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# Dose responses of diamond detectors to monoenergetic X-rays

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## Abstract

The characterisation of a detectors response in the kilovoltage range is necessary to understand its response to scattered radiation in the megavoltage range. Scattered radiation is absorbed in the detector by the highly  $Z$ -dependent photoelectric process. Measurements of diamond detector response to highly filtered quasi-monoenergetic X-rays and synchrotron-generated monoenergetic photons have been performed revealing effects that relate to the presence of copper and silver used to form electrical contact with the crystal. A three-component model of energy absorption, utilizing tabulated cross-sections for C, Cu and Ag, is proposed and a calculation of phantom scatter factors for diamond detector is given.

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## 1. Introduction

The emergence of high spatial-resolution diagnostic and therapeutic radiation techniques has been witnessed in recent years. In particular, synchrotron-based angiography, fluorescence microtomography and micro-beam radiosurgery, and linear accelerator-based stereotactic radiosurgery, all demanding high spatial-resolution for dosimetry. Silicon based solid-state dosimeters, including diodes and MOSFET detectors offer high sensitivity but have a relatively high atomic number compared to biological tissue and require signifi-

cant corrections for energy response, especially below 100 keV [1,2]. Diamond detectors have the advantage of high sensitivity as well near soft-tissue equivalence and are suitable as radiation detectors in radiotherapy dosimetry for high-energy photon and electron beams [3–6]. Though the response of a diamond detector to high-energy photon is in good agreement with an ionization chamber in water phantoms for small field sizes or close to surface, there are significant difference when the field size and depth are increased. This is presumably due to increases in photoelectric absorption in the electrical contacts (Cu, Ag) on the crystal. Several workers have measured the response of diamond detectors to low X-ray energies [7,8]. These measurements show the energy response of diamond relative to an ionization chamber departs from the ratio of the mass–energy-absorption coefficients of

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carbon and air, unlike the energy response of diode detector, which agrees well with the ratio of the mass–energy-absorption coefficients of silicon and air [1].

This paper presents measurements of the energy response of a diamond detector to highly filtered quasi-monoenergetic X-rays and synchrotron-generated monoenergetic photons. These measurements reveal the effects in the dose response of the diamond detector that relate to the presence of copper and silver. A three-component model for mass–energy-absorption coefficients and electron stopping powers is proposed, utilising tabulated data for C, Cu and Ag. Phantom scatter factors were measured for 6 MV X-rays and calculated according to an extension of Burlin cavity theory described by Yin et al. [2] and using a Monte Carlo method to compute electron spectra due to primary photons and scattered photon spectra.

## 2. Materials and methods

The energy response of two diamond detectors (PTW, Freiberg), were measured with a Pantak HF-320 X-ray unit in the energy range 24–208 keV utilising a set of highly filtered quasi-monoenergetic beams [1,9] and synchrotron-generated monoenergetic photons (SRS, station 16.5, Daresbury Laboratory, UK) in the range 7.7–10 keV, which is in the vicinity of the Cu K-edge. The calibration of the diamond detectors with respect to a PTW 23344 thin window parallel plate ionization chamber in the horizontally planar synchrotron field was achieved by scanning a beam of approximately 1 mm × 10 mm over a vertical range of 10 mm to achieve a 10 mm × 10 mm field. A preirradiation dose was applied to the diamond detectors until a stable signal was achieved.

The construction of the PTW diamond detector was assessed using high resolution radiographs. The volume of the crystal (the sensitive volume) for the diamond detector is about 6 mm<sup>3</sup> and the thickness is about 0.4 mm. Copper wires are bonded to the crystal with a silver loaded epoxy resin. The whole structure is encapsulated in an epoxy resin. The front face of the diamond is 1 mm beneath the outer surface of the housing.

A calculation of the phantom scatter factor of diamond detector has been carried out using a model that separates scatter and primary photons, treating them according to the predominant process of absorption [2], hence,

$$D_{\text{det}} = \int \Psi_{\text{p,e}}(\varepsilon)(S(\varepsilon)/\rho)_{\text{det}} d\varepsilon + \int \Psi_{\text{s,\gamma}}(\varepsilon)(\mu_{\text{en}}(\varepsilon)/\rho)_{\text{det}} \varepsilon d\varepsilon, \quad (1)$$

where  $\Psi_{\text{p,e}}$  is the electron spectrum generated from primary photons and  $\Psi_{\text{s,\gamma}}$  is the scatter photon spectrum, both computed using the Monte Carlo code, EGSnrc.  $(S/\rho)_{\text{det}}$  is the mass-collision stopping power and  $(\mu_{\text{en}}/\rho)_{\text{det}}$  is the mass–energy-absorption coefficient of the detector material as a function of the energy,  $\varepsilon$ .

## 3. Results

Fig. 1 shows the dose responses for two diamond detectors to highly filtered quasi-monoenergetic X-rays, which were normalized to unity at a mean photon energy of 208 keV. The ratios of mass–energy-absorption coefficient carbon to air are compared with a combined mass–energy-absorption coefficient. Table 1 gives the effective composition of Ag, Cu and C by mass in the detector determined by best-fit to the energy response data guided also by high resolution radiographs. An estimate of the uncertainties of the weights is also given and are substantial in the case of copper which has a lesser influence than silver due to its lower atomic number.

Fig. 2 gives the response of two diamond detectors in the vicinity of the copper K-edge (8.9789 keV), measured with a synchrotron-generated monoenergetic photon beam. The energy response for two diamond detectors near copper K-edge is in reasonable agreement with the K-edge step predicted according to the three component model of mass–energy-absorption coefficients although large errors occur at greater energy separations due to poorly defined attenuation in the detector and phantom at such low energies.

Fig. 3 shows the measurement and calculation of phantom scatter factors (excluding the head scatter contribution) at 15 cm depth in a water

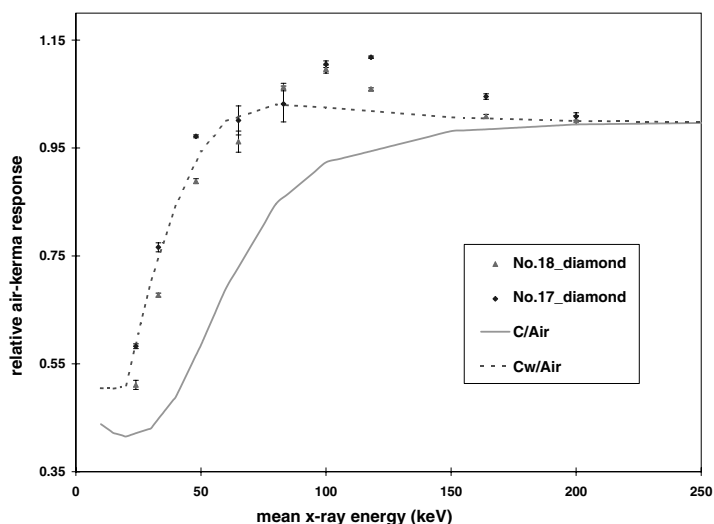


Fig. 1. Relative air-kerma response of the diamond detectors (PTW) to NE2550 Protection Level Secondary Standard ionization Chamber (Bicron-Nuclear Enterprises, Reading, UK), normalized to mean energy 208 keV, mass absorption coefficients and component model.

Table 1  
Weighting by mass with components of Ag, Cu and carbon for the diamond detector

Component	Cu	Ag	C
Weight	0.005	0.0025	0.9970
Error	0.005	0.001	0.0005

phantom for a diamond detector and an ionization chamber. The diamond detector overestimates the dose according to the ionization chamber by more than 4% at large field sizes. Good agreement with less than 1% error is achieved using the component model presented.

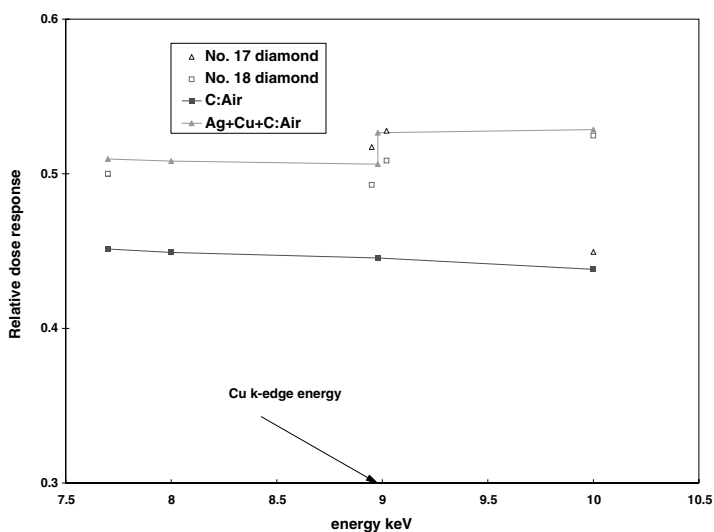


Fig. 2. Diamond detector response near the copper K-edge.

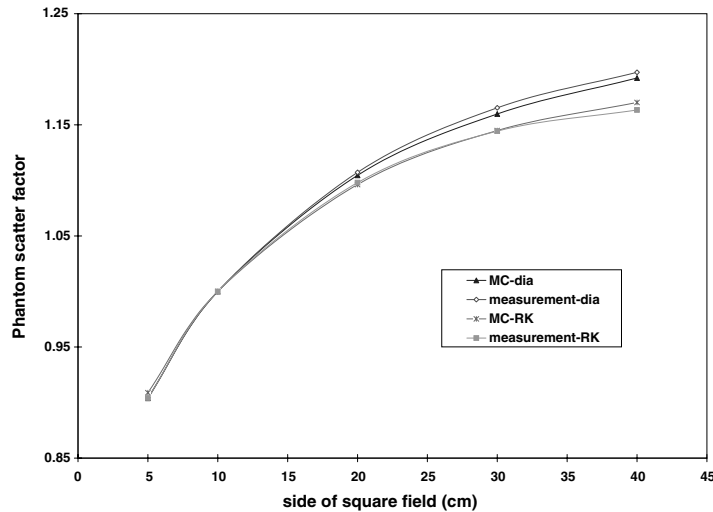


Fig. 3. Phantom scatter factors as a function of field size for a diamond detector and ionization (RK) chamber in a 6 MV photon beam at a depth of 15 cm in water.

#### 4. Discussion and conclusion

Previous work has shown that a greatly improved estimate of phantom scatter can be obtained with a diode detector which is corrected for the mass-absorption and mass-collision stopping-power ratios of silicon to water. The relative energy response of a diamond detector to water has poor agreement with the mass-energy-absorption coefficients of carbon and water, as well as the relative response of a diamond detector and ionization chamber to phantom scatter which demonstrate discrepancies that should be taken into account to achieve dosimetric accuracy at the 1% level.

The diamond detector construction and function introduces an influence from the high  $Z$  materials, Cu and Ag, used as contacts. Unlike the silicon diode detector where the sensitive depletion region is separated from the contacts by an inactive substrate, charge separation occurs throughout the crystal. The photoelectric effect deposits energy locally and predominates at low photon energy for high  $Z$  material. By determining a weighted contribution from the Cu and Ag contacts, via experimental analysis of the energy response in the kilovoltage range, an improved agreement has been obtained.

The diamond detector energy response data obtained near the copper K-edge energy shows that synchrotron radiation offers an accurate means of determining the abundance and influence of high  $Z$  components in the detector in an energy range where attenuation renders intercomparisons between detectors problematic.

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