Montecarlo simulation code in optimisation of the IntraOperative Radiation Therapy treatment with mobile dedicated accelerator

M Catalano¹,², S Agosteo³, R Moretti¹, S Andreoli¹

¹ USC Fisica Sanitaria, Ospedali Riuniti di Bergamo, Italy
² Scuola di Specializzazione in Fisica Sanitaria, University of Milan, Italy
³ Dipartimento di Ingegneria Nucleare, Politecnico, Milan, Italy

e-mail: catalano.maddalena@libero.it

Abstract. The principle of optimisation of the EURATOM 97/43 directive foresees that for all medical exposure of individuals for radiotherapeutic purposes, exposures of target volumes shall be individually planned, taking into account that doses of non-target volumes and tissues shall be as low as reasonably achievable and consistent with the intended radiotherapeutic purpose of the exposure. Treatment optimisation has to be carried out especially in non-conventional radiotherapeutic procedures, as Intra Operative Radiation Therapy (IORT) with mobile dedicated LINear ACcelerator (LINAC), which does not make use of a Treatment Planning System. IORT is carried out with electron beams and refers to the application of radiation during a surgical intervention, after the removal of a neoplastic mass and it can also be used as a one-time/stand alone treatment in initial cancer of small volume. IORT foresees a single session and a single beam only; therefore it is necessary to use protection systems (disks) temporarily positioned between the target volume and the underlying tissues, along the beam axis. A single high Z shielding disk is used to stop the electrons of the beam at a certain depth and protect the tissues located below. Electron back scatter produces an enhancement in the dose above the disk, and this can be reduced if a second low Z disk is placed above the first. Therefore two protection disks are used in clinical application. On the other hand the dose enhancement at the interface of the high Z disk and the target, due to back scattering radiation, can be usefully used to improve the uniformity in treatment of thicker target volumes. Furthermore the dose above the disks of different Z material has to be evaluated in order to study the optimal combination of shielding disks that allow both to protect the underlying tissues and to obtain the most uniform dose distribution in target volumes of different thicknesses.

The dose enhancement can be evaluated using the electron back scatter factor (BSF) and comparing percent depth dose curves in different target volume thicknesses for disks of different Z. Since measuring BSF can be quiet complicated a Monte Carlo study was performed.

The main goal of the paper is to study the optimal combination of shielding disks to be used in intraoperative radiotherapy (IORT) for a dedicated LINAC with a beam mean energy of 7.2 MeV.
Simulated depth-dose curves without shields were compared with measured data obtained (1) with motorised diode in water phantom and with (2) gaf-chromic film in RW3 slab phantom. The simulated depth dose curve in presence of the shields was compared with preliminary gaf-chromic HS film data, obtained for a target volume of 2.0 cm thickness; the material of the disk in contact with the target volume is aluminium (Al), copper (Cu) or lead (Pb), while the disk below is always lead or copper in order to protect tissues below. Work is in progress for the comparison of all the simulated data with measured data for all the disk combinations at different target volume thicknesses.

1. Introduction

IORT (Intra Operative Radiation Therapy) refers to the application of radiation (X-ray or electrons) during a surgical intervention, after the removal of a neoplastic mass. IORT uses a direct irradiation on the tumour area, for the possible localisation of sub-clinical disease or macroscopic residue in the case of non-radical resection. IORT foresees a single session only; it allows the achievement of a selective radiation boost on the tumour volume. Contrary to conventional radiotherapy, in IORT it does not appear feasible at the moment the elaboration of a plan of treatment based on manually acquired profiles or TC images. Then, the planning of the treatment is necessarily limited to the consultation of graphs and charts containing the isodose curves measured under standard conditions.

The technical advantages of IORT consist in the direct visual control of the target volume and in the possibility to protect the healthy tissues by moving them away from the path of the radiation beam. The use of electron beams allows the deposition of a homogeneous dose to a selected layer of tissues that surrounded the tumour after surgical exportation. At the same time tissues positioned on the beam axis under the target volume must be protected; generally disks of high atomic number (Z) are used, positioned between the target volume and the organ at risk. These shields determine a modification of the dose distribution in the overlying target volume due to backscattering radiation and in some cases a significant increase in the overall dose delivered to the patient. This effect can be reduced if a second lower Z disk is placed above the first. Therefore two protection disks are used in clinical application: in contact with the target volume there is the lower Z disk that reduces the back scattering radiation due to the higher Z disk below that is used to protect the underlying tissues from the primary radiation. On the other hand, the dose enhancement at the high Z target-disk interface, due to back scattering radiation, can be usefully used to treat thicker target volumes.

The dose variation at the target-disk interface due to back scattering can be evaluated in the following ways: (1) using the electron back scatter factor (BSF) which is defined as the ratio, at fixed depth, of the dose with and without the internal shields; (2) comparing percent depth dose curves pattern in different target volume thicknesses for disks of different Z, that allows to determine the most uniform dose distribution; (3) performing the normalization of the data respect to the build-up dose in phantom without the shield (so it is possible to determine the percent dose delivered to the target at the disk interface respect to the prescribed dose at build up without shields).

Therefore the aims of the work are the following: the determination of the optimal disk material combination to obtain the most uniform dose distribution for all the clinical target volume thicknesses and the determination of the disk material combination to obtain the backscattering dose that can be used to treat higher target volume thicknesses.

The dose distribution optimisation will be useful for the breast cancer IORT treatment performed at Ospedali Riuniti di Bergamo; a mobile LINAC (NOVAC7) that can deliver electron beams with nominal energies of 3, 5, 7 and 9 MeV (with surface mean energy, $E_0$, of about 4, 5, 6 and 7 MeV respectively) is in use. In clinical practice, a field of $E_0 = 7.2$ MeV ($R_{90} = 2.1$ cm) is employed because the optimal uniform dose distribution to treat clinical target thicknesses (up to 2.5 cm) is obtained with this beam energy.
In clinical practice the material of the disk put below should always be a high Z material (lead or copper) in order to protect the underlying tissues from the primary incident electron beam, while the disk above, can be aluminium (Al), copper (Cu) or lead (Pb); so the possible combinations in clinical practice can be Al/Pb, Cu/Pb, Pb/Pb, Al/Cu, Cu/Cu, Pb/Cu, where the first material is that of the disk above in contact with the target volume and the second is that of the disk put below.

Anyway, in this work all the possible combinations of the two disk materials were simulated, not only the possible clinical set-ups with the lead or copper disk in the position below; in this way it is possible to determine the backscattering radiation of different materials (Al, Cu, Pb) and how the backscattering radiation of the disk below influences the dose at the interface of the disk above.

A Monte Carlo study using Fluka simulation code [1, 2] was performed to determine the backscattering radiation dose distributions, the percent depth dose curves in presence of the different disk combinations.

2. Materials

2.1. Mobile dedicated LINAC

NOVAC7 (Hitesys, Italy) is a mobile LINAC that can deliver electron beams with nominal energies of 3, 5, 7 and 9 MeV (with surface mean energy, E₀, of about 4, 5, 6 and 7 MeV respectively). The emission of electrons is pulsed with a frequency of 5 Hz, a pulse duration of 4 µs and a very high dose per pulse (up to 10 cGy per pulse).

The dosimetric characterization of the accelerator (depth dose curves and dose profiles at a fixed depth) was performed with a diode in water phantom with a motorized system for the movement of the diode (RFA plus Scanditronix). Analyzing the Percent Depth Dose curves (PDD) in water phantom we concluded that it is possible to treat adequately target volume thicknesses up to 2.5 cm. Although, the presence of internal shieldings during clinical practice could allow to treat also higher target thicknesses up to 3 cm thanks to the backscattering radiation dose.

The LINAC is composed of a controlling console positioned near the operating room, an UPS (Uninterruptible Power Supply) and a motorized mobile unit that can be moved by a joystick remote control. The mobile unit has a basement (it contains the motors and the cooling system), an articulated arm (that contains the modulator) and a radiating head (that contains the accelerating structure and the system of monitor-chambers). NOVAC7 can be moved and displaced inside the operating room with a caster installed in the base and can be pushed towards the operating table and the patient, so as to be easily positioned with great accuracy in the treatment position. Thanks to the degrees of freedom of the modulator, the head and the wheel, all the movements can be performed with four different speeds. Beam collimation is performed with perspex cylindrical applicators (5 mm thickness, diameter between 4 and 10 cm), that are either parallel (0°) or bevelled (22.5°), mounted on exit window head. The Source-Skin Distance (SSD) is 80 cm for the applicators with a diameter up to 8 cm and 100 cm for the applicators with a diameter of 10 cm.

The NOVAC7 installed at Operating Department of Ospedali Riuniti di Bergamo is currently employed for the treatment of early breast cancer patients. After quadrantectomy, the breast flaps are mobilized over the disks and sutured by temporary separated stitches taking the entire thickness of the breast. Then, the sterile collimator is introduced through the skin incision and stands to target surface.

From February 2006 to January 2007, 110 female patients have been irradiated; the thickness of target volume ranged between 1.0 and 2.5 cm. In clinical practice, a field of E₀=7.2 MeV is employed because the most uniform dose distribution to treat clinical target thicknesses up to 2.5 cm (R₉₀ = 2.1 cm) is obtained with this beam energy.

The typical layout of the breast cancer treatment is reported in figure 1.
2.2. Protection disks

In order to protect adequately the tissues underlying the target volume, a disk of high atomic number (Z) materials must be temporary positioned between the target volume and the underlying tissues, along the beam axis. The disk is located between gland and pectorals muscle. However, a high Z shield determines a modification (increase) of the dose distribution at the shield-target interface due to backscattering radiation and in some cases this difference is significant. This contribution depends on the atomic number (Z) and on the thickness of the shield, on the thickness of the target volume and of the energy of the field near the interface [3]. The backscattering radiation dose contribution can be reduced if a second low Z disk is placed above the first.

At the present time, for the treatment of early breast cancer patients with the mobile LINAC at Ospedali Riuniti di Bergamo, the combination Al/Pb disks is in use, that is the aluminium disk is positioned above towards target volume and the lead disk is under the aluminium disk, in contact with pectoral muscle to protect the lung. Lead disks of 0.5 cm thickness determine a complete protection of the underlying tissues; in order to shield the backscattering radiation of lead it is necessary to interpose a disk of lower Z material (Aluminium or copper disk, of 0.5 cm thickness) between target volume and lead disk. The diameter of disks used in clinical practice are, 2 cm larger than the diameter of the corresponding applicator (e.g., for the applicator of diameter 5 cm, disks of diameter 7 cm are used).

2.3. FLUKA simulations

FLUKA is a Monte Carlo code able to simulate the transport and interaction of electromagnetic and hadronic particles in any target material over a wide energy range [4, 5]. It is a multipurpose, multi-particle code that can be applied in many different fields. The code characteristics at intermediate energies makes it particularly reliable in treating problems in the fields of radiotherapy. The energy loss of hadrons and electrons is treated by means of the Bethe-Bloch theory with delta ray production transport, supplemented with average ionisation potentials, density and shell corrections according to ICRU 37 and 49 [6]. The production of delta-rays is described explicitly above a user-defined threshold, below which a continuous energy loss with statistical fluctuations is assumed. FLUKA can deal with every single element material and every compound or mixture of single elements. Combinatorial geometry is implemented. The energy deposition can be scored in geometry independent binning structure, of Cartesian or cylindrical kind.

Figure 1. Typical layout of IORT treatment in operating room: The LINAC is positioned towards the operating table, so that the beam collimator (the cylindrical plex applicator) is hold in the correct position for the irradiation of the target volume.
The geometry of the problem is defined as combination of bodies (infinite planes, infinite cylinders parallel to the coordinate axes, rectangular parallelepiped, sphere, etc) obtained by Boolean operations: union (“or”), subtraction (“not”) and intersection (“and”). Each region must be filled with an homogeneous material. The geometry must be contained within a surrounding “blackhole” that is an infinitely absorbing material which captures all the escaping particles.

The geometry of the problem is the following: the part of the LINAC that follows the accelerating cavities, and consists of a titanium exit window, the two monitor chambers embedded in a plex structure, the plex connection between this upper part of the accelerator and the applicator, the cylindrical plex applicator (10 cm diameter, SSD 100 cm); the applicator is positioned perpendicularly on the phantom; the disks of different materials are simulated at different depths in the phantom, simulating different target tissues thicknesses from 1 cm to 3 cm: simulations were performed for target thicknesses of 1, 1.5, 2, 2.5 3 cm. (figure 2).

![Figure 2. Schematic representation of the geometry of the simulation: the monitor chambers; the cylindrical plex applicator connected to the monitor chambers is perpendicular to the water phantom; the two disks of different materials positioned perpendicular to the incident beam at different depths that range from 1 cm to 3 cm to simulate different target thicknesses.](image)

The source simulated is an electron beam of $E_0 = 7.2$ MeV because the most uniform dose distribution to treat clinical target thicknesses is obtained with this beam energy. The energy of the initial electron beam was iteratively modified until the depth at which the absorbed dose had dropped to 50% of the maximum dose (i.e. $R_{50}$) agreed with measured relative depth dose curves to within 1 mm.

The energy density can be scored in a geometry independent binning structure and averaged over the run. The minimum and maximum step size is given region by region; an optimisation algorithm makes the results of the optimisation independent from the step size.

The maximum step size of 0.02 cm in the phantom region was set; using the USRBIN card. A cylindrical spatial structure was defined so that it was possible to calculate the depth dose distribution in all the radial positions, as the collimator geometry is cylindrical. The grid has a radial interval 0.22 cm. A number of $5 \times 10^6$ histories has been used for simulations.
In order to simulate the backscattering dose determined from different disk material combinations, the geometry of an applicator of 10 cm diameter (SSD 100 cm) in contact with the RW3 phantom was created in the presence of the following disk material combinations: only Al, Al/Al, Al/Cu, Al/Pb, only Cu, Cu/Al, Cu/Cu, Cu/Pb, only Pb, Pb/Al, Pb/Cu, Pb/Pb. The first material indicates the disk that is positioned in contact with the target volume, and the second is the disk below. The simulations were performed for all these disk combinations and for all target volume thicknesses in order to determine the backscattering radiation contribution of all materials and verify how the of backscattering radiation of the disk below influences the dose at the interface of the disk above. But the disk combinations in clinical practice will always have a lead or copper disk as shield below to protect completely underlying tissues.

2.4. gaf-chromic films

Gaf-chromic HS dosimetry films (International Speciality Products, USA) (lot #: No. N0745HS55) have been used for the experimental evaluation of PDD in RW3 slab phantom (PTW, Germany).

The active layer of these films (about 40 µm thick) is sandwiched between two sheets of clear, transparent polyester (about 97 µm). The thickness of the active layer will vary slightly from batch-to-batch in order to provide the product with a reproducible sensitometric response. These films may be measured with transmission densitometers, film scanners or spectrophotometers. When the active component is exposed to radiation, it reacts to form a blue coloured polymer with absorption maxima at about 615 nm and 675 nm. Therefore, the response of films is enhanced by measurement with red light. The response of the gaf-chromic HS is essentially energy-independent and is linear with dose up to 30 Gy [7].

The films appear as 5" x 5" sheet and are cut into 1.5 x 1.5 cm pieces for the exposure. Film uniformity, evaluated for a single randomly chosen sheet, was within 5%. The films were analysed about 48 h after the irradiation using a dedicated scanner (Epson 1680 Pro); a commercial software, PicoDose (Tecnologie Avanzate, Italy) was used to evaluate the statistics of Optical Density and Dose values of film pieces.

The film calibration was obtained irradiating 1.5 x 1.5 cm film pieces (of the same package) in RW3 slab phantom, at build-up depth, up to 30 Gy with 7.5 MeV electron beam supplied by a conventional LINAC (Saturne 41 General Electric, USA). The overall uncertainty of dose evaluation with Gaf-chromic HS dosimetry films was about 5% (1 Standard Deviation).

3. Methods

The simulated PDD were compared with the experimental PDD for an electron beam of $E_0 = 7.2$ MeV ($R_{50} = 31$ mm), without disks, using the applicator of 10 cm diameter, obtained (1) with motorised p-type diode in water phantom and with (2) HS gaf-chromic films in RW3 slab phantom. The depth dose curves with the diode were acquired with a measuring step of 1 mm; gaf-chromic films were positioned in RW3 phantom at 2 mm measuring step. At each depth 3 pieces (1.5 x 1.5 cm) of the film belonging to the same package were used. The dose value at each depth is the mean value of the three dose values measured. The dose integrated from the films ranged between 2 and 30 Gy. All experimental doses were normalised at the maximum dose measured with the motorised diode in water phantom (build up:13 mm).

The comparison of simulated and further experimental data in presence of disks is in progress.

At the moment, the comparison was performed for a target thickness of 2.0 cm and for the following disk material combinations: Al/Pb, Cu/Pb e Pb/Pb. Gaf-chromic films were positioned at every 2 mm depth in RW3 slab Phantom. At each depth three pieces (1.5 cm x 1.5 cm) of films of the same package were used. The dose value at each depth is the mean value of the three measurements. Also in this case, the experimental doses were normalised to the maximum dose measured with motorised diode in water phantom (13 mm). These preliminary experiments were performed in order
to determine the dose distribution for the clinical disk set up in use (Al/Pb), and to compare it with other possible clinical setups (Cu/Pb and Pb/Pb) where a lead disk (high Z material) is put as second disk in contact with the underlying tissues; a target thickness of 2 cm was selected as it is a frequent clinical target thickness value.

Once the simulation results with internal shield has been compared with the experimental ones and were found in good agreement the analysis of simulated PDD curves and BSF calculation at the target-disk interface was carried out for all the disk combinations and for Al, Cu and Pb disks alone for target thicknesses ranging between 1.0 and 3.0 cm.

Finally, the optimal disk material combinations were selected, for each target thickness, that determined the most uniform dose distribution in the target without hot spot dose points at the disk-target interface; furthermore it was verified if there is a disk combination that enhances dose that would allow to treat also higher target volume thicknesses up to 3 cm. This is a preliminary selection that will be further validated experimentally.

4. Results and discussion

4.1. Experimental evaluation versus simulated data

In figure 3, the experimental PDD obtained with diode in water phantom and with HS gaf-chromic film in slab phantom were compared with simulated PDD without shield disks. A good agreement between these curves is observed up to 3.0 cm depth, with differences within 5%. The maximum dose point obtained from simulations and from measurements with gaf-chromic films is at 15 mm and at 13 mm, respectively. Anyway PDD between 11 and 16 mm is higher than 99%. These data confirm a good agreement between experimental and simulated data, so simulations of all possible combinations of disks were performed to analyse the different backscattering radiation contribution of different disk material combinations.

In figure 4, for the target thickness of 2.0 cm, the experimental PDD obtained with HS gaf-chromic film in slab phantom were compared with simulated PDDs for the following disk couplings: Al/Pb, Cu/Pb and Pb/Pb. The first material is that of the disk positioned in contact with the target volume and the second is the disk below. In clinical application up to now the disk couplings used are Al/Pb. Also in this case simulated and experimental PDD are in agreement within 5%.

4.2. Simulated data of Percent Depth Dose and Back Scattering Factor with internal shields

The simulated PDD at interface for Al, Cu and Pb disks alone and for different disk combination and for different target volume thicknesses are presented in table 1. The PDD without internal shield are reported for comparison, and the dose increment at target-disk interface for different disk materials is determined normalizing to the build up dose without the shieldings the dose at 13 mm for all the simulated PDD. In this way it is possible to determine the percent dose increment at disk/target interface respect to the prescribed dose (at build up, 13 mm) due to backscattering radiation; considering the PDD curves it is possible to determine the most uniform dose distribution in the target volume, without dose hot spots at disk interface. Some general observation can be made on the basis of the simulated PDD at interface of all disk combination:

- for the disk combinations in which the first disk material is fixed (either Al, Cu or Pb) there are no substantial differences of PDD at interface when the disk below is varied. In other words, the disk material below does not influence the dose at the target-disk interface. However, in one case in which aluminum disk is put above the lead disk for 1.0 and 1.5 cm target thickness there is 5% higher PDD at disk interface than for combinations in which the disk below is Cu or Al (table 1); that means that for low target thicknesses the Al disk does not reduce lead backscatter radiation as for thicker target volumes.
• for the disk combinations in which the disk below is fixed (either Al, Cu or Pb) there are differences of PDD at interface when the disk material above varies, up to 50% when lead disk is at target interface (table 1).

We can remark that the backscattering dose depends in general on the material of the disk positioned in contact with target volume except for the Al/Pb disk combination: for 1 cm and 1.5 cm target thicknesses the backscattering radiation of lead is not completely reduced by aluminum disk (table 1). Indeed aluminum disk backscattering dose contribution at target interface determines a PDD of 108% for 1 cm target thickness, and 110% for 1.5 cm target thickness; in the presence of a lead disk below the Al disk, the PDD at target/disk interface is 113% for 1 cm target thickness (5% higher than with aluminum alone); and 116% for 1.5 cm target thickness (6% higher than with aluminum alone).

In figure 5 the BSF obtained from simulated data are reported for all disk couplings: the data are grouped in the following way: the first disk material, that is at target interface, is fixed, and the material of the disk below is varied. The disk combinations are: Al alone Al/Al, Al/Cu, Al/Pb, Cu alone Cu/Al, Cu/Cu, Cu/Pb and Pb alone Pb/Al, Pb/Cu, Pb/Pb. The BSF depends dramatically on the disk material at target interface and increases with the atomic number (Z) of the material at each target thickness as it is for the PDD at interface.

For target thicknesses that range from 1 cm up to 3.0 cm the BSF ranges for different disk materials at target interface are the following (figure 5): 1.1-1.2 for Al, 1.2-1.4 for Cu and 1.5-1.6 for Pb.

4.3. Indication of the best internal shield coupling to get the most uniform dose distribution in target

For each target thickness the optimal shield coupling was selected to get the most uniform dose distribution in the target volumes of different thicknesses. The material of the disk below, in contact with underlying tissues has to be copper or lead to determine the attenuation of the primary beam down to 5% to shield lung and underlying tissues.

The following consideration can be made from the simulated PDD curves (data not reported):
• for 1.0 cm target thickness the most uniform dose distribution is obtained with the disk combination Al/Cu; the dose begins to increase due to backscattering at 0.7 cm up to 1.0 cm (at target/disk interface the PDD is 5% higher than the build up dose);
• for 1.5 cm target thickness the most uniform dose distribution is obtained with the disk combination Al/Cu; the dose begins to increase due to backscattering at 1.0 cm up to 1.5 cm (at target/disk interface the PDD is 10% higher than the build up dose);
• for 2.0 cm target thickness the most uniform dose distribution is obtained with the combination Al/Cu; the dose increases due to backscattering from 1.5 to 2.0 cm (at target-disk interface the PDD is 10% higher than the build-up dose);
• for 2.5 cm target thickness the most uniform dose distribution is obtained with the disk combination Al/Pb; the dose is almost uniform in the target;
• for 3.0 cm target thickness the most uniform dose distribution is obtained with the combination Pb/Pb; a dose decrease is observed at 2.0 cm with a minimum at 2.7 cm were the dose is almost 5% lower than build up dose; the dose then grows up from 2.7 cm to 3.0 cm reaching almost 5% higher dose than build up dose.

We can conclude that the disk combination that optimize the dose distribution in the target volume are not those used up to now in clinical practice (Al/Pb for all the target thicknesses). All these data must be further compared with experimental measurements. Work is in progress to measure with the gaf-chromic film further depth dose distributions with different material combinations at different depths. So, it will be possible to introduce in clinical practice the new disk combinations.
Figure 3. Experimental data of PDD without shield disks (black squares: diode in water phantom; red triangles: HS gaf-chromic film in RW3) versus simulated data in RW3 phantom (blue squares) ($E_0 = 7.2$ MeV, applicator diameter 10 cm).

Figure 4. Experimental PDD for a target thickness of 2 cm ($E_0 = 7.2$ MeV, applicator diameter 10 cm) with HS gaf-chromic film in RW3 (red squares) versus simulated data in RW3 phantom (open squares and triangles, crosses) for the following disk couplings: Al/Pb, Cu/Pb and Pb/Pb. The first disk material is that in contact with the target volume, the second is the disk below in contact with the underlying tissue.

Table 1. Computed doses of simulations at target/disk interface normalized respect to the value of the build up dose at 13 mm of the PDD without the disks, for different disk combinations of three materials available: aluminium (Al), copper (Cu) and lead (Pb); the first material is that of the disk in contact with target volume and the second is the disk below in contact with the underlying tissues. The electron energy is $E_0 = 7.2$ MeV and the applicator diameter is 10 cm. Target tissue thicknesses used in simulations are: 1, 1.5, 2, 2.5, 3 cm. PDD without disks are reported at the different depths in order to highlight the dose increment due to backscattering.
Figure 5. Back Scattering Factor (BSF) calculated from simulated data, for different disk combinations: in red BSF are reported for the couplings where the disk above, in contact with target volume, is aluminium and the disk below is varied (Al alone, Al/Al, Al/Cu, Al/Pb). In black the BSF for the combinations where the Cu disk is positioned above (Cu alone, Cu/Al, Cu/Cu, Cu/Pb) and in blue the BSF for the couplings where Pb disk is positioned above (Pb alone, Pb/Al, Pb/Cu, Pb/Pb). The electron energy is $E_0 = 7.2$ MeV and the applicator diameter is 10 cm.

5. Discussion and Conclusions

IORT treatment foresees a single session and a single beam only; therefore it is necessary to use protection systems temporary positioned between the target volume and the underlying tissues, along the beam axis.
In order to protect adequately the organ at risk, disk of high atomic number (Z) materials must be used (lead or copper).

These shields determine a modification of the dose distribution in the overlying target volume due to backscattering radiation and in some cases a significant increase in the overall dose delivered to the patient. This effect can be reduced if a second low Z disk is placed above the first (aluminum). Two disks are therefore used in clinical application: the disk above, in contact with target volume is a low Z material disk, the one below is a high Z material disk. The materials available are Aluminium, copper and lead. A Monte Carlo study using Fluka simulation code [1, 2] was performed to determine the backscattering radiation dose distributions. Preliminary experimental measurements with gaf-chromic films and diodes are in agreement with simulated data. To evaluate the different backscattering radiation produced from different materials, all the combinations of disks were simulated for different target volume thicknesses. BSF at disk-target interface are determined for all disk combinations. In clinical practice the high Z material (Cu or Pb) has to be positioned in contact with the underlying tissues to determine the reduction of the primary beam dose down to 7%. The PDD in target volumes of different thickness was analysed in order to determine for which disk combination the dose distribution is most uniform.

Furthermore it was possible to determine the disk combination of high Z materials (Pb/Pb) that determines a backscattering radiation that enhances dose in 3 cm thick target volume making the dose distribution uniform also in this target volume; up to now target thicknesses of a maximum of 2.5 cm are treated, but on the basis of this study it will be possible to include in IORT treatments also in patients with deeper tumours (higher target thicknesses), that were discarded up to now.

Further experiments with gaf-chromic films are in progress to compare experimental simulated PDD curves.

The analysis of percent dose distribution for different target thicknesses with different disk combination allows to optimize IORT treatment, in order to obtain the most uniform dose distribution.

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