ELEMENTAL SYNTHESIS OF REAL TISSUE MICRODOSIMETRIC RESPONSES TO HIGH ENERGY NEUTRONS: PRINCIPLES AND LIMITATIONS

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Abstract

The factors which could limit the elemental synthesis of real tissue microdosimetric responses are discussed and a determination of the response due to oxygen from 15.5 MeV neutrons is described.

Introduction

Neutron microdosimetric measurements attempt to reproduce the charged particle energy deposition in a small volume of tissue (typically 1-2 μm) by sampling that obtained in a much larger gas-filled cavity surrounded by tissue equivalent material. Unfortunately, however, it is not possible to synthesize a wall material having the same proportions of the major elements (C,H,N and O) as real tissue, the latter containing significantly more oxygen, and proportionately less carbon, than, for example, the widely used "tissue equivalent" A150 plastic. Since the cross sections for neutron induced charged particle production vary strongly both with neutron energy (particularly above 15 MeV or so) and the elemental isotopes concerned, the microdosimetric response of real tissue differs significantly from that of tissue equivalent materials. These differences at 15 MeV were shown by Caswell and Coyne [1] to be ~ 15% in integral quantities like y_D (the dose averaged lineal energy deposition), but at energies of interest in current neutron therapy (up to 65 MeV or so) data uncertainties make estimation of the resulting microdosimetric differences between real and simulated tissue very difficult to quantify.

In order to overcome this problem we proposed [2] that the microdosimetric distributions be determined on an elemental basis, eg. for C, H, O and N separately, so that the response for any particular tissue type could be 'synthesised', i.e. constructed from that of its constituent elements. In order to do so we proposed to construct counters differing only in the element of interest, and hence to find the response for that element by a difference technique. Thus, the response of hydrogen alone would be determined from counters made of polythene (CH_2) and carbon; an example of the microdosimetric response of such detectors to the p(62)Be Clatterbridge beam and the resulting hydrogen-only spectrum is shown in Fig. 1.

In this paper we consider in more detail the principles and limitations of the technique proposed.

Underlying principles

For the elemental synthesis approach to give an exact prediction of the real tissue response the shape of the microdosimetric response due to each element has to be identical both in the detectors involved in its determination and in real tissue, that is, the shape of the elemental response must be independent of the matrix in which it is incorporated. The subtraction or synthesis procedures can then be performed using simple scaling factors for differences in, for example, elemental density. There are three factors which determine whether or not this criterion is satisfied, namely

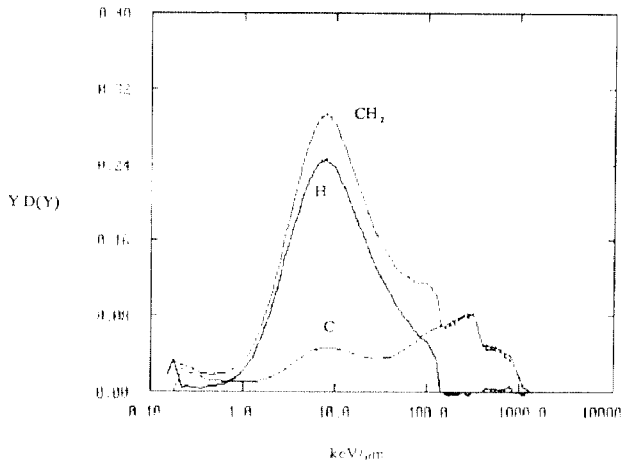

Fig. 1 Response of CH_2 and C counters to the p(62) Be neutron beam at Clatterbridge, and the resulting microdosimetric response for H only.

(a) differences between the neutron spectrum incident in real tissue and in the different detectors involved,

(b) differences in charged particle stopping powers for the matrices involved, and

(c) microdosimetric events produced by the filling gas.

We shall present a preliminary examination of the importance of each in turn.

(a) Neutron spectrum perturbation

When a neutron beam is incident on any body the resulting spatial dependence of the neutron spectrum in the body depends on the neutron scattering and absorption properties of the constituent elements and their distribution. If we then introduce a local inhomogeneity into the body the neutron spectrum will be perturbed, both in the inhomogeneity and in the surrounding medium. The magnitude and spatial extent of this perturbation depends upon how much the neutron interaction properties of the inhomogeneity differ from those of the surrounding medium. At the same time, we note that it will be the neutron spectrum in the immediate vicinity of the detector cavity which will determine the response to heavy ion, alpha particle and low energy proton events, whereas the high energy proton component will be generated through a much larger volume of the detector. Thus, the spatial dependence of the neutron flux within the counter could be important.

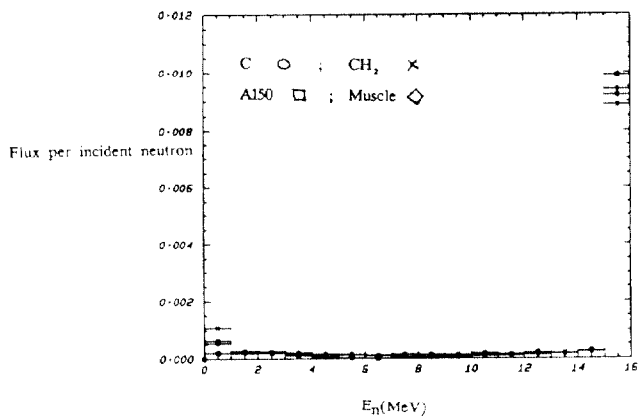

Fig. 2. Calculated neutron flux at a central cavity (per source neutron incident) in a detector having 3 cm thick walls of different materials.

In order to estimate the importance of this detector perturbation we used the Monte Carlo code MCNP [3] to calculate the neutron flux in a central cavity in polythene, carbon and A150 plastic counters having 3cm thick walls and irradiated with 15.5 MeV neutrons. These spectra are shown in Fig. 2, where they are compared with that in muscle. From this we see that there are differences ~ 10% in the 15.5 MeV neutron flux per incident neutron at the cavity. At the low energy end the differences are larger; however, calculations using narrower energy intervals show that this difference is in very low energy neutrons (< 100 keV). The differences calculated using NESTLES [4] in microdosimetric response for polythene (which showed the largest effect) is shown in Fig. 3, where we see that the shapes of the alpha particle and heavy ion components (arising from high energy neutrons) are identical, but that there are differences in the proton response. In Fig. 4 we see the corresponding figure for carbon where the differences are negligible. Note that if measurements are made in a body phantom (normally containing water as a tissue equivalent medium) then the polythene will give the least perturbation and carbon the most.

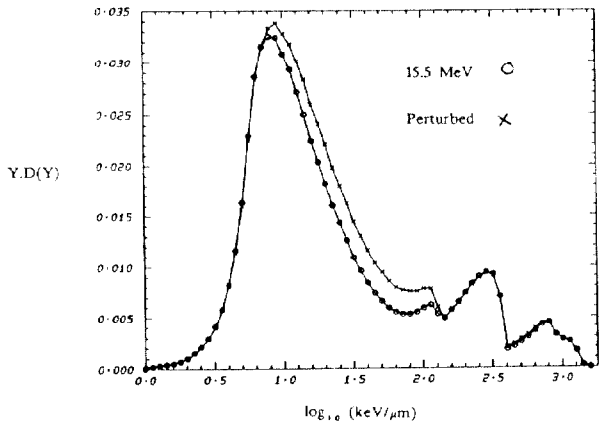

Fig. 3. Calculated microdosimetric response of a CH_2 detector exposed to 15.5. MeV neutrons with and without perturbation.

Overall, these differences will limit the accuracy of the synthesis approach, but the magnitude of the limitation remains to be determined for in-phantom measurements, ie. those of most relevance to neutron therapy.

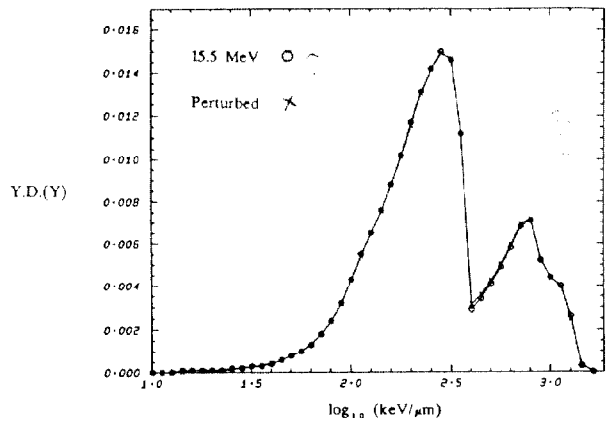

Fig. 4. Calculated microdosimetric responses of a carbon detector exposed to 15.5. MeV neutrons with and without perturbation.

(b) Stopping power effects

The shape of the microdosimetric response from a given element will be affected by the energy dependence of the stopping power for each of the charged particle types involved. Thus, in order for the elemental synthesis approach to work the stopping powers of the different media involved have to have the same shape, noting that differences in magnitude can be accommodated using a linear scaling factor. The energy dependence of the ratios of the stopping powers for protons and alpha particles in polythene and carbon are shown in Fig. 5 where we see that the ratios are constant above a few MeV, and that the maximum difference (~ 15%) occurs around the Bragg peak energies. Within the limitations imposed at low energies it is therefore possible to scale spectra for stopping power differences, as has been done when measuring elemental kerma factors [5].

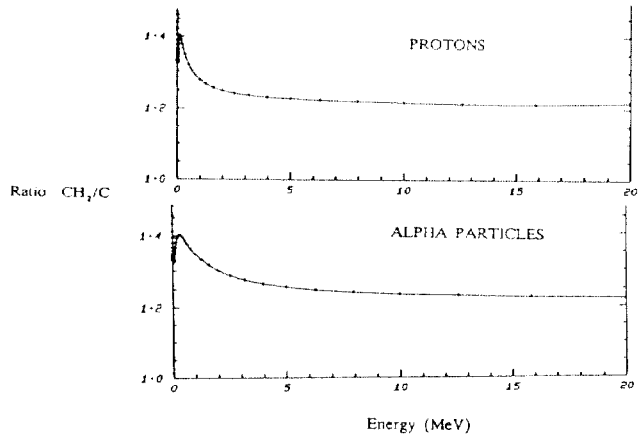

Fig. 5. Energy dependent stopping power ratios for protons and alpha particles in CH_2 and C.

(c) Gas events

Our own Monte Carlo code [6] has been used to calculate the gas events in different counters, an example of which is shown in Fig. 6, where we see that events produced in the filling gas contribute to the microdosimetric response above 100 keV μm^{-1} or so, and contribute typically 20% of the events. However, the fractions clearly depend on the gas, the gas pressure and on the wall materials. A combination of computation and experiment will be used to correct for this. Because the proportion of gas events is generally small, errors arising from these corrections should also be small, and less than other uncertainties [7].

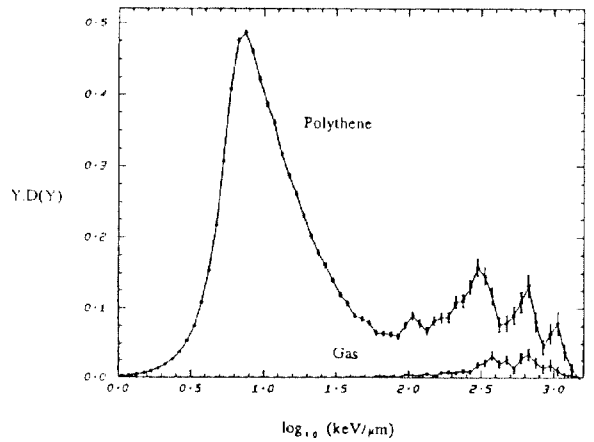

Fig. 6. Monte Carlo calculation of the microdosimetric response of a CH_4 filled (2μm) polythene counter exposed to 15.5 MeV neutrons

Experimental determination of the microdosimetric response of oxygen at 15.5 MeV

We have already noted the use of CH_2 and carbon counters to determine the elemental microdosimetric response of hydrogen (see Fig. 1).

Using the pencil grid technique described elsewhere to provide a conducting cathode [2] we have built a cylindrical, 14 cm thick walled Al_2O_3 counter with a central, spherical, cavity, and used this in conjunction with a 16 mm walled Al counter to determine the response of oxygen alone to 15.5 MeV neutrons. The spectrum from each detector is shown in Fig. 7 whilst the resulting oxygen-only response is shown in Fig. 8, where it is compared to that for a carbon counter. Interestingly we see that the shapes of the carbon and oxygen responses are similar.

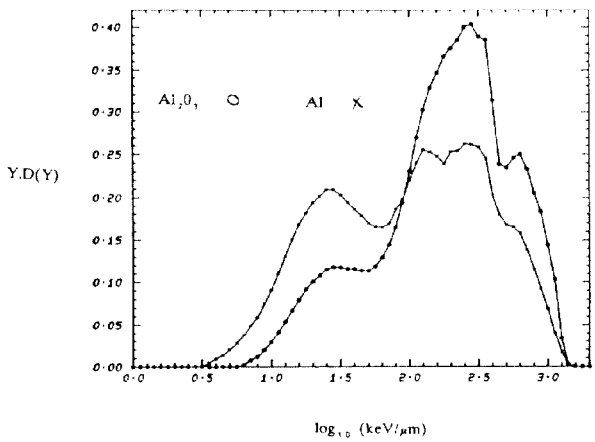

Fig. 7. Y.D(Y) spectrum for Al and Al_2O_3 microdosimeters exposed to 15.5 MeV neutrons.

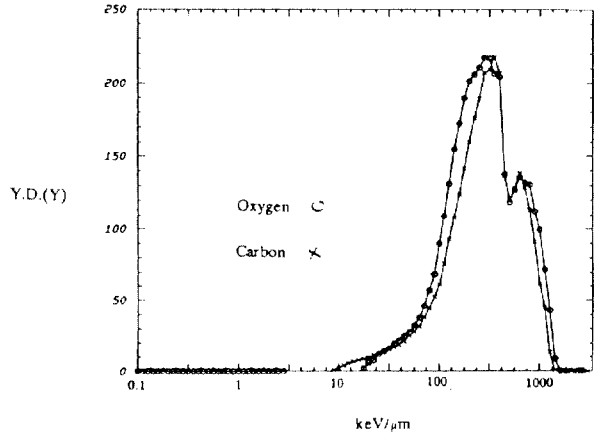

Fig. 8. Microdosimetric response of oxygen and carbon to 15.5 MeV neutrons.

Conclusions

We have examined the factors which affect the accuracy of our proposed elemental sythensis approach for determining real tissue microdosimetric responses. Of these, detector perturbation is likely to provide the greatest uncertainty. However, how the resulting uncertainties compare to with arising from the use of tissue equivalent plastic remains to be determined, the first step being to examine the importance of detector perturbation in in-phantom measurements, ie. the measurement of greatest clinical interest.

Acknowledgements

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