APPENDICES

APPENDIX A

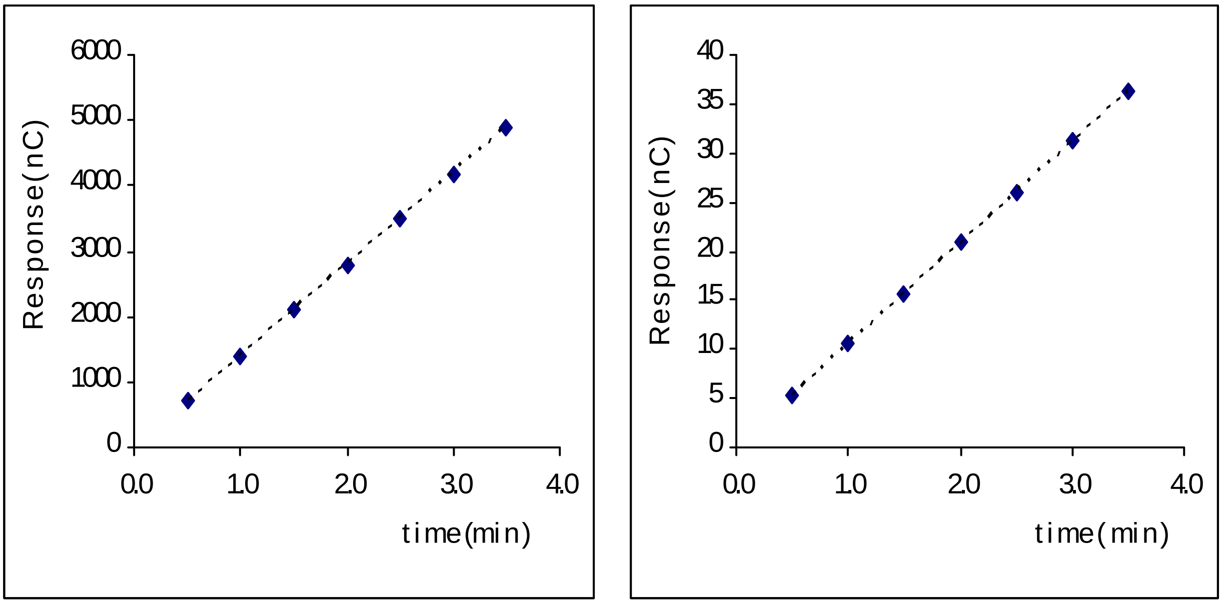
AN EVALUATION OF THE PERFORMANCE OF THE SYNTHETIC DIAMOND PROBE ON EXPOSURE TO ^{60}Co RADIATION

A.1 Dosimetric measurements

The dosimetric performance of the probe was also evaluated on exposure to ^{60}Co radiation using DGB1 (chosen because of its low and stable dark current) as the sensing element. The measurements that were conducted include: linearity of timer, timer error, *OF*s and *TMR*s.

A.2 Timer linearity and end effect (timer error) measurements

As external beam units are calibrated against an internal timer or monitor unit (MU) (AAPM TG-40, 1994), linearity of response of a radiation detector with time or MU is essential. Illustrated in Figs A1 (a) and (b) respectively are response-time graphs for a ^{60}Co unit measured with a 0.6 cc Farmer type chamber and the diamond probe. The figures demonstrate that the response of each detector is linear with the timer. However, the response of the diamond probe taken at +50 V bias is much higher compared to the response of the ion chamber recorded at +400 V. Each detector was connected to a PTW Unidos E electrometer system. The dose rate used at the time of measurements was 78.17 cGy/min.



(a) (b)

Figure A1: Response-time graphs for (a) 0.6 cc Farmer chamber and (b) diamond probe demonstrating the linearity of timer for the ^{60}Co unit.

The gradients of the graphs gave values of 1390 and 10.4 nC/min for the diamond probe and ion chamber, respectively indicating that the diamond probe is about 134 times more sensitive than the ion chamber.

The timer error (transit time) for a ^{60}Co unit is an end effect that describes the finite amount of time required by the shutter to move from the fully closed to the fully open position and also from the fully open to the fully closed position. That is, the transit time is the finite time during transit of the ^{60}Co source from the fully shielded position (beam off) to the fully exposed position (beam on) and during retraction into the safe. As a result the total radiation dose delivered during each treatment cycle is equal to the prescribed dose plus the transit dose component. The transit dose is the dose delivered during the proportion of the transit time for which the source is exposed. However, the transit dose is not accounted for by the machine internal timer and this has to be determined separately as the timer error can significantly influence the response of the detector (IAEA TRS 398, 2000). As also noted in TG-21 protocol (AAPM, 1983), ^{60}Co units may have a non-linear relationship between dose per unit time and time, particularly for short exposure times and it is recommend that appropriate corrections should be made. As new or high dose rate sources utilise short exposure times, the transit dose becomes a significant aspect so the dose rate of the machine has to be corrected periodically with respect to the shutter effect for accurate delivery of treatments (AAPM TG-40, 1994).

Since the transit dose (depending on its magnitude) may affect clinical outcome, it is relevant to determine the timer error as this time is a measure of transit dose component for ^{60}Co teletherapy units (Kinhikar et al., 2007). The timer error can be determined by utilising the graphical solution of zero exposure on a response-time graph where relative measurements of integrated charges are taken for different amounts of time. The measurements are then fitted linearly and extrapolated to zero response (or the so-called zero exposure). The intercept on the time axis equals the timer error. Alternatively, the timer error (τ) can be computed mathematically from the multiple exposure technique given by equation:

$$\tau = (R_m - R_s)t / (mR_s - R_m) \quad \textbf{(A1)}$$

where two exposures of integrated charges are collected at the same bias voltage, a single exposure, R_s in a set time t, and a multiple exposure, R_m in the same time, but split into m short exposures of time t/m each, where $2 \le m \le 5$. In this study, three short exposures (i.e., $m = 3$) were made in a total time of six minutes (i.e., $t = 6$ minutes resulting in $t/m = 2$ mins).

Table A1: Values of the single and multiple exposures including timer error

Detector	Response of detector (nC)		Timer error (minutes)
	R_s	R_m	
0.6 cc ion chamber	62.32	62.58	0.01
Diamond probe	8362.0	8393.0	0.01

Presented in Table A1 are the measured values of R_s and R_m for the ion chamber and diamond probe together with the timer error computed from Eq. (A1). The timer error computed for each detector using both the graphical solution of zero exposure (Fig. A1) and the multiple exposure technique gave the same value of 0.01 minute. If the sensitivity of the diamond sensor had been influenced by a trapping and de-trapping mechanism due to the effect of ambient light causing it to be unstable, then the response of the diamond probe could have deviated from linearity and the value of the timer error could have been different.

The multiple exposure technique which employed two different irradiation regimes for the measurements of integrated charges (R_s and R_m) for the timer error determination physically means that if the detector response for one measurement regime differs from the other with the measurements taken for the same amount of time, then there is an end effect (Ade, 2009), as the presented results demonstrate (Table A1). Clinically, the disparity in response means that if a ^{60}Co teletherapy treatment delivery is interrupted, say '*m*' times, or fractionation treatment is being considered (i.e., the treatment is being delivered in a large number of small fractions with a high dose rate source rather than in a single large fraction with a low dose rate source) then such an interruption or fractionation regime may systematically affect dosimetry if the end effect is considered significant.

A.3 Output factors (*OF*s)

For high-energy beams delivered by clinical linear accelerators, *OF*s are used for the determination of monitor units whereas for ^{60}Co teletherapy units, they are used to calculate treatment time. In this study, *OF*s for clinical photon beams for a given source-axis distance (SAD) are defined as the ratio of the charge measured at a reference depth of 4.4 cm (5 cm water equivalent) in phantom for a set field size to that at the same depth for a 10x10 cm^2 reference field. That is,

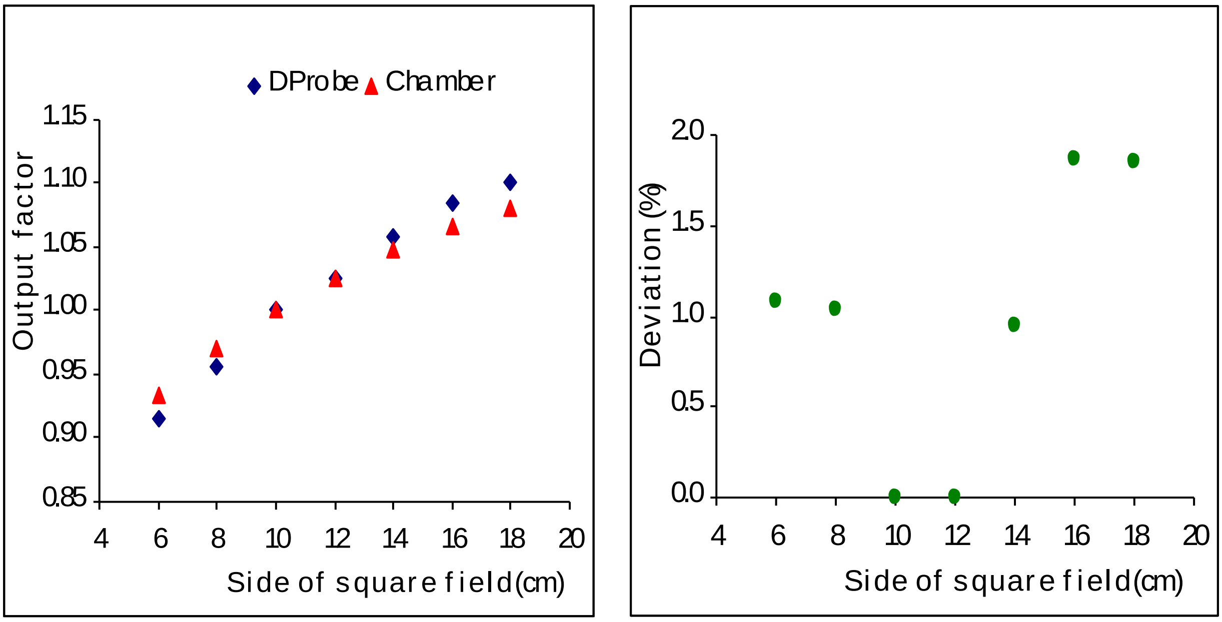
$$OF = M(d_{ref}, f)/M(d_{ref}, f_o) \quad \textbf{(A.2)}$$

where $M(d_{ref}, f)$ and $M(d_{ref}, f_o)$ are the charge readings recorded for a square field of size f and f_o is the reference 10x10 cm^2 field, respectively.

Illustrated in Fig. A2 (a) are the *OF*s determined with the diamond probe at 80 cm SAD compared with data taken with the ion chamber for various square fields (6x6 cm^2 to 18x18 cm^2), defined by photon jaws alone in a similar manner as reported by Ciacaglioni et al. (2012). The percent deviation (modulus) between the *OF*s measured with the two detectors is shown in Fig. A2 (b). The results demonstrate that the *OF*s determined with the diamond probe agree favourably with measurements taken with the ion chamber within 2%.

A.4 Tissue-maximum ratios (TMRs)

Dosimetric calculations for high-energy radiotherapy beams utilise either SSD or SAD techniques or both (Khan, 2003). Whereas *PDD* is the quantity of choice for dosimetric calculations involving SSD techniques, *TMR* is a suitable parameter for calculations that involve SAD techniques.



(a) (b)

Figure A2: Output factors for various square fields (a) and percent deviations between the output factors (b) measured with the diamond probe and 0.6 cc Farmer chamber.

As Fig. A3 demonstrates, and stated in Eq. A3, for a given field size, f_d, *TMR* is defined as the ratio of the dose on the central axis of the radiation beam at a given point in phantom to the dose at the same point at the reference depth of dose maximum, d_{max}. That is,

$$\boldsymbol{TMR\ (d, f_d) = D_d/D_{dmax}} \qquad \textbf{(A.3)}$$

For ^{60}Co teletherapy radiation, d_{max} equals 0.5 cm in water (0.44 cm Perspex equivalent). Figure A4 (a) shows a plot of ^{60}Co *TMR*s as a function of phantom depth for a 10 x 10 cm^2 field measured with the diamond probe (DProbe) at 80 cm SAD. Also shown on the plot is reference data for comparison. The percent deviation between the data taken with the probe and reference is demonstrated in Fig. A.4 (b). A maximum deviation of 1.5% was obtained.

A.4 Conclusion

The presented results for the measurements of linearity of response, timer error, *OF*s and *TMR*s taken with the synthetic diamond probe agree favouravbly with data recorded with reference detectors. This strongly suggests that the synthetic diamond probe is a potential candidate for the clinical dosimetry of ^{60}Co teletherapy radiation.

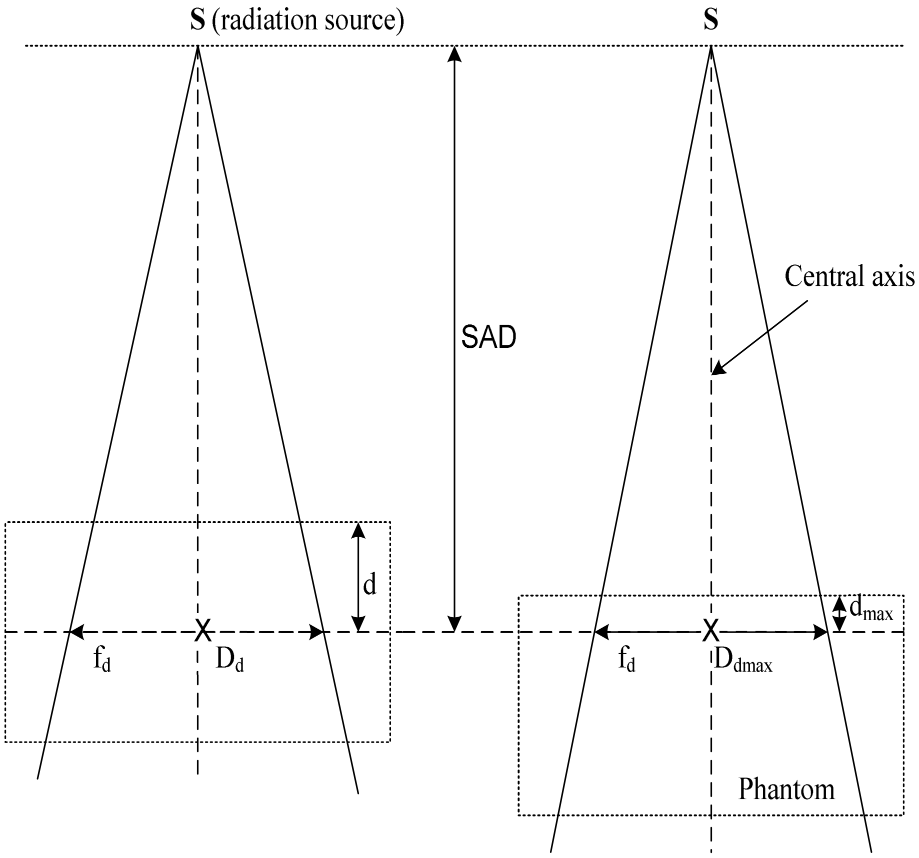
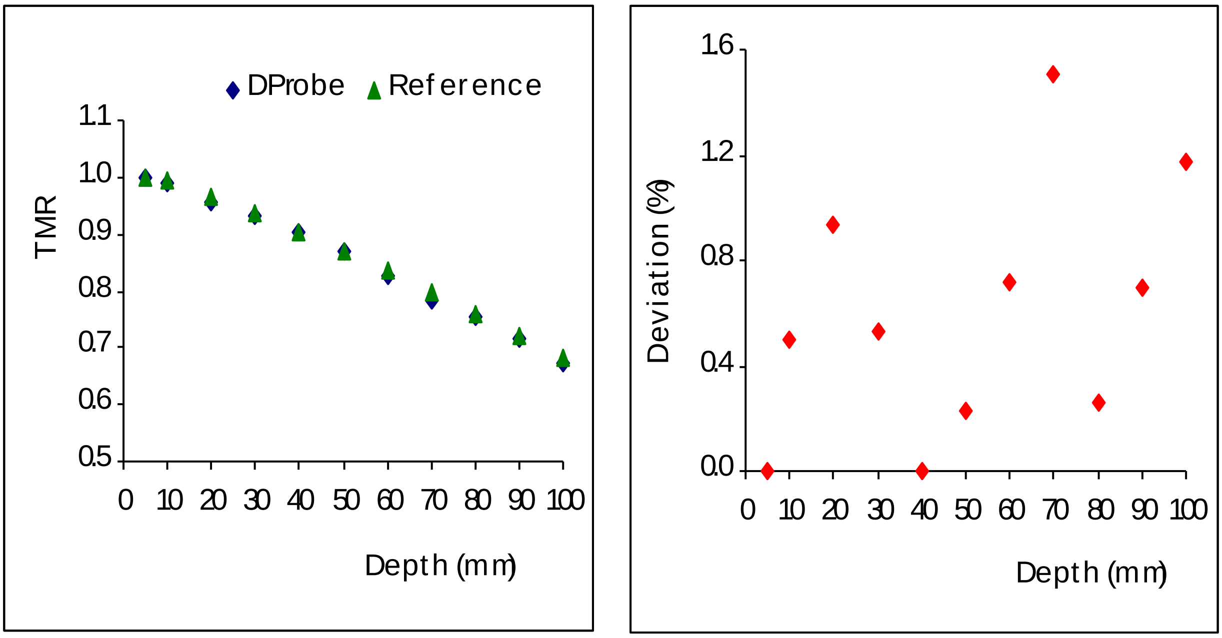


Figure A3: A schematic illustrating the definition and measurement geometry of TMR.



(a) (b)

Figure A4: ^{60}Co *TMR*s as a function of depth (a) and deviations between the *TMR*s (b) measured with the diamond probe and a reference. Reference data taken from Khan (2003).

APPENDIX B

In this study, a measuring accuracy of ±2% was considered in order to evaluate the significance of the variation of Δ on beam energy and bias voltage. It was claimed that with this tolerance and considering a Δ value of 1.02 (which gives a 2% deviation from linearity), the ICRU (1976) overall ±5% margin can be achieved even when the dose rate is varied by a factor of 10. The justification of this claim is provided below.

The following information is taken into account:

- Percent depth dose (*PDD*) is defined as the ratio, expressed as a percentage, of the absorbed dose at any depth d, to the absorbed dose at the depth of dose maximum, d_{max}, that is,

  $$PDD = [D_d)/D_{dmax})] \times 100 \qquad \text{(B1)}$$

- The Laub (1997) expression for dose rate dependence correction for relative dose measurements is:

  $$D_{rel}(d) \rightarrow [D_{rel}(d)]^{1/\Delta} \qquad \text{(B2)}$$

  where $D_{rel}(d)$ is the relative dose measured with a diamond detector at the depth of measurement d, and Δ is the dose rate linearity index;

- For a radiation detector whose response does not vary with dose rate, $\Delta = 1.00$;
- When the dose rate is varied by a factor of 10, $D_{dmax} = 10D_d$.

Now for PDD, Eq. (B2) may be expressed as:

$$PDD = [D_d/D_{dmax}]^{1/\Delta} = [D_{dmax}/D_d]^{\Delta} \qquad \text{(B3)}$$

Then, for $D_{dmax} = 10D_d$ and $\Delta = 1.02$,

Eq. (B3) becomes: $PDD = (10)^{1.02} = 10.47$

But for $\Delta = 1.00$, $D_{dmax}/D_d = 10$

Therefore, the uncertainty in dose determination = $\left[\left(\frac{10.47-10}{10}\right) \times 100\right] = 4.7\%$

Similarly, for $\Delta = 0.98$ (which also gives a 2% deviation from linearity),

The uncertainty in dose determination = -4.5%.

It is clear from the analysis that if the deviation of Δ from linearity is within 2% and the dose rate is varied by a factor of 10, the ICRU (1976) overall ±5% uncertainty can be achieved. Therefore, if the variation of Δ with beam energy is within 2%, then a single value of Δ could be used for various beam energies within a given clinical range.

APPENDIX C

PUBLICATIONS, PATENTS AND CONFERENCE PRESENTATIONS

C.1 Publications and submitted Papers

1. **Ade, N**., Nam, T.L., 2015. The influence of defect levels on the dose rate dependence of synthetic diamond detectors of various types on exposures to high-energy radiotherapy beams. Radiat. Phys. Chem. **108**, 65.
2. **Ade, N**., Nam, T.L., Derry, T.E., Mhlanga, S.H., 2014. The dose rate dependence of synthetic diamond detectors in the relative dosimetry of high- energy electron therapy beams. Radiat. Phys. Chem. **98**, 155.
3. **Ade, N**., Nam, T.L., Mhlanga, S.H., 2013. An evaluation of some pertinent parameters that influence the dosimetric performance of synthetic diamond detectors. Radiat. Phys. Chem. **86**, 42.
4. **Ade, N**., Nam, T.L., Assiamah, M., 2012. A synthetic diamond probe for both low-energy mammography X-rays and high-energy electron therapy beams. Radiat. Phys. Chem. **81**, 232.
5. **Ade, N**., Nam, T.L.. The influence of detector size relative to field size in small-field photon-beam dosimetry using synthetic diamond crystals as sensors. *Submitted in March 2014 to Radiation Physics and Chemistry*.

C.2 Patents

1. Nam, T.L., **Ade, N.** 2011. Improved Multi-Purpose Ionizing Radiation Detector. SA Patent. 2011/07889.
2. Nam, T.L., **Ade, N**. “Radiation Probe”, Functional Design Applications: SA Patent registered (F2012/02184); EU registered (002 239 889-001); China accepted (2013 302225 167); Japan accepted (2013-012009); US pending (FD29/456,332).

C.3 Conference Presentations

1. **N. Ade** and T.L. Nam. “Dosimetric characterization of synthetic diamond crystals of various types and sizes under small-photon beam conditions.” 59th Annual Conference South African Institute of Physics (SAIP), 7-11 July, 2014, University of Johannesburg.
2. **N. Ade,** T.L. Nam, S.H. Mhlanga. “The variation of dose rate dependence parameters of synthetic diamond detectors with electron energy.” 58th SAIP Annual Conference, 8-12 July, 2013, University of Zululand.”

3. **N. Ade** and T.L. Nam. **"**Diamond as a potential material for medical applications." Wits 4th Cross-Faculty Postgraduate Symposium. Wits Professional Development Hub, 19th and 22nd October, 2012.
4. **N. Ade**, T.L. Nam and S.H. Mhlanga. "Performance Evaluation of HPHT and CVD Diamond Detectors with Mammography X-rays and Electron Therapy Beams: Pre-irradiation and Dose Rate Dependence." SAAPMB 2012 Conference, 17-21 September 2012, Radisson Blu Hotel, Port Elizabeth.
5. **N. Ade**, T.L. Nam and S.H. Mhlanga. "Effects of impurities and defect levels on the performances of synthetic diamond crystals when used as radiation sensors for medical applications." 57th SAIP Annual Conference 9-13 July 2012, University of Pretoria.
6. **N. Ade** and T.L. Nam. "Dosimetric response of synthetic diamond crystals of various types to diagnostic mammography X-rays and electron therapy beams." The 6th International Conference of the Africa Materials Research Society (Africa MRS), 11-16 December, 2011, Victoria Falls, Zimbabwe.
7. **N. Ade**, T.L. Nam and M. Assiamah. "A synthetic diamond probe for both low-energy mammography X-rays and high-energy electron therapy beams." 56th SAIP Annual Conference, 12-15 July 2011, Centurion – Pretoria.
8. **N. Ade**, T.L. Nam and M. Assiamah. "A Novel Tissue-Equivalent Synthetic Diamond Probe for Medical Dosimetry." 50th Annual SAAPMB/SARPA Congress, 19-21 September, 2011, Centurion – Pretoria.

References (Chapter Nine and Appendix A)

AAPM TG-21, 1983. A protocol for the determination of absorbed dose from high energy photon and electron beams. *Med. Phys.* **10**, 741.

AAPM TG-40, 1994. Comprehensive QA for radiation oncology. *Med. Phys.* **21**, 581.

Ade, N., 2009. Transit dosimetry in ^{192}Ir high dose rate brachytherapy. MSc Research Report, University of the Witwatersrand, Johannesburg.

Assiamah, M., 2004. Dosimetric techniques for mammography mass screening programs. *PhD Thesis, University of the Witwatersrand, Johannesburg***.**

Assiamah, M., Nam, T.L., Keddy, R.J., 2007. A synthetic diamond probe for low-energy X-ray dose measurements. *Appl. Radiat. Isot.* **65**, 545.

Balducci, A., Macro Marinelli, Milani, E., Morgada, M.E., Prestopino, G., Scoccia, M., Tucciarone, A., Verona-Rinati, G., 2005. Trapping-detrapping defects in single crystal diamond films grown by chemical vapor deposition. *Appl. Phys. Lett.* **87**, 222101.

Bampton, F.K., 1976. A medical application for radiosensitive diamonds. *Ind. Diamond Rev.* **36,** 55.

Barnett, E., MacKenzie, M., Fallone, B., G 2005. IMRT point dose measurements with a diamond detector. *Radiol. Oncol.* **39**, 71.

Bergonzo, P., Tromson, D., Descamps, C., Hamrita, H., Mer, C., Tranchant, N., Nesladek, M., 2007. Improving diamond detectors: A device case *Diamond Relat. Mater.* **16**, 1038.

Betzel, G.T., Lansley, S.P., Baluti, F., Reinisch, L., Meyer, J. 2010. Operating parameters of CVD diamond detectors for radiation dosimetry. *Nucl. Instrum. Methods Phys. Res*. A **614**, 130.

Björk, P., Nilsson, P., Knöös, T., 2002. Dosimetry characteristics of degraded electron beams investigated by Monte Carlo calculations in a setup for intraoperative radiation therapy. *Phys. Med. Biol*. **47**, 239.

Brahme, A., Svensson, H., 1976. Phys. Med. Biol. 21, 304.

Bruzzi, M., Bucciolini, M., Casati, M., DeAngelis, C., Lagomarsino, S., Løvik, I., Onori, S., Sciortino, S., 2004. CVD diamond particle detectors used as on-line dosimeters in clinical radiotherapy. *Nucl. Instrum. Methods Phys. Res.* A **518**, 421.

Burgemeister, E.B., 1981. Dosimetry with a diamond operating as a resistor. *Phys. Med. Biol.* **26**, 269.

Buttar, C.M., Airey, R., Conway, J., Hill, G., Ramkumar, S., Scarsbrook, G., Sussmann, R.S., Walker, S., Whitehead, A. 2000. A study of radiotherapy dosimeters based on diamond grown by chemical vapour deposition. *Diamond Relat. Mater.* **9**, 965.

Ciancaglioni, I., Marco Marinelli, Milano, E., Prestopino, G., Verona, C., Verona-Rinati, G., Consorti, R., Petrucci, A., De Notaristefani, F., 2012. Dosimetric characterization of a synthetic single crystal diamond detector in clinical radiation therapy small photon beams. *Med. Phys.* **39**, 4493.

Cirrone, G.A.P., Cuttone, G., Lo Nigro, S., Mongelli, V., Raffaele, L., Sabini, M.G., 2006. Dosimetric characterization of CVD diamonds in photon, electron and proton beams. *Nucl. Phys. B (Proc. Suppl.)* **150**, 330.

Das I.J., Diamond detector In: Rogers, D.W.O., Cyglar JE, Clinical Dosimetry Measurements in Radiotherapy. Madison, WI: *Medical Physics Publishing,* 2009. pp. 891-912.

De Angelis, C., Bucciolini, M., Viscomi, D., Marczewska, B., Onori, S., 2010. Characterization of a HPHT diamond detector for clinical applications. *Nucl. Instrum. Methods Phys. Res*. A **612**, 576.

Faggio, G., Marinelli, M., Messina, G., Milani, E., Paoletti, A., Santangelo, S., Verona-Rinati,G.,1999. Structural characterisation of ionising-radiation detectors based on CVD diamond films. *Microsystem Technologies*, **6**, 23.

Fidanzio, A., Azario, L., Venanzi, C., Pinzari, F., Piermattei, A., 2002. *Instrum. Methods Phys. Res.* A **479**, 661.

Fidanzio, A., Azario, L., Viola, P., Ascarelli, P., Capelli, E., Conte, G., Piermattei, A., 2004. *Nucl. Instrum. Methods Phys. Res*. A **524**, 115.

Fish, M.L., Massler, O., Reid, J.A., MacGregor, R., Comins, J.D., 1999. The application of photoluminescence and Raman spectroscopy of synthetic diamond. *Diamond Relat. Mater.* **8**,1511.

Galbiati, A., Breese, M.B.H., Knights, A.P., Sealy, B., Sellin, P.J., 2001. Characterisation of a coplanar CVD diamond radiation detector. *Nucl. Instrum. Methods Phys. Res*. A **466**, 52.

Gervino, G., Marino, C., Silvestri, F., Lavagno, A., Truc, F., 2010. Dosimetry with diamond detectors. *Nucl. Instrum. Methods Phys. Res*. A **617**, 230.

Górka, B., Nilsson, B., Svensson, R., Brahme, A., Ascarelli, P., Trucchi, D.M., Conte, G., Kalish, R., 2008. Design and characterization of a tissue-equivalent CVD-diamond detector for clinical dosimetry in high-energy photon beams. *Physica Medica*, **24**, 159.

Guerrero, M.J., Tromson, D., Rebisz, M., Mer, C., Bazin, B., Bergonzo, P., 2004. Requirements for synthetic diamond devices for radiotherapy dosimetry applications *Diamond Relat. Mater.* **13**, 2046.

Haryanto, F., Fippel, M., Laub, W., Dohm, O., Nüsslin, F., 2002. Investigation of photon beam output factors for conformal radiation therapy—Monte Carlo simulations and measurements *Phys. Med. Biol.* **47**, N133.

Heydarian, M., Hoban, P.W., Beckham, W.A., Borchardt, I.M, Beddoe, A.B., 1993. Evaluation of a PTW diamond detector for electron beam measurements. *Phys. Med. Biol*. **38**, 1035.

IAEA International Atomic Energy Agency. *Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry based on Standards of Absorbed Dose to water*. TRS-398, IAEA, Vienna, 2000.

International Commission on Radiation Units and Measurements (ICRU): Report no. 21, 1972. Radiation Dosimetry: Electrons With Initial Energies Between 1 and 50 MeV, Washington DC, USA.

International Commission on Radiation Units and Measurements, Determination of Absorbed dose in a Patient Irradiated by Beams of X or Gamma rays in Radiotherapy Procedures, ICRU Report **24**, ICRU, Bethesda, 1976.

Kania, D.R., Landstrass, M.I., Plano, M.A., 1993. Diamond radiation detectors. *Diamond Relat. Mater.* **2**, 1012.

Khan, F.M. The Physics of Radiation Therapy, 3rd ed. Philadelphia: Lippincott & Wilkins, 2003.

Kinhikar, R.A., Sharma, S., Upreti, R., Tambe, C.M., Deshpande. D.D., 2007. Characterizing and configuring motorized wedge for a new generation telecobalt machine in a treatment planning system. *J. Med. Phys*. **32**, 29.

Lansley, S.P., Betzel, G.T., Meyer, J., Baluti, F., Reinisch, L., Meyer, J., 2009. Investigation of the suitability of commercially available CVD diamond for megavoltage X-raydosimetry. *Nucl. Instrum. Methods Phys. Res.* A **607**, 659.

Laub, W.U., Wong, T., 2003. The volume effect of detectors in the dosimetry of small fields used in IMRT. *Med. Phys.* **30**, 341.

Laub, W.U., Kaulich, T.W., Nusslin, F., 1999. A diamond detector in the dosimetry of high-energy electron and photon beams . *Phys. Med. Biol.* **44**, 2183.

Manfredotti, C., Apostolo, G., Fizzotti, F., Lo Giudice, A., Morando, M., Pignolo, R., Polesselo, P., Truccato, M., Vittone, E., Nastasi, U., 1998. CVD diamond tips as X-ray detectors. *Diamond Relat. Mater.* **7**, 523.

Manfredotti, C., 2005. CVD diamond detectors for nuclear and dosimetric applications. *Diamond Relat. Mater.* **14**, 531.

Manfredotti, C., Apostolo, G., Fizzotti, F., Lo Giudice, A., Morando, M., Pignolo, R., Polesselo, P., Truccato, M., Vittone, E., Nastasi, U., 1998. CVD diamond tips as X-ray

detectors. *Diamond Relat. Mater.* **7**, 523.
Marczewska, B., Kupriyanov, I., Pal'Yanov, Yu., Nowak, T., Olko, P., Rębisz, M., Waligórski,
M.P.R., 2007. A study of radiation dosimeters based on synthetic HPHT diamond. *Diamond Relat. Mater.* **16**, 191.
Marsolat1, F., Tromson, D., Tranchant, N., Pomorski, M., Le Roy, M., Donois, M., Moignau, F., Ostrowsky, A., De Carlan, L., Bassinet, C., Huet, C., Derreumaux, S., Chea, M., Cristina, K., Boisserie, G., Bergonzo, P., 2013. A new single crystal diamond dosimeter for small beam: comparison with different commercial active detectors. *Phys. Med. Biol.* **58**, 7647.
Mavunda, R.D., Zakari, Y.I., Nam, T.L., Keddy, R.J., 2008. The presence of defects and their influence on the performance of CVD diamond as an α-particle radiation sensing element. *Appl. Radiat. Isot.* **66,** 1128.
Nam, T.L., Karfunkel, U., Keddy, R.J., Every, A.G., 1991. The effect of nitrogen impurity on the radiation detection properties of synthetic diamond. Radiat. Eff. Def. Solids **116**, 233.
Pickard, C.D.O., Davis, T.J., Wang, W.N., Steeds, J.W., 1998. Mapping crystalline quality in diamond films by micro-Raman spectroscopy. *Diamond Relat. Mater.* **7**, 238.
Planskoy, B., 1980. Evaluation of diamond radiation dosemeters. *Phys. Med. Biol.* **25**, 519.
Prins, J.F., 1989. Preparation of ohmic contacts to semiconducting diamond. *J. Phys. D: Appl. Phys.* **22**, 1562.
Ramkumar, S., Buttar, C.M., Conway, J., Whitehead, A.J., Sussman, R.S., Hill, G., Walker, S., 2001. An assessment of radiotherapy dosimeters based on CVD grown diamond. Nucl. Instrum. Methods Phys. Res. A **460**, 401.
Rikner, G., 1985. Characteristics of a p-Si detector in high energy electron fields. *Acta Radiol. Oncology* **24**, 71.
Schirru, F., Kisielewicz, K., Nowak, T., Marczewska, B., 2010. Single Crystal Diamond Detector for Radiotherapy. J. Phys. D: Appl. Phys. **43**, 265101.
Scott, A.J.D., Kumar, S., Nahum, A.E., Fenwick, J.D., 2012. Characterizing the influence of detector density on dosimeter response in non-equilibrium small photon fields. *Phys. Med. Biol.* **57**, 4461.
Somigliana, A., Cattaneo, G.M., Fiorino, C., Borelli, S., del Vecchio, A., Zonca, G., Pignoli, E., Loi, G., Calandrino, R., Marchesini, R., 1999. Dosimetry of Gamma Knife and linac-based radiosurgery using radiochromic and diode detectors. *Phys. Med. Biol.* **44**, 887.
Surovtsev, N.V., Kupriyanov, I.N., Malinovsky, V.K., Gusev, V.A., Yu Pal'yanov, N., 1999.

Effect of nitrogen impurities on the Raman line width in diamonds. J. Phys.: Condens. Matter **11**, 4767.

Tranchant, N., Tromson, D., Descamps, C., Isambert, A., Hamrita, H., Bergonzo, P., Nesladek, M., 2008. High mobility single crystal diamond detectors for dosimetry: Application to radiotherapy. *Diamond Relat. Mater.* **17**, 1297.

Tromson, D., Rebisz-Pomorska, M., Tranchant, N., Isambert, A., Moignau, F., Moussier, A., Marczewska, B., Bergonzo, P., 2010. Single crystal CVD diamond detector for high resolution dose measurement for IMRT and novel radiation therapy needs. *Diamond Relat. Mater.* **19**, 1012.

Van der Merwe, D.G., Keddy, R.J., 1999. Relative electron dosimetry using a synthetic diamond probe. *Radiat. Phys. Chem.* **54**, 325.

Vatnisky, S., Järvinen, H., 1993. Application of a natural diamond detector for the measurement of relative dose distributions in radiotherapy. *Phys. Med. Biol.* **38**, 173.

Westermark, M., Arndt, J., Nilsson, B., Brahme, A., 2000. Comparative dosimetry in narrow high-energy photon beams. *Phys. Med. Biol.* **45**, 685.

Whitehead, A.J., Airey, R., Buttar, C.M., Conway, J., Hill, G., Ramkumar, S., Scarsbrook, G.A., Sussmann, R.S., Walker, S., 2001. CVD diamond for medical dosimetry applications. *Nucl. Instrum. Methods Phys. Res*. A **460**, 20.

Zhu, T.C., 2010. Small Field: dosimetry in electron disequilibrium region. Journal of Physics: Conference Series **250**, 012056.