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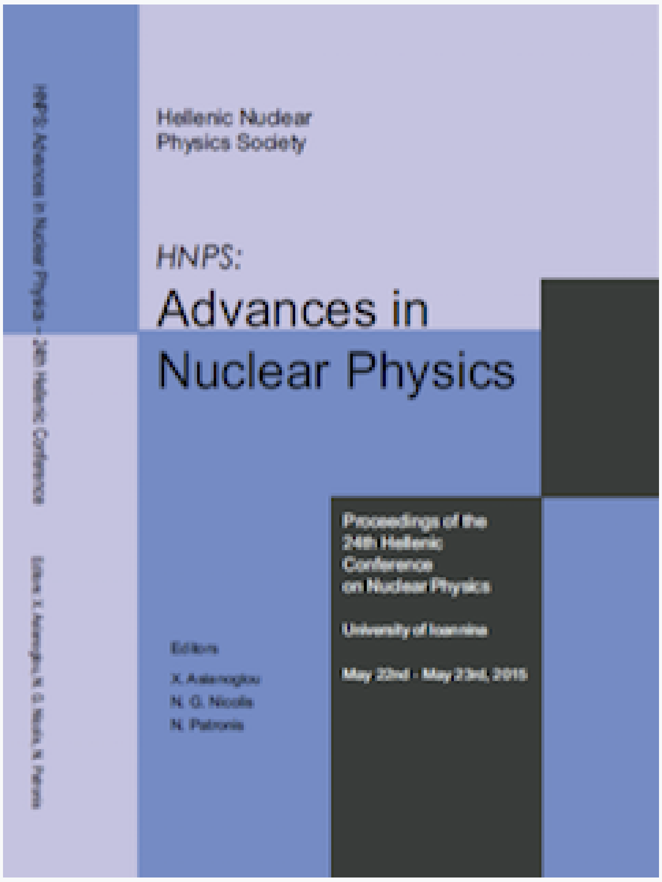

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Dose Distribution near Tissue In-homogeneities in Megavoltage Radiation Therapy

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Abstract

The presence of an in-homogeneity inside the human body modifies the radiation dose distribution in tissue. Such disturbances are even higher close to the interface between materials of different atomic number, Z. During radiotherapy with megavolt photons a remarkable lack of particle equilibrium is displayed in the transition zones between soft tissues and either bones or devices implanted in the human body for medical purposes, resulting in large dose gradients.

The disturbance in the dose distribution in soft tissue close to a high Z material in regions where the photon beam enters or exits the in-homogeneity, is quantified by the Backscatter Dose Factor (BSDF) and Forward Scatter Dose Factor (FSDF), respectively. In the present work BSDF and FSDF dependence on photon energy, material thickness, atomic number and field size were studied experimentally. For this purpose, slabs made of high Z material (aluminum, copper and lead) were inserted in a PMMA (Plexiglas) phantom. Irradiations were performed using a Co-60 teletherapy unit and two 6 MV linear accelerators. Dose measurements were carried out using MD-55 and HD-810 Gafchromic films.

The results of the study showed that the presence of the in-homogeneity increased the absorbed dose in the low Z material before the in-homogeneity (BSDF >1.00) and decreased after it (FSDF <1.00). Moreover, it was found that BSDF increases as the in-homogeneity thickness increases (up to a saturation thickness). On the contrary, FSDF decreases with increasing in-homogeneity thickness. In addition, both disturbances increase with increasing Z of the in-homogeneity. Outcome of this study was high quality experimental data to be used for benchmarking BSDF and FSDF calculations performed by dedicated Monte Carlo and analytical radiotherapy treatment planning systems.

Keywords: backscatter radiation, forward scattering, in-homogeneity, radiotherapy, radiochromic films

INTRODUCTION

The success of a radiotherapy treatment is related to the detailed knowledge of the distribution of the absorbed dose in the irradiated volume, since its objective is to maximize the damage to the malignant tumor or other lesion-type, keeping the absorbed dose to healthy tissues below the threshold for adverse effects. However, the dose distribution can be significantly modified by in-homogeneities in the human body with elemental composition that differs from that of the surrounded tissues. Such in-homogeneities may be either naturally existing (e.g. cortical bones surrounded by muscle), or implanted devices, (e.g. intravascular, esophageal and cardiac prostheses, cardiac pacemakers, defibrillators, hip implants, pins, rods, screws and plates to anchor fractured bone while it heals, spinal implants, surgical

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clips, dental implants and fillings etc.) [1]. The effect is enhanced close to the interfaces between the implanted device and the neighboring tissues, where there is severe lack of electronic equilibrium. Taking into account the limitations of the currently used radiation treatment planning systems, one has to quantify the dose perturbation in a low atomic number (Z) material, such as soft tissue, close to its interfaces with a high Z material in teletherapy with MV photons. To this end, a correction factor (CF) is used, defined as

$$CF = D_i / D_h,$$

where, D_i is the absorbed dose to the low Z-material at a short distance x from the high Z in-homogeneity at 5 cm depth in the phantom and D_h the dose at the same point with no in-homogeneity in place. There are two types of CFs, i.e. one that takes into account the dose perturbation close to the beam entrance surface to the in-homogeneity (backscatter dose factor – BSDF), and one close to the beam exit surface (forward scatter dose factor – FSDF).

The scope of this study was to assess experimentally the quantities BSDF and FSDF and their dependence on photon beam energy spectrum (E), the distance from the in-homogeneity (x), the in-homogeneity thickness (t), the size of the radiation field (A) and the atomic number (Z) of the in-homogeneity material. The employed dosimetric technique is based on the change of the optical characteristics of radiochromic films due to radiation induced polymerization [2].

EXPERIMENTAL DETAILS

Irradiations were performed using a Co-60 Alcyon II unit and two linear accelerators, a Philips / Elekta SL 75-5 and a Varian Clinac DHX unit, operated at 6 MV. A 30x30x15 cm^3 phantom made of PMMA (polymethylacrylate) slabs was placed at 100 cm source-to-surface distance (SSD) and the field size was set at 10 cm x 10 cm. Slabs of 30x30 cm^2 of various thicknesses made of aluminum (Z=13), copper (Z=29) and lead (Z=82) were inserted between the PMMA slabs. Dose measurements were carried out using HD-810 and MD-55 radiochromic films by Gafchromic, ISP Technologies Inc. (the latter are often referred to as MD55-2 films) Such films were inserted at various locations in the phantom before and after the in-homogeneity and provided dose measurements at a distance of approximately 4 and 120 μm from the neighboring slab, respectively. The HD-810 and MD-55 films have a similar response to water for photons of energy higher than ~150 keV. Their optical density (OD) was measured 4 days post-irradiation using document scanners in the 300 dpi reflection mode [3,4]. The images were split into three color components (red, green and blue, RGB analysis) with the ImageJ software. In addition, the films were calibrated for the studied photon spectra, for all three color components in the reflection mode (Fig. 1).

RESULTS AND DISCUSSION

Substantially enhanced dose was found in PMMA close to its entrance interface with the in-homogeneity (BSDF>1.0) and decreased after the in-homogeneity (FSDF < 1.0). For example, as can be seen in Fig. 2(a), a ~140% dose enhancement in PPMA has found at ~4 μm distance before the PMMA/Pb interface during ^{60}Co gamma irradiation (BSDF=2.4), dropping to a few percent at about 1.5 mm (0.18 g cm^{-2}). The presence of a thick Pb plaque had practically no influence on the measured dose at x-distances larger than ~2.5 mm. Similar effects, but of less magnitude, were observed in the case of the thick Cu in-homogeneity (e.g. BSDF of ~1.55 at x=~4 μm, and ~1.05 at x> ~1.5 mm) and even lower in the case of a thick Al in-homogeneity (not shown in Fig.2). The use of higher energy photons (~1.8 vs ~1.2 MeV mean photon energy) resulted to a smaller dose enhancement at short distances from the interfaces (e.g. Fig.2(b)); however the dose was enhanced over a wider zone before the interface, becoming almost constant at x> ~2.5 mm, e.g., 1.05 in the case of copper.

BSDF increases with in-homogeneity thickness, t, up to a critical value, t_{max}. For example, Fig.3(a) indicates the t-influence on BSDF at x = 220 μm of the studied materials, when irradiated with 6 MV X-rays and Fig.3(b) shows the influence of Al slab thickness in the case of ^{60}Co-γ irradiations. In addition, it was found that in case of a thick Pb in-homogeneity, BSDF increases with increasing field size between 4 cm x 4 cm and 20 cm x 20 cm.The Z-dependence of BSDF at upstream distances of 4 and 120 μm (Fig.4) was described with relationships of the form BSDF =a + b $Z^{1/2}$ for both studied photon spectra, thus allowing the prediction of the BSDF value for any other material.

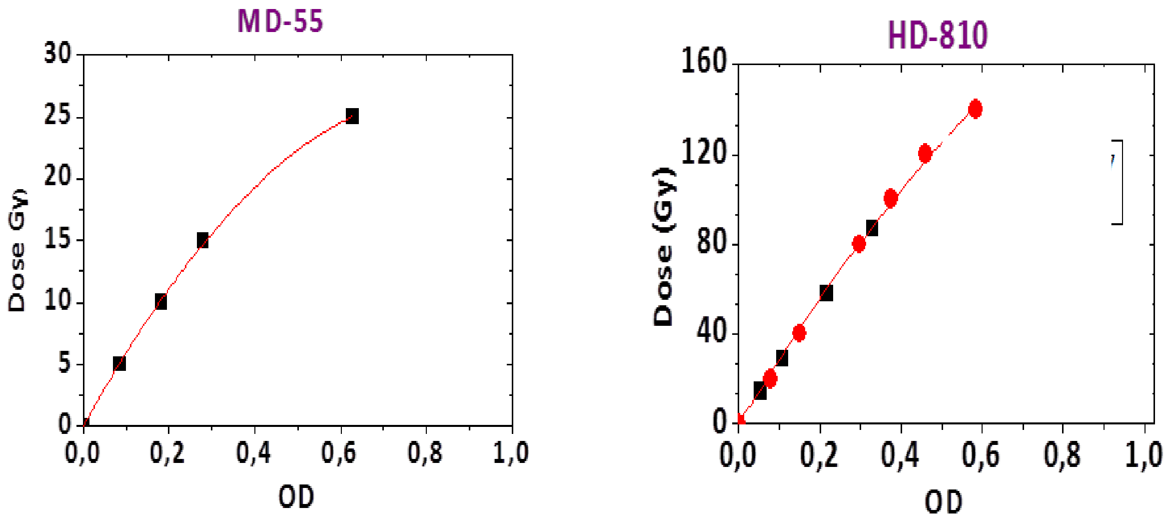

Figure 1: Dose calibration curves of MD55 and HD-810 films at 6 MV X-rays (transmission mode - red component).

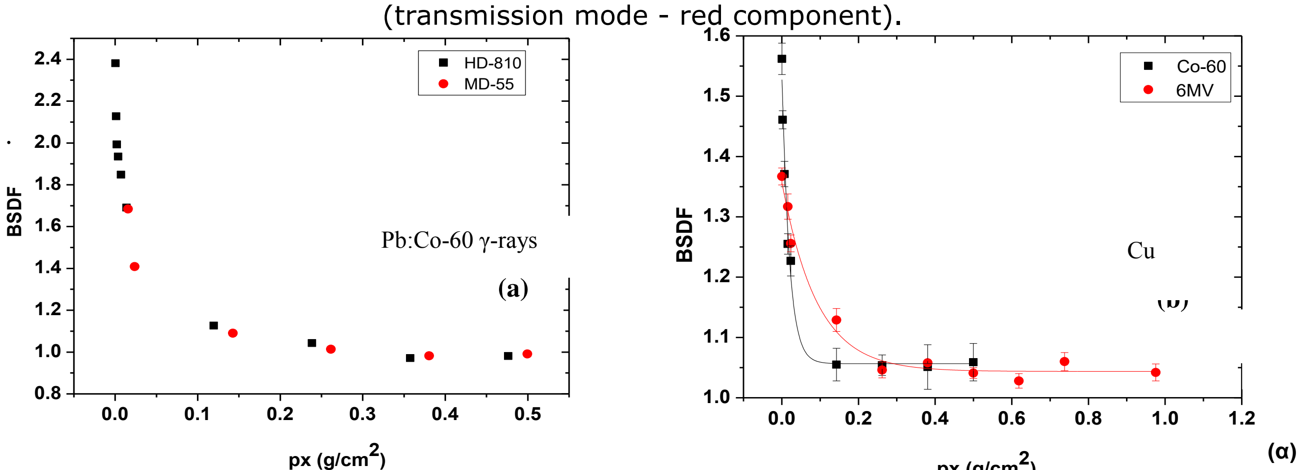

Figure 2: BSDF dependence on the film in-homogeneity specific distance (ρx).

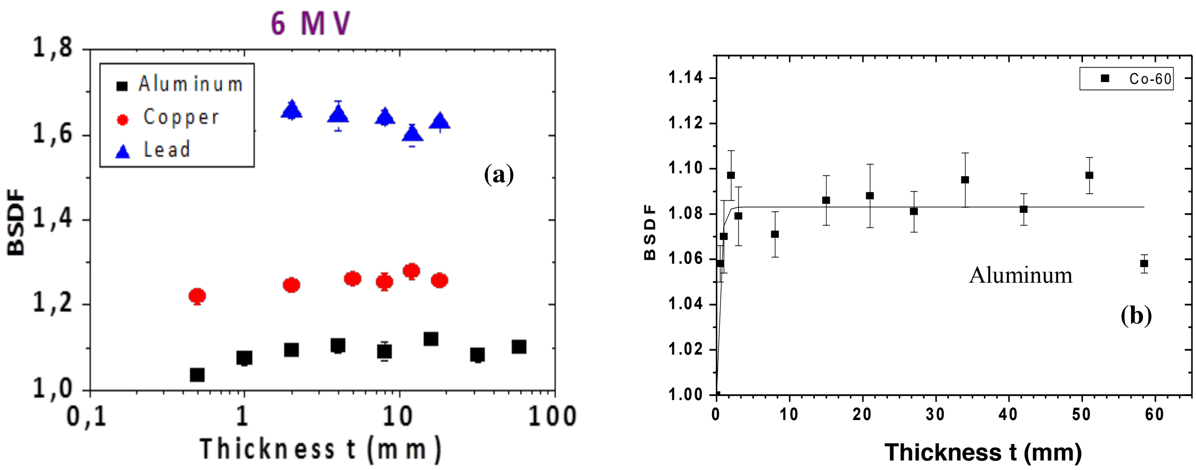

Figure 3:BSDF (x = 220 μm) dependence on the inhomogeneity thickness.

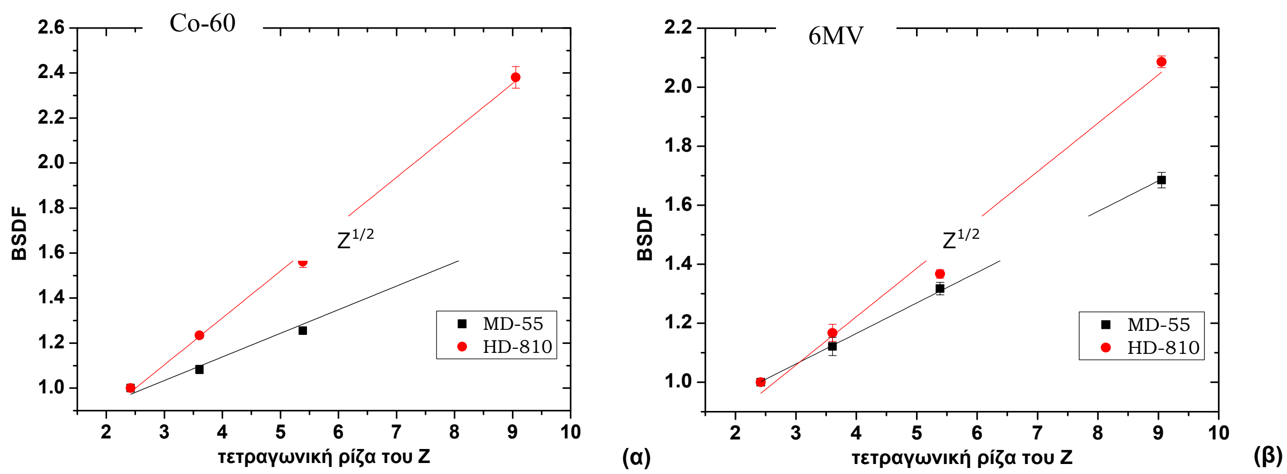

Figure 4: BSDF factor dependence on the in-homogeneity atomic number (Z).

The dose in PMMA at a short distance from the exit plane of the in-homogeneity was lower than that at the same depth in the case of the homogenous phantom (FSDF<1.00). For example, a fast decrease of FSDF at x=120 μm was found with increasing Cu and Pb thickness in the case of a 6 MV X-ray 10 cm x 10 cm field (Fig.5(a)). This change was attributed to two factors, the beam attenuation in the high Z in-homogeneity and the interface effect. In an attempt to study only the interface effect, the measured doses at x=120 μm after the interface, D_i, were also compared with the doses, D_I, at the same total depth and SSD with the high Z slabs of specific thicknesses between 0.45 and 14 g cm^{-2}, located not between the PMMA slabs, but on top of them. Even in that case, the dose after the interface was lower by about 13% than that in the case that the in-homogeneity was positioned upstream (Fig.5(b)).

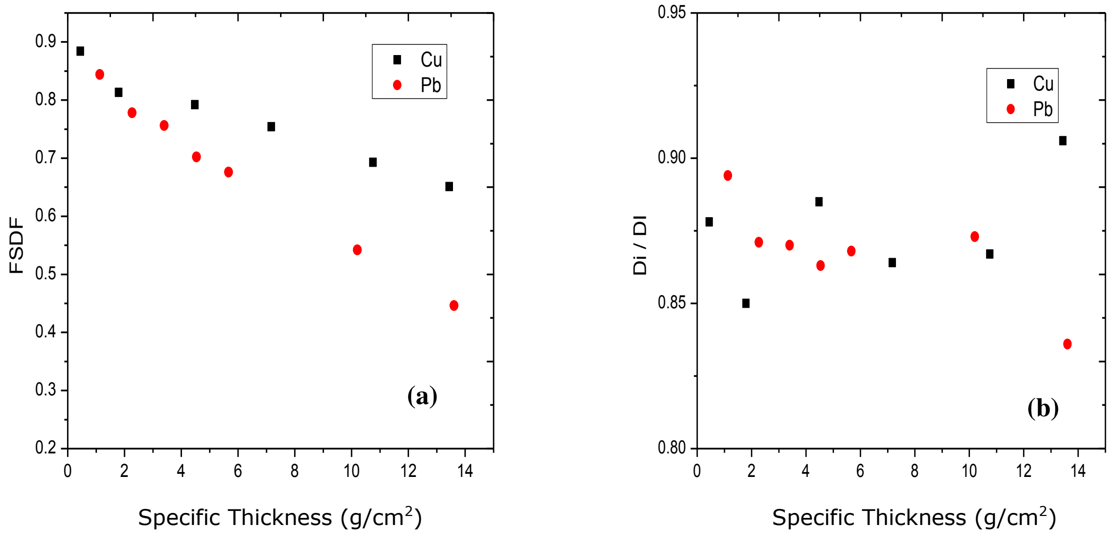

Figure 5: FSDF dependence on the specific thickness of the in-homogeneity with and without attenuation correction.

CONCLUSIONS

In conclusion, enhanced doses were found in the studied low Z material close to the entrance interface to the high Z in-homogeneity (BSDF>1.0) and reduced after it (FSDF<1.0). BSDF is an energy dependent quantity, which decreases with increasing distance from the interface, depends on the square root of Z and increases with increasing in-homogeneity thickness up to a saturation thickness. These findings were in agreement with those obtained by Monte Carlo simulations using the MCNP5 code. FSDF also varies with Z and decreases with increasing in-homogeneity thickness due to the combination of two factors, beam attenuation and lack of electronic equilibrium close to the interface. Some initial simulations using the MCNP6 Monte Carlo code show promising results.

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