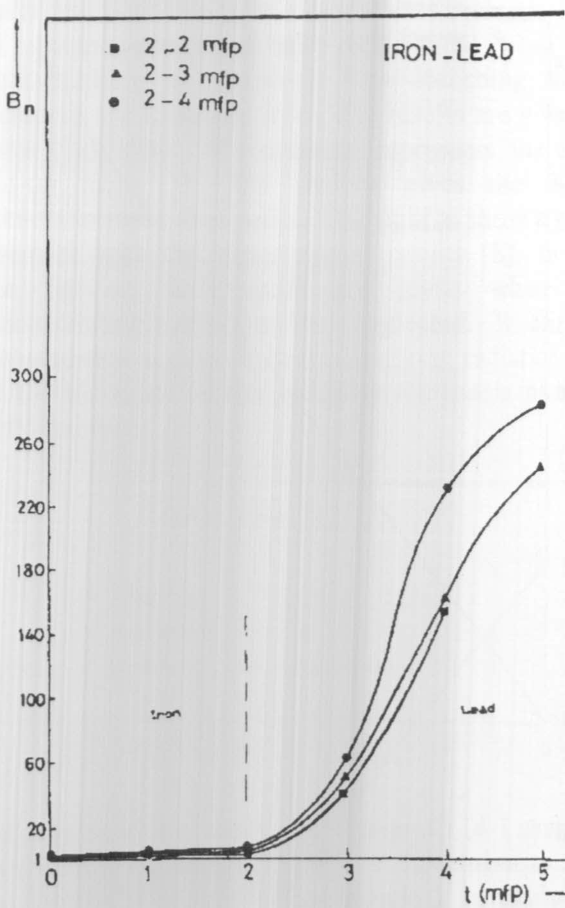

Figure 3-a. Number build-up factor for a two la medium due to a planar normal source of 6 Mev. layer: iron, 2mfp. Second layer: lead with diff thicknesses. Curve parameter is the thickness of se layer in mfp.

It can be expected that the behaviour in the first is refereed to the absence of backscattered ph from the lead region and the cause of the increa the build-up factor in the second layer is appearance of Bremsstrahlung radiation annihilation radiation in the lead region. Due t advantages of the Monte-Carlo method in calcul more details about the histories of the photo penetrating the double-layered media, the behavi build-up factor could be explained. The spectru the photons at the interface between the two lay calculated and plotted in Figure (4) for lead-iron for iron-lead.

the lead region to the iron region is small, this explains the behaviour of the number build-up factor in the first layer. The number build-up factor exhibits a larger increase in the lead region because in lead, the uncollided photons with energy of 6 MeV execute pair production. Consequently Bremsstrahlung radiations, and annihilation radiation appear in the medium and contribute to the collided photons which lead to the increase in the number build-up factor.

Optimization of a radiation shield

This study is carried out to determine the optimum composition of a shield, i.e. to decide if a pure Lead shield or a pure Iron shield or a laminated shield of both of them-arranged in a certain manner-is the better one. The calculations are carried out to determine the build-up factors at the outer surface of a finite thickness shield for the different cases mentioned above. The shield thickness is considered to be 5 mfp in each case, and the incident photon energy is 6 MeV. Computed values of the number build-up factor at the outer surface are plotted against the composition of the double layered shield in Figures (5a),(5b). Results for the case of one-layered shield are also plotted in the same figures.

In these figures, the ordinate represents the number build-up factor, the absicca represents the thickness fraction of the second material to the total thickness of the double layered shield as a percentage ratio.

In Figure (5a), it is observed that the value of the number build-up factor for a double layered shield of Iron-lead is greater than its value for a single layered shields having the same thickness and made of either lead or Iron. The max. value of the number build-up factor occurs for a double-layered shield consisting of about 40% Iron and 60% Lead.

Computation are also carried out when the arrangement of the two materials in the double-layered shield is reversed. Results are shown for this situation in Figure (5b). The order of the arrangement has a great influence on the number build-up factor and the curve shows a minimum. For this arrangement the double layered shield is better and the number build-up factor reaches its minimum value for a shield consisting of about 50% Lead, and 50% Iron.

It can be concluded that the optimum shield from the radiation protection point of view and considering Iron and Lead as the shield materials, is obtained when Lead and Iron are arranged as the first and the second layer with equal thickness in the double-layered shield.

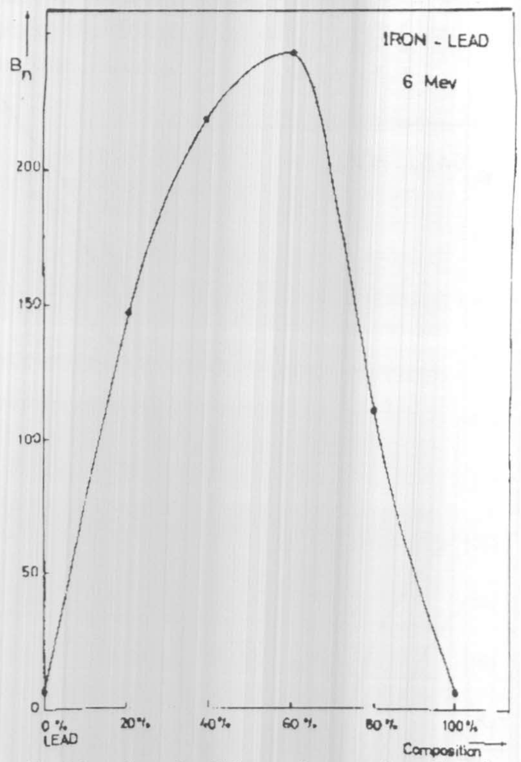

Figure 5. Number build-up factor for 5 mfp o iron-lead combination shield for 6 Mev gamma ra

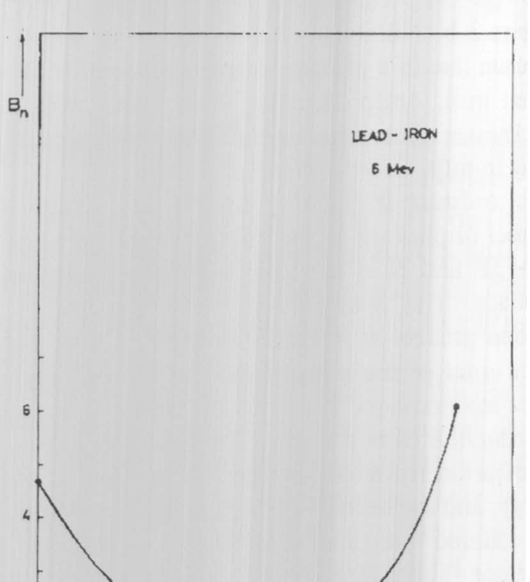

Figure 5-b. Number build-up factor for 5 mfp lead-iron combination shield for 6 Mev gamma r

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