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# The influence of Monte Carlo source parameters on detector design and dose perturbation in small field dosimetry

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**Abstract**. To obtain accurate Monte Carlo simulations of small radiation fields, it is important model the initial source parameters (electron energy and spot size) accurately. However recent studies have shown that small field dosimetry correction factors are insensitive to these parameters. The aim of this work is to extend this concept to test if these parameters affect dose perturbations in general, which is important for detector design and calculating perturbation correction factors.

The EGSnrc C++ user code cavity was used for all simulations. Varying amounts of air between 0 and 2 mm were deliberately introduced upstream to a diode and the dose perturbation caused by the air was quantified. These simulations were then repeated using a range of initial electron energies (5.5 to 7.0 MeV) and electron spot sizes (0.7 to 2.2 FWHM).

The resultant dose perturbations were large. For example 2 mm of air caused a dose reduction of up to 31% when simulated with a 6 mm field size. However these values did not vary by more than 2 % when simulated across the full range of source parameters tested.

If a detector is modified by the introduction of air, one can be confident that the response of the detector will be the same across all similar linear accelerators and the Monte Carlo modelling of each machine is not required.

## 1. Introduction and aim

Small air gaps upstream to a diode active volume heavily perturb small photon fields causing a large reduction in dose to the active volume[1,2]. Therefore air can be deliberately introduced into diode designs to negate the inherent over-response of diodes in small photon fields[2]. The amount of air required to produce a diode which responds uniformly at all field sizes depends on the diode design[2].

The aim of this work is to study the dependence of the dose reduction caused by controlled amounts of air on the Monte Carlo initial source parameters (incident electron spot size and energy) of a linear accelerator. Hence this study reveals if a new diode design involving any amount of air can be used with confidence across a population of similar linear accelerators.

## 2. Background

Dosimetry of small photon fields presents many challenges, one of the largest being the perturbation of the beam by the detector used[3-5]. Traditional radiation detectors such as ionization chambers and diodes become relatively large compared to the size of the field, and therefore the composition of these detectors becomes important when calculating the response of the detector in a small field.

Alfonso *et al*[4] proposed a formalism where the change in sensitivity of a detector as a function of small field size is accounted for by applying an additional factor $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ to standard output factor measurements.

$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ has been systematically calculated for diodes using Monte Carlo modelling[6-9] and its value depends strongly on the composition of the detector[10]. Diodes have been shown to have increased sensitivity in small fields due to the high density of the silicon active volume[11,12] as well as high density metals which may be upstream to the active volume[10]. It has been shown that $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ values calculated via Monte Carlo simulations for diodes are independent of the initial source parameters used to model the linear accelerator (incident electron energy and focal spot size)[8-10]. However in each case the exact composition of the detector has been modelled, so the results are very specific to those detectors.

In a recent study Charles *et al*[2] used Monte Carlo simulations to study the effect of deliberately introducing air into diodes such that the dose reduction caused by the air eliminated the field size dependence of the diode. The authors successfully calculated the amount of air that would be required for a shielded diode, an unshielded diode and a theoretical unenclosed silicon chip to respond uniformly at all field sizes. In each case the air was simulated to be on the upstream end on the diode.

## 3. Methodology

### *3.1. Monte Carlo simulation overview*

All linear accelerator Monte Carlo simulations were performed using the user code BEAMnrc[13] and a previously modeled Varian iX (Varian Medical Systems, Palo Alto, CA)[2,14,15]. The field size used throughout this study was a 6 mm × 6 mm square.

All diode simulations were performed using the EGSnrc C++ user code cavity[16]. The unmodified diode used in this study was a simple cylindrical silicon chip (see figure 1). All detector simulations were performed in water at a depth of 5 cm and source to detector distance of 100 cm. All dose calculations were performed on the central axis of the beam.

In the phantom material, the electron and photon cut off energies were chosen to be 521 and 10 keV respectively. Inside the volume of the simulated diode they were reduced to 512 and 1 keV respectively for increased accuracy within the detector volume and air gaps. Sufficient histories were simulated so that the statistical uncertainty of the Monte Carlo calculated correction factors was maintained at less than 0.5%.

### *3.2 Modification of the diode with air*

Air was introduced immediately upstream to the silicon active volume (see figure 1). For each case the dose to active volume of the diode was calculated, as was the dose reduction caused by the air gap. Here dose reduction refers to the percent change in dose when compared to the dose to the detector with no air present. That is:

$$\text{Dose reduction } (x) = [(D_{\mathrm{Det,air}(x)} - D_{\mathrm{Det,air}(0)}) / D_{\mathrm{Det,air}(0)}] \times 100$$

$D_{\mathrm{Det,air}(x)}$ is the dose to the detector with x mm thickness of air placed upstream.

The simulations were initially performed with an incident electron energy onto the target of 5.8 MeV

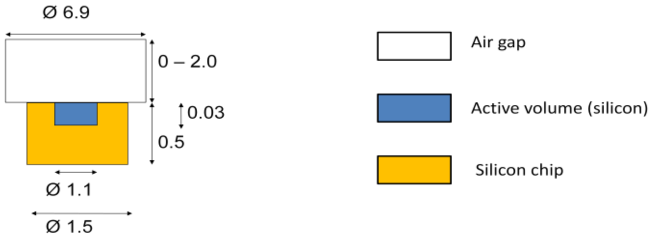

**Figure 1.** The simulation geometry of the detector used in this study (a basic silicon chip) and the upstream air gap. The dimensions are shown in mm. The diagram is not to scale.

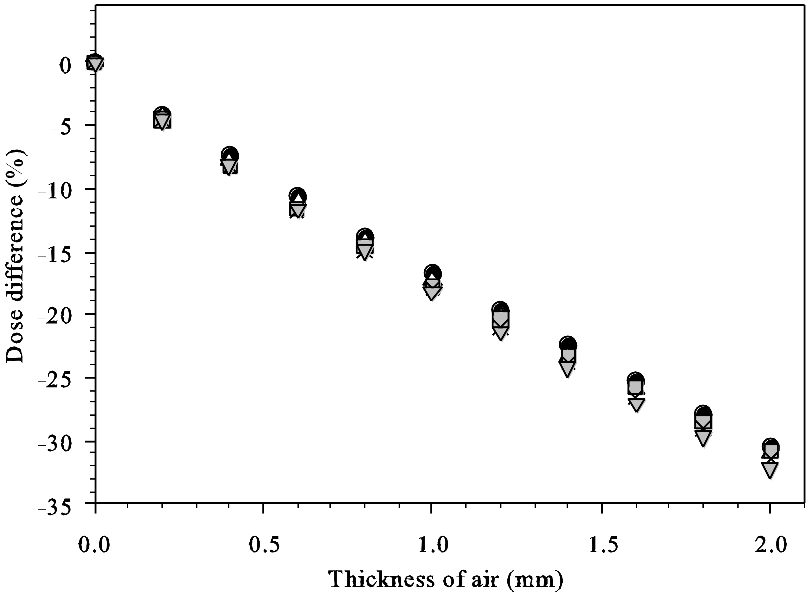

**Figure 2.** The dose reduction as a function of upstream air thickness. Dose reduction refers to the change in dose relative to a simulation with no air gap. Shown here are the results using an incident electron energy of 5.8 MeV and an incident electron spot size of 0.4 mm (black circles), 0.7 mm (white triangles), 1.2 mm (grey squares) and 2.2 mm (crosses). Also shown is the results for an incident electron energy of 7.0 MeV (grey upside-down triangles) (spot size = 1.2 mm).

and a focal spot size of 1.2 mm. The simulations were repeated for an incident electron energy of 7.0 MeV (the focal spot size remained 1.2 mm) and the dose differences caused by the air were compared. Keeping the energy constant at 5.8 MeV, the simulations were then repeated using the following focal spot sizes: 0.4, 0.7, and 2.2 mm. Once again the dose reduction caused by the air was compared across the different focal spot sizes.

## 4. Results and discussion

The dose difference as a function of air gap thickness is presented in figure 2 for the two different incident electron energies and for the various focal spot sizes. It can be seen that while the air strongly perturbs the dose to the detector, this dose difference does not vary greatly with the initial source parameters.

Air causes a large dose reduction to the active volume due to the filtering of electrons with a high angle of incidence[1]. However the dose reduction results were consistent across all input parameter variations. The consistency of these results suggests that the incident source parameters do not significantly affect the subsequent angular distribution of the dose depositing electrons in water. One can therefore be confident that introducing any amount of air into a detector design will result in a consistent effect across multiple linear accelerators.

## 5. Conclusions

This study showed the influence on initial source parameters on the dose perturbation caused by air placed immediately upstream to a silicon active volume at the central axis of the beam. If a detector is modified by the introduction of air, one can be confident that the response of the detector will be the same across all similar linear accelerators and the Monte Carlo modeling of each machine is not required.

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