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MICRODOSIMETRY OF THERAPY ELECTRON BEAMS — MEASUREMENTS AND MONTE-CARLO SIMULATIONS

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Abstract — Microdosimetry can be an important tool in fundamental radiobiology towards an improved understanding of the primary mechanisms of radiation action. In addition, its applications in radiation protection and in clinical radiology have been of increasing importance. The variance–covariance method relates to such applications; it permits the determination of the dose averaged microdosimetric parameters in radiation fields of varying intensity. Measurements with the variance–covariance method are here reported for therapy electron beams with acceleration voltages from 5 to 20 MV. The experimental results are compared with Monte-Carlo simulations.

INTRODUCTION

Electron beams with energies ranging from a few MeV to 20–30 MeV have specific and recognised indications in radiation therapy[1] and there are several reports on microdosimetric measurements in such beams[2–6]. Most of these measurements have been made with the conventional single event technique[2–5] under conditions of drastically reduced dose rate. The dose rate reduction can be achieved only by technical experts and it excludes, therefore, measurements in clinic routine. The variance–covariance method[1] permits the determination of the dose averaged microdosimetric parameters in radiation fields of varying intensity. In the present study microdosimetric measurements were performed in therapy electron beams with acceleration voltages from 5 to 20 MV. The experimental results are compared with Monte-Carlo simulations.

MEASUREMENTS AND RESULTS

The measurements were performed in the beams of a linear accelerator (Philips SC 75-20) in the Clinic for Radiation Therapy of the University of Würzburg. The acceleration voltage of this machine can be varied from 5 to 20 MV. The dose rate in radiation therapy is usually 4 Gy.min^{-1}. The resolution of the analogue-to-digital convertors in the measurement system requires a minimum level of the variance or fluctuations between consecutive measuring intervals. This minimum amounts to a standard deviation of about 5%, and it restricted the dose rate to roughly 0.1 Gy.min^{-1} in the present experiments. Reducing the machine current by a factor of 40 raises no problem, however.

A pair of tissue-equivalent cylindrical proportional counters (height equal to diameter) with methane based tissue-equivalent gas was employed for the measurements. The geometry and construction of the detectors have been described earlier[7]. The tissue-equivalent walls are 12 mm thick. The two detectors are linked to the same gas flow system and to the same high voltage supply; any fluctuations of gas gain in the two detectors are, therefore, correlated and are — as is the case with the dose rate fluctuations — eliminated with the variance–covariance method. The proportional counters are calibrated with a collimated ^{241}Am α ray source for different gas gains.

During the measurements the two counters were placed in the centre of the radiation beam. The source to detector distance was 160 cm. At seven different acceleration voltages microdosimetric measurements were performed for a simulated diameter of 0.5 μm. Figure 1 shows an example of raw measured data, i.e. a double set of voltages, increasing step-wise in the consecutive measurement

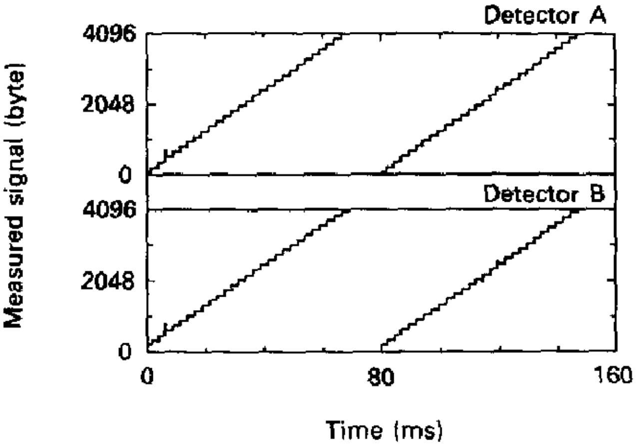

Figure 1. Raw measured data from two microdosimetric detectors in the radiation field of electron beams of 8 MV. Although the variations in the magnitude of the steps are not visible in this representation, they are the essence of the measurements.

intervals. The combined influence of the counter wall (12 mm A150) and the distance in air (160 cm) can be roughly accounted for by the simplified statement that all measurements correspond to the radiation qualities of electron beams at about a depth of 15 mm in unit density tissue.

Strong electrical noise around an accelerator is unavoidable. Figure 2 gives an example of the electric disturbance in the same condition that prevailed during the microdosimetric measurements; the only difference was, that the detectors were outside the beam. Figure 1 shows that the noise amplitude is of the same order as the amplitudes produced by electron pulses. If this noise were not removed from the measured data, the derived variance would be much larger than the actual microdosimetric variance, and erroneously large values of $\bar{y}_D$ would be obtained.

In contrast to the signals produced by electron beams (Figure 1), the noise amplitude presents both increments and decrements. Every decrement indicates electric noise. Accordingly, around each decrement 10 data pairs were cancelled. With this modification of the data the influence of electric noise is substantially reduced. The data sets are then used to derive the microdosimetric parameter dose mean lineal energy, $\bar{y}_D$.

Measurements were performed at seven different acceleration voltages. The term 'acceleration voltage' is used here rather than 'electron energy', because the electron beams at a given acceleration voltage are not monoenergetic, but have broad energy spectra(8). At each acceleration voltage measurements were made three times. The experimental results are shown in Figure 3. The full dots give the mean values of three different measurements, their error bars give the standard error.

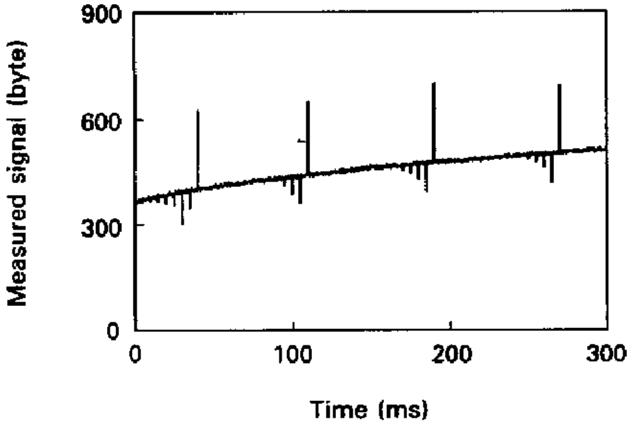

Figure 2. Influence of the electric noise from the linear electron accelerator on a control measurement outside the beam; the gradual increase is due to the leakage current.

MONTE-CARLO CALCULATIONS

To substantiate the experimental investigations the spectra of lineal energy have been calculated by means of Monte-Carlo simulations. The primary problem in a Monte-Carlo simulation is the derivation of appropriate cross sections. The main physical data that are used in the present calculations have been discussed earlier in Appendix B of Kellerer *et al* (1992)(9). This set of cross sections of water vapour was used for calculations with electrons up to 20 MeV; this appears acceptable, since the cross sections reproduce the collision stopping power up to 100 MeV with good accuracy, in comparison with data given in ICRU 37(10). At high electron energies one should, in principle, consider not only collision losses but also the deceleration of electrons in the atomic or nuclear fields. However, for small simulated target volumes the radiative losses can be disregarded, because the released energy is dissipated at appreciable distances from the particle track.

Within the detectors the methane based tissue-equivalent gas is used; its interactions with electrons can be simulated adequately by the deceleration of electrons in water vapour. The density effect is the main factor that makes the cross sections of water vapour differ considerably from those of A-150. The difference between simulation and experiment is the difference of electron numbers which enter the gas counter from the wall simulated in terms of water vapour and that consisting of A-150. The ratio of the differences is then proportional to the ratio of the collision stopping power of the two media, $L_{A150}(T)/L_{water\ vapour}(T)$, where T is the kinetic energy of the primary electrons. Accord-

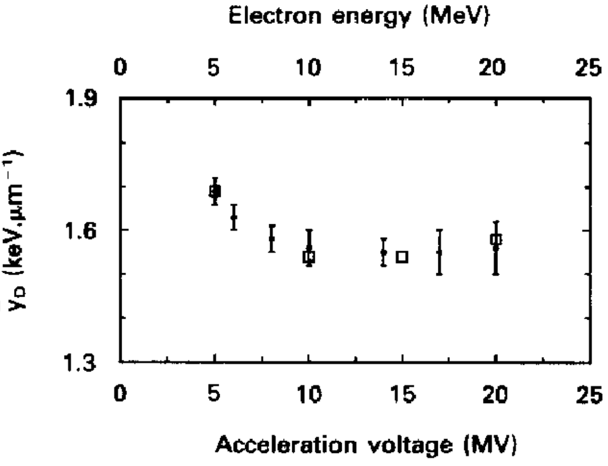

Figure 3. Dose mean lineal energy at different acceleration voltages for a simulated diameter of 500 nm. The filled dots give the mean values of three measurements, together with the standard errors. The open squares show the results of computational simulations.

ingly, the calculated event size has been modified by multiplication with this correction factor.

Since the equivalent wall thickness is 15 mm, and the site diameter is only 500 nm, almost all the computing time is used to follow the degradation processes of electrons in the detector wall. In order to reduce computing times two procedures have been adopted in the computations. The first procedure is a 'dynamic cut-off', all secondary electrons in the wall are disregarded immediately, if their energy is clearly too low to reach the reference volume. The second procedure is, to create an inchoate distribution of transfer points for a primary electron behind a slab of 15 mm, and then to sample the detector volume repeatedly with same track by using different lateral shifts. In other words, one electron simulation is used to produce several energy deposition events in the counter. This sampling was performed as if the gas cylinders of the detectors were very long; due to the guard electrodes that have each the same length as the sensitive volume, this approximation is adequate. Owing to the two simplifying procedures computation times are reduced drastically. Comparisons have shown no recognisable bias in the calculated energy spectra due to the simplifications. Computation times are, however, considerable even with the above procedures.

Results of the simulations are presented in Figure 3, together with the measured data; the agreement is good. Added calculations were performed for the same cylinder geometry, but with a smaller wall thickness of only 0.1 mm. Figure 4 summarises the results for a simulated diameter of 0.5 μm. Computational results for an electron energy of 10 MeV at different simulated site diameters are given in Figure 5.

CONCLUSIONS

Measurements in terms of the variance–covariance method can be performed in clinical radiation therapy beams under conditions achievable in practice; this removes the need for complex manipulations of the radiation sources to reduce the dose rates by a large factor. Accordingly, the method has the potential to be applied in routine quality testing of the beams.

The measurements in the high energy electron beams show a slight non-monotonic dependence of $\bar{y}_D$ on the acceleration voltage. It is not easy to identify the factors that are responsible for this dependence, and such a clarification is, therefore, not attempted in the present study. Simulation studies for the same gas volume, but with a considerably thinner wall, show merely a monotonous decrease of $\bar{y}_D$ with electron energy. The same calculations, however, with a thick wall result in the same somewhat unexpected dependence that was found in the measurements. The agreement between the measurements and the computations is, thus, sufficiently close to suggest that both the experimental results and the computational data are correct.

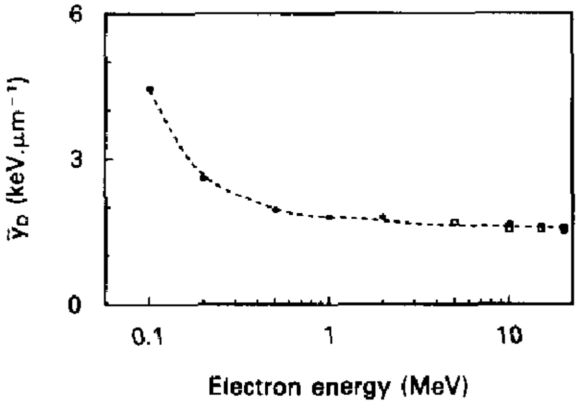

Figure 4. Dose mean lineal energy for detector wall thicknesses of 0.1 (●) and 15 (□) mm; the simulated site diameter is 500 nm. The dashed line is inserted merely for easier visualisation.

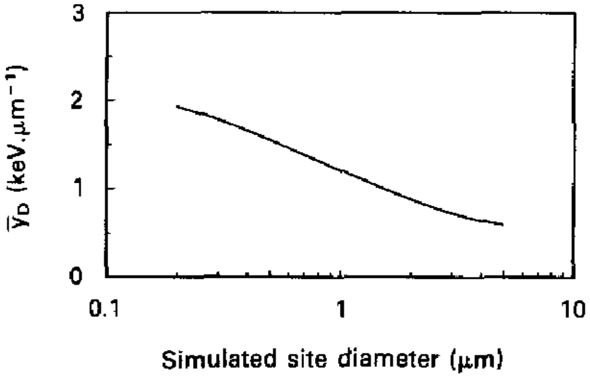

Figure 5. Dose mean lineal energy of electron with kinetic energy of 10 MeV at different simulated diameters in water vapour. The thickness of the detector wall is 0.1 mm.

ACKNOWLEDGEMENTS

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