INFLUENCE OF INHOMOGENITIES ON GAMMA-RAY FLUX DISTRIBUTIONS

M. Abou Mandour and Noha Shaaban
Nuclear Engineering Department, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

The main goal of the present study is to use a self developed Monte Carlo code to investigate the behaviour of the high energy gamma rays in a homogeneous medium where a slab-inhomogenity is embedded in it. The position of the inhomogenity within the homogeneous medium , the thickness of the inhomogenity and the kind of its material are the factors that strongly affect the behaviour of the flux.

Keywords: Gamma-Rays, Inhomgenities, Radiation, Flux distribution,

1. INTRODUCTION

The aim of the present study is to investigate the effect of the presence of an inhomogenity placed in a homogeneous medium on the gamma flux distribution for the two situations : if the inhomogenity is of a heavier or a lighter material than the rest of the medium. In shielding problems, most of the shields contain voids or regions of relatively poor attenuation characteristics which might constitute a source of excess radiation leakage in shield configuration. Such irregularities could be gaps around plugs, ducts used for coolant circulation, inhomogeneous materials, etc. These irregularities can be considered as a path exists through which gamma rays can stream with little or no reduction in energy and the radiation reaching the outside of the shield will be considerably increased. In radiation therapy the presence of an inhomogenity is more frequent and its effect on the absorbed dose distribution inside and behind the inhomogenity has to be precisely estimated and taken into consideration in the planning treatment.

2. COMPUTATIONAL TECHNIQUE

The calculation of photon transport by the Monte Carlo method involves two interrelated tasks. The first is of a general nature and involves: a) generation of a data base of photoelectric, Compton scattering and pair production cross sections, b) The development of a Monte Carlo model for the random sampling of photon histories[1].

The second task is more specific, and involves the extraction of information from the sampled histories to solve a particular problem. As a part of the second task, one must take into account the passage of photons through the various material boundaries which define the configuration of the medium. The developed code treats the transport of photons through a homogeneous medium in which an inhomogenity is embedded at a certain depth inside it. The Monte Carlo model takes into account all secondary radiations including Compton electrons , bremsstrahlung , electron-positron pairs and annihilation radiations. the present code incorporates a precise method in dealing with the bremsstrahlung production by electrons or positrons.

The life histories of the photons are simulated by the use of random sampling techniques to sample the probability laws that describe the real particle's behaviour, and to trace out step by step the particle's random walk through the medium. The history of the particle is followed until it can no longer contribute information of interest to the problem. i.e, if the photon leaves the medium, is absorbed or its energy is degraded below a cutoff limit (0.01 MeV).

The cross section data for the main three types of the interaction of photons are required to be used through the program. This data are obtained by a new data base program called 'Xcom' prepared by

Berger and Hubbell [2]. It carries out this task for any element, compound or mixture at energies between 1 KeV and 100 GeV.

The photoelectric absorption cross section s_{ph} are obtained by Scofield [2] only up to 1.5 MeV using a Phase-Shift calculation for a central potential and a Hartree-Slater atomic model. At higher energies , a semi-empirical formula by Hubbell connects Scofiels values at 1.5 MeV to the higher energy limit calculated by Pratt [2]. The pair production cross section s_{pp} are based on complicated combinations of formulas from Bethe-Heitler theory [5] with various other models to take into account screening, coulomb, radiative and disagreement near the threshold corrections. The Compton scattering cross section s_c per electron are obtained from a combination of the Klein-Nishina formula [3] and nonrelativistic Hartree-Fock incoherent scattering function to account for radiative and double Compton scattering corrections.

The self-developed Monte Carlo code is first verified via two comparisons. Firstly , the uncollided flux calculated by the Monte Carlo code is compared with the analytical derived formula expressing the flux in the medium. This comparison shows good agreement. Secondly, the dose build-up factors is calculated for a homogenous medium and compared with experimental results [4]. Again the comparison shows good agreement.

3. EFFECT OF INHOMOGENITY

In this study, the effect of the presence of an inhomogenity embedded in a homogenous medium on the gamma flux distribution is considered. In the field of radiotherapy , the amount of variation in the flux in and behind the inhomogenity is of considerable importance. The inhomogenity is assumed to have the shape of a slab of finite thickness. The effect of the position of the inhomogenity in the medium, its thickness, and the kind of its material are the main factors which affect the behaviour of the flux inside the medium.

A parametric study is carried out to understand and evaluate the effect of each of these factors on the behaviour of the flux. Two cases are considered, the first is the case of a heavy material placed inside a homogenous lighter material.

The second case is that of an inhomogeneity of lighter material embedded in a heavy homogeneous medium. The materials considered are Aluminum as a light material and Lead as a heavy material. The inhomogeneous medium is subjected to a planar normal flux of gamma rays. The calculations are carried out for an inhomogeneity of thickness of 1 mfp. The thickness of the layer before the inhomogenity is varied to be 1 , 2 , 3 mfp subsequently. In each case the total thickness of the inhomogeneous medium is assumed to be 5 mfps.

The case where a heavy material (Lead) is embedded inside a homogeneous lighter material (Aluminum) is considered and the results are shown in Figure (1). The flux increases considerably for the case when the inhomogenity is put near the entrance surface of the medium. This enhancement decreases by shifting the inhomogenity to greater depths. To understand this behaviour , the forward and backward fluxes are calculated separately and for comparison are plotted in Figures (2-4) together with the total flux. Also the spectrum of the photons at the interface between the medium and the inhomogenity is calculated and plotted in Figures (5), (6), (7).

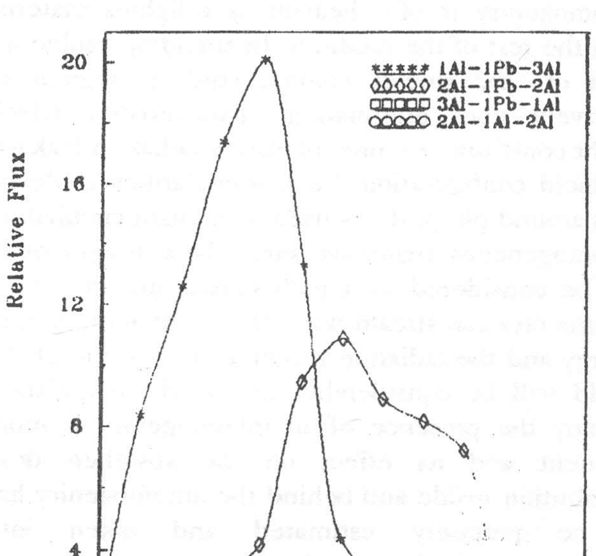

Figure 1. Flux distribution versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons.

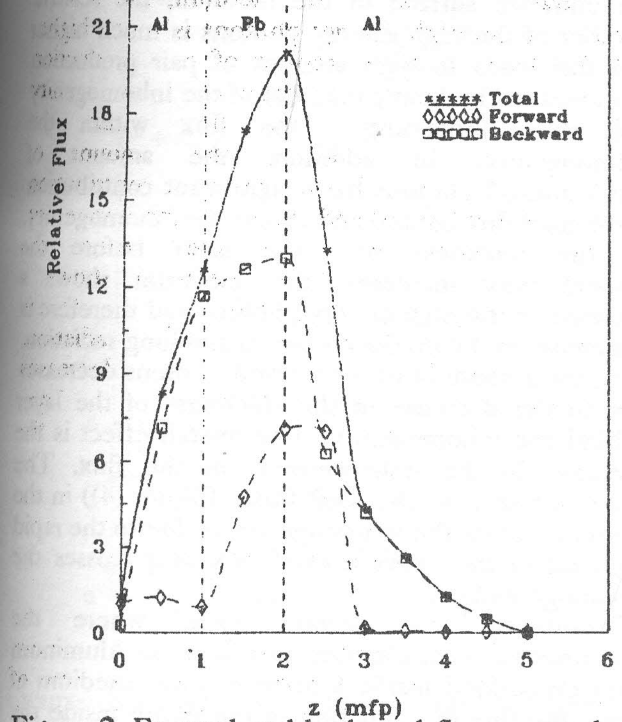

Figure 2. Forward and backward flux versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons.

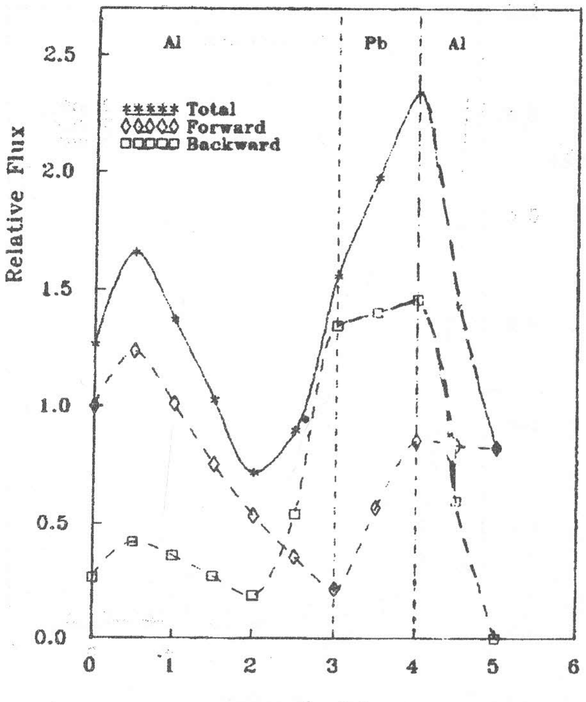

Figure 4. Forward and backward flux versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons.

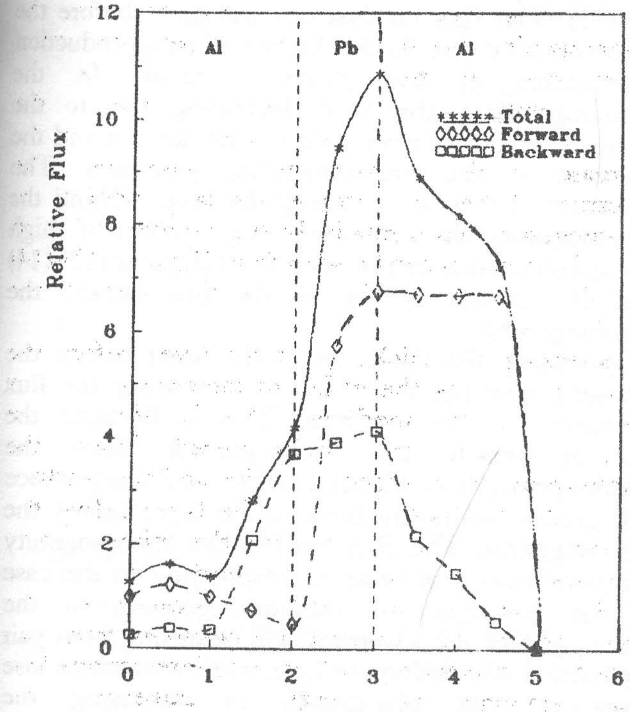

Figure 3. Forward and backward flux versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons.

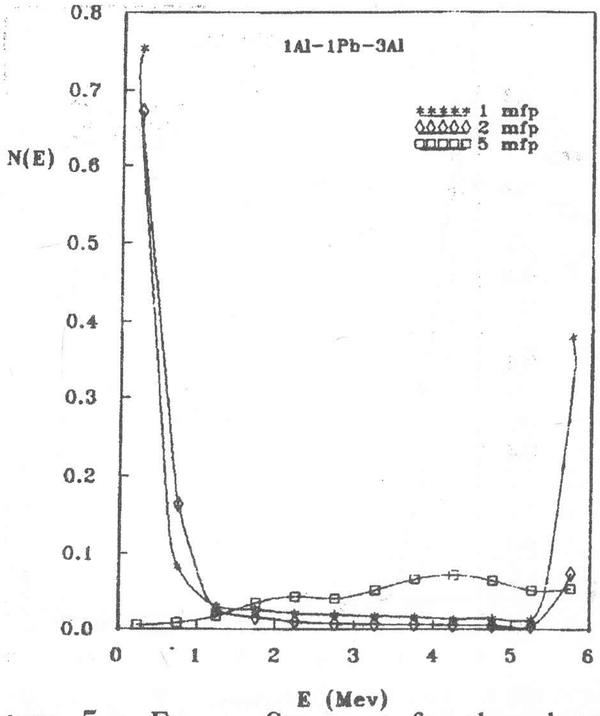

Figure 5 : Energy Spectrum for the photons traversing inhomogeneous medium for a planar normal source of 6 MeV photons.

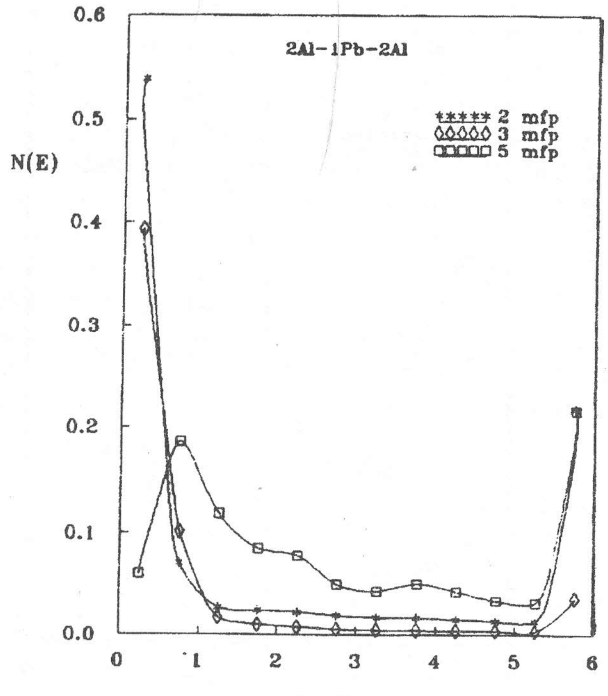

Figure 6. Energy Spectrum for the photons traversing inhomogeneous medium for a planar normal source of 6 MeV photons.

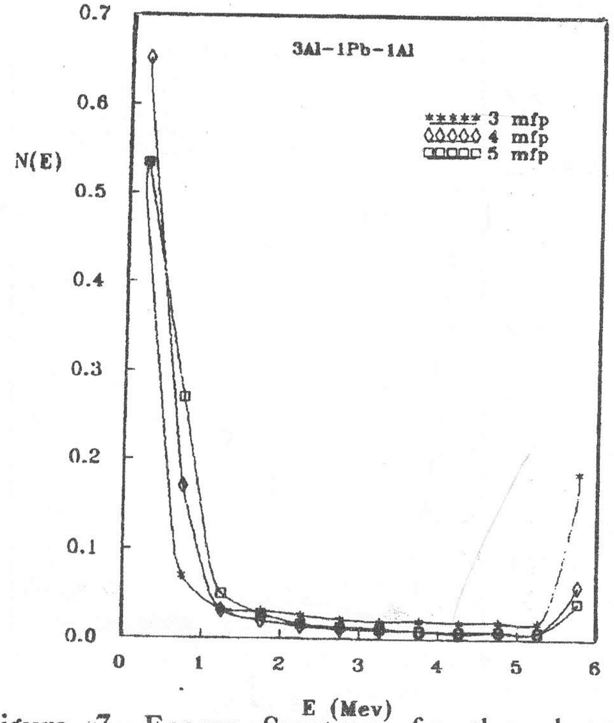

Figure 7. Energy Spectrum for the photons traversing inhomogeneous medium for a planar normal source of 6 MeV photons.

One can see that, when the inhomogenity is near the entrance surface of the medium, the relative number of the high energy photons is much higher and this leads to high amount of pair production processes in the heavy material of the inhomogenity and thus, increasing the flux within the inhomogenity. In addition, the amount of backscattered photons has a significant contribution to the total flux behind and inside the inhomogenity. As the thickness of the layer before the inhomogenity increases, the spectrum shows a decrease in the high energy photons and therefore is a decrease in the produced bremsstrahlung radiation. Also, the amount of backscattered photons decreases due to the decrease in the thickness of the layer behind the inhomogenity. The overall effect is the decrease in the enhancement in the flux. The minimum seen in the total flux (Figure (4)) in the medium before the inhomogenity is due to the rapid decrease in the backscattered flux as it crosses the inhomogenmity.

Considering the second case, where the inhomogenity is of a lighter material as an Aluminum layer embedded inside a homogeneous medium of Lead, the flux as a function of the depth inside the medium is calculated and plotted in Figure (8). Also, the forward and backward fluxes are calculated and plotted together with the total flux in Figures. (9)-(11). The flux increases in the layer before the inhomogenity due to the higher of pair production interactions in the heavy material. In the inhomogenity , the flux decreases due to the decrease in the pair production interactions and the decrease in the bremsstrahlung processes. The spectrum of the flux entering the layer behind the inhomogenity has a relatively big number of high energy photons as can be seen from Figures (12)-(14) and this causes the rise in the flux behind the inhomogenity.

Decreasing the thickness of the layer before the inhomogenity has the effect of increasing the flux maximum in the medium. This is because the photons which are backscattered from the inhomogenity have higher energies and can produce pair production interactions in the layer before the inhomogenity. The flux behind the inhomogenity increases over that value corresponding to the case of the homogeneous medium because in the inhomogenity the electrons and positrons from pair production interactions or Compton interactions lose small amounts of energy in traversing the inhomogenity and therefore are capable of producing bremsstrahlung radiation behind the inhomogenity.

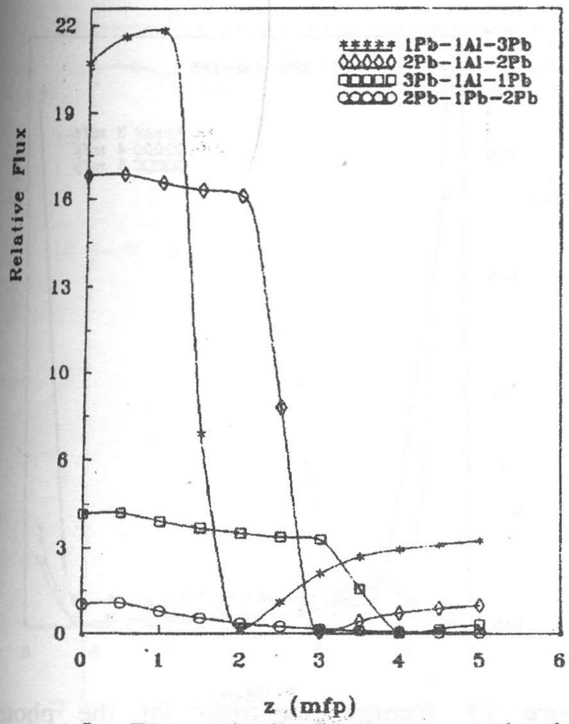

Figure 8. Flux distribution versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons.

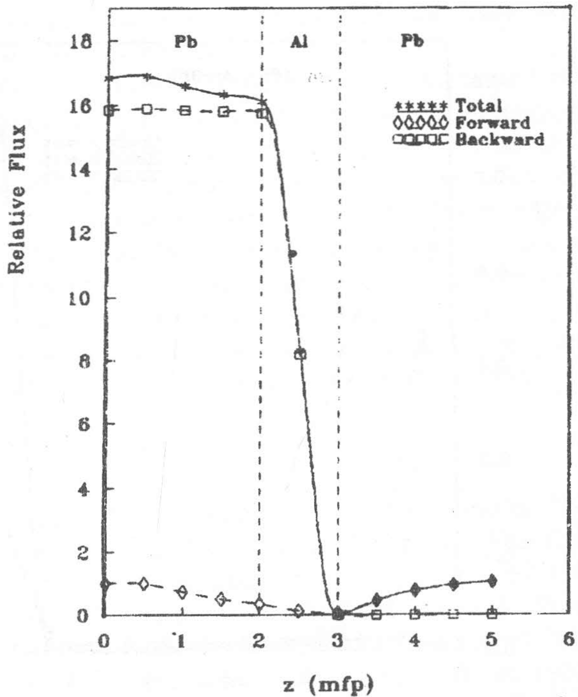

Figure 10. Forward and backward flux versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons.

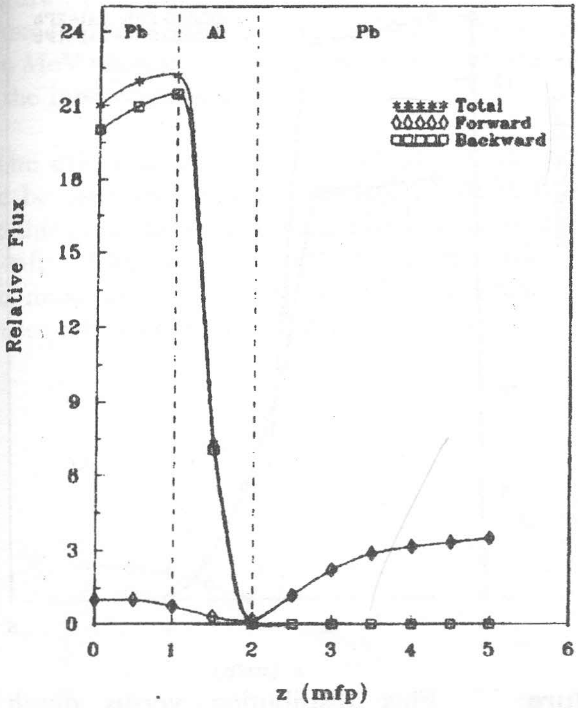

Figure 9. Forward and backward flux versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons.

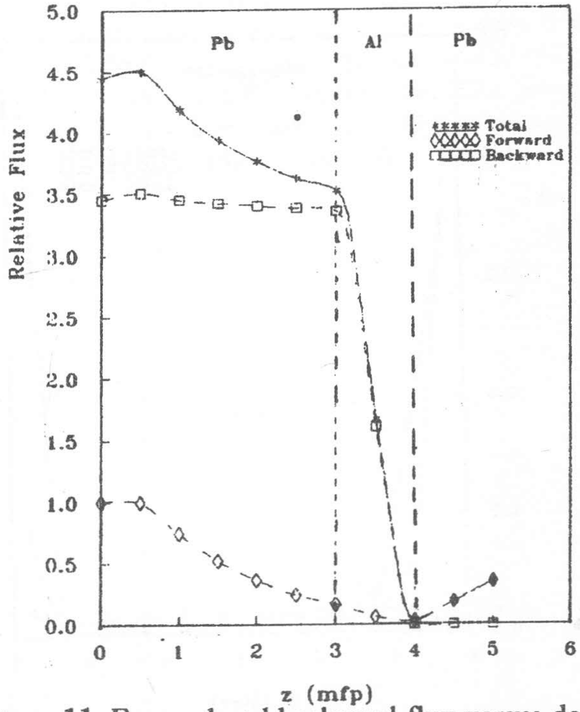

Figure 11. Forward and backward flux versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons.

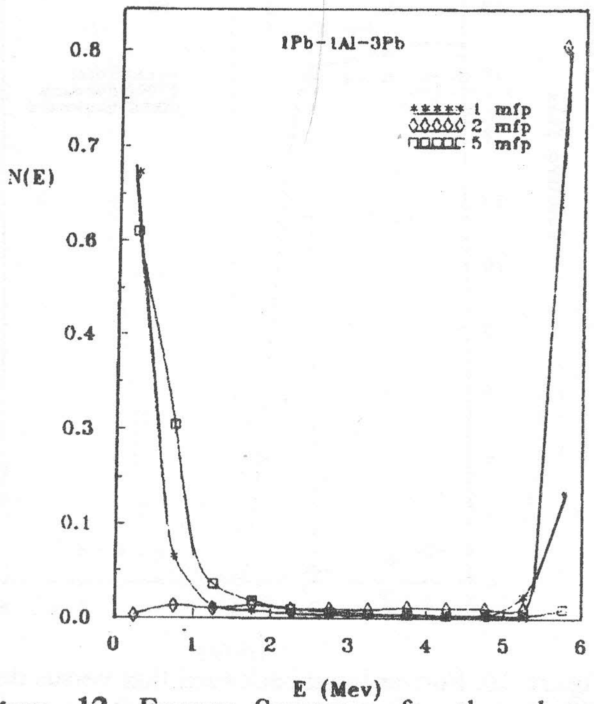

Figure 12. Energy Spectrum for the photons traversing inhomogeneous medium for a planar normal source of 6 MeV photons.

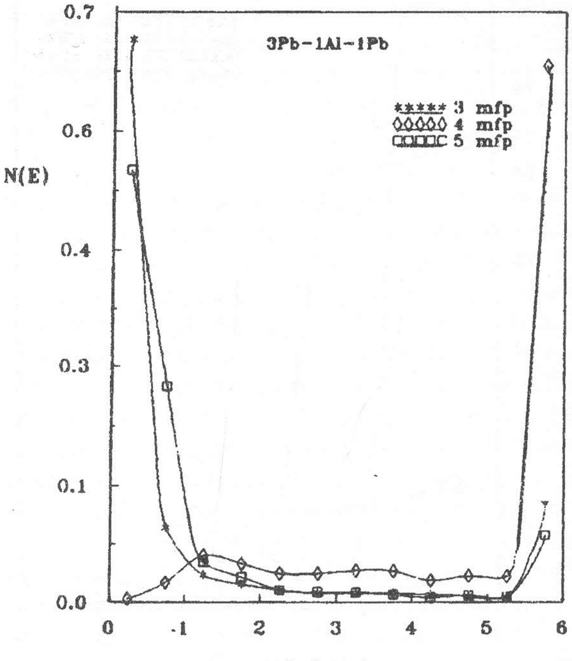

Figure 14. Energy Spectrum for the photons traversing inhomogeneous medium for a planar normal source of 6 MeV photons.

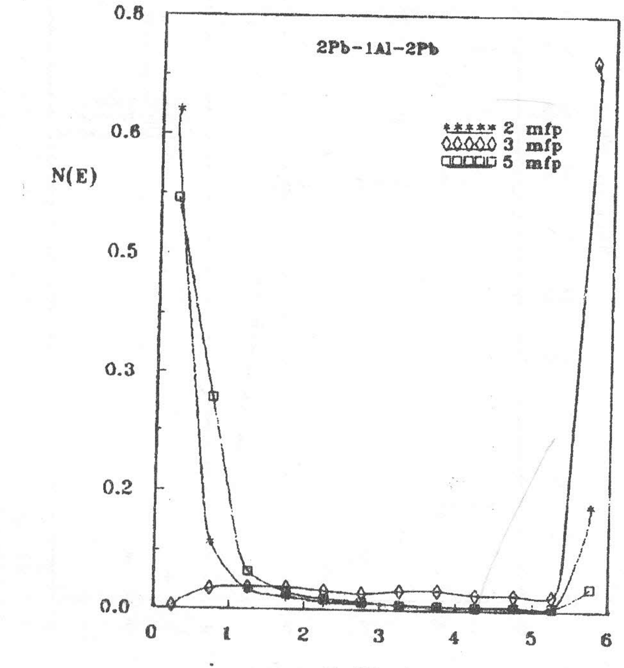

Figure 13. Energy Spectrum for the photons traversing inhomogeneous medium for a planar normal source of 6 MeV photons.

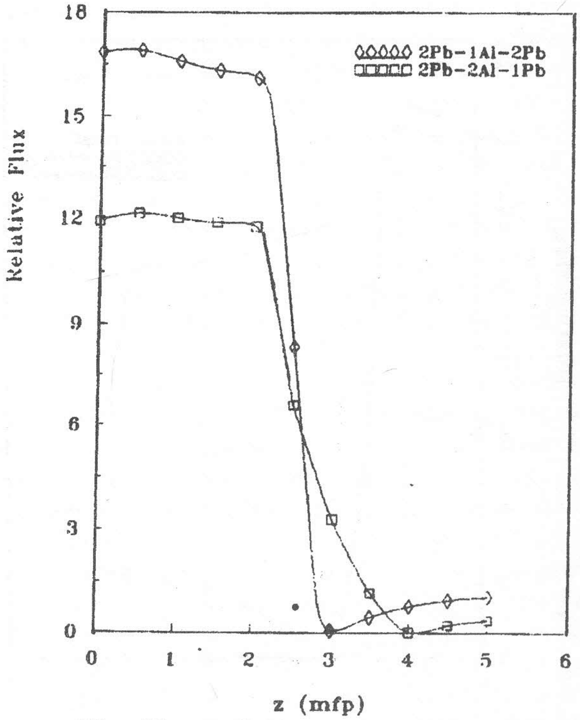

Figure 15. Flux distribution versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons. Curve parameter is the thickness of the inhomogenity.

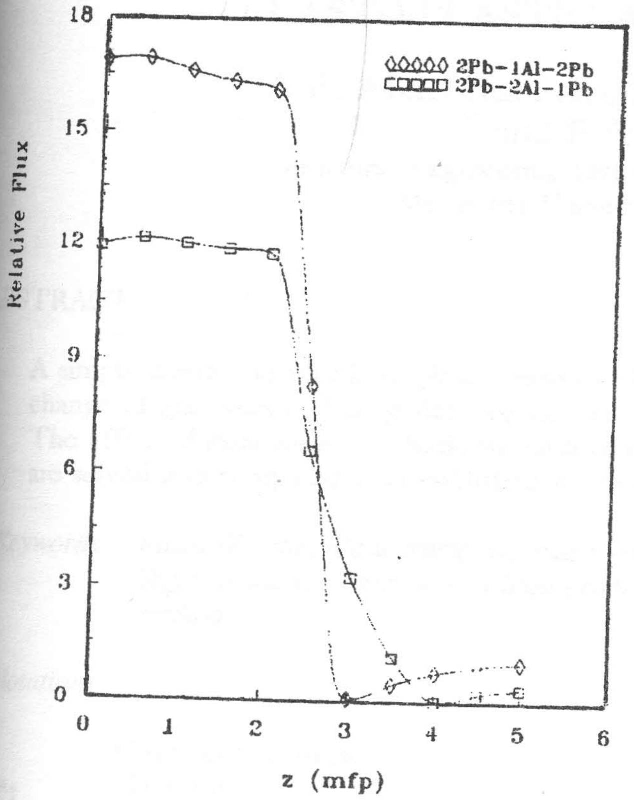

Figure 16. Flux distribution versus depth in inhomogeneous medium for a planar normal source of 6 MeV photons. Curve parameter is the thickness of the inhomogenity.

The effect of the thickness of the inhomogenity can be seen in Figures (15)-(16). In these figures, the thickness of the inhomogenity is increased to be 2 mfp. This has the effect of increasing the flux-maximum in the medium for the case of the denser inhomogenity and it has the effect of decreasing the flux-minimum for the case of the lighter inhomogenity.

It is clear from comparing the two discussed cases of embedding an inhomogenity inside a homogenous medium that the flux distribution before , inside and behind the inhomogenity is significantly affected by the thickness of the layer before the inhomogenity and the thickness of the inhomogenity. Also, the flux distribution has a different behaviour in the two cases : that of an inhomogenity of a lighter material and that of an inhomogenity of a heavier material relative to the homogeneous medium.

REFERENCES

[1] M.A. Abou Mandour and E. Ganem. "New Gamma Build-up Factors Including The Effect Of Bremsstrahlung", *Kerntechnik*, 52 , 57 1988.

[2] M.J. Berger and J.H. Hubbell, "XCOM : Photon Cross Sections on A Personal Computer", *NBSIR 87-3597, National Bureau of Standards*, 1987.

[3] O. Klein and Y. Nishina, "Uber die Streuung von Strahlung druch Freie Elektronen nach der Neuen Relativistiscchen Quantum Dynamic von Dirac", *Z. Fur Physik*, 52, 853, 1929.

[4] W. Johnson Reed et al, "Gamma Ray Attenuation of Energy of Approximately 6 MeV and 8 MeV", *Nuc. Sci. Eng.* 43, 32-41, 1971.

[5] H.A. Bethe and W. Heitler "On The Stopping of Fast Particles and On The Creation Of Positive Electrons", *Proc. Roy. Soc.* A14, 1934 83.