PULSE DOSIMETRY OF MIXED RADIATION FIELD AROUND AN ELECTRON LINEAR ACCELERATOR

Takayoshi YAMAMOTO, Keiji ODA and Masaharu KAWANISHI

The Institute of Scientific and Industrial Research
Osaka University, Suita, Osaka 565

1. Introduction

The pulse width of the output beam from an electron linear accelerator ranges from several μsec to several tens of psec, and hence the ionizing radiations emitted from a proper target are also pulsed ones and they, in general, form a mixed field of neutrons and X-rays.

In measuring such a mixed field it is desirable, though difficult, that both energy spectrum and fluence rate of the respective radiation could be determined separately.

On the other hand, there is a case where no efforts are needed for the separate measurement to attain some limited objects. For example, the total absorbed dose of some material or the net dose equivalent is an integration of the effect due to the respective radiation and the separation is not always necessary. In order to obtain the dose equivalent in a mixed field it is, in principle, necessary to identify and specify each radiation in determining the quality factor. We, however, have developed a method to evaluate the net dose equivalent approximately with an ionization chamber without identification and specification of each radiation [1].

The method is applicable to a mixed field around any particle accelerator as well as a linear accelerator so long as the fluence rate is high enough. Hence, it is suitable for evaluation of the dose equivalent when some one is exposed to a mixed radiation of high fluence rate in accident near the target or in the maze through the shielding, and it is not applicable to the case where the fluence rate of neutrons is so low as the environmental radiation outside the shielding.

2. Dosimetry in pulsed-mixed field

The absorbed dose of some material placed in a pulsed-mixed radiation field could be estimated with an ionization chamber through the cavity chamber theory by measuring the total charges liberated in a cavity. It is, however, necessary to obtain LET_∞-spectrum of the mixed field in a tissue in order to evaluate the effect of the field to the human being strictly because of the LET_∞-dependence of the quality factor. There is some approximate method escaping from this difficult procedure by proper averaging.

In general, both absorbed dose and quality factor are a function of the stopping power and the dose equivalent for a pulsed-mixed field is defined as

$$H = \int_0^{\tau_0} \left[\int_0^{\infty} QF(L)\, D(L,t)\, dL \right] dt$$

$$= \overline{QF} \cdot \int_0^{\tau_0} \left[\int_0^{\infty} D(L,t)\, dL \right] dt = \overline{QF} \cdot \mathrm{D} , \qquad (1)$$

where D is the total absorbed dose and $\overline{QF}$ is the average quality factor when the absorbed dose is regarded as the probability density function of the stopping power. Accordingly, if $\overline{QF}$ could be obtained by some method, H could be determined from eq.(1) because D is obtainable with an ionization chamber.

The quality factor is expressed as a function of the stopping power in water in the recommendation of ICRP 26. Accordingly, if in a mixed field the effective stopping power is defined as

$$\overline{L} = \frac{\sum_i \tilde{L}_i \cdot \int_0^{\tau_i} \left[\int_0^{\infty} \phi_i(E,t)\, dE \right] dt}{\sum_i \int_0^{\tau_i} \left[\int_0^{\infty} \phi_i(E,t)\, dE \right] dt} = \frac{W \tau_0 Q}{\Psi} , \qquad (2)$$

the corresponding $QF(\overline{L})$ could be determined uniquely. It is, in general, not equal to $\overline{QF}$ mathematically, but approximately there might not occur so much errors even if we put

$$\overline{QF} \cong QF(\overline{L}) . \qquad (3)$$

In eq.(2) $\phi_i(E,t)$ is the fluence rate of i-th radiation species and $\tilde{L}_i$ is the effective stopping power of the i-th one averaged over $\phi_i(E,t)$. Moreover, Ψ is the total fluence, W is the so-called W-value in a tissue-equivalent material, which is nearly constant independently of the radiation quality and τ_0 is the pulse duration, which is assumed to be equal for every pulsed radiation. Total number density of ion pairs generated in a cavity is denoted by Q.

After all, the dose equivalent is approximately expressed as

$$H \cong QF(\overline{L}) \cdot \mathrm{D} . \qquad (4)$$

Consequently, H can be evaluated from the experimental data obtained with only an ionization chamber.

3. Experimental results and discussions

The total ionic charges generated in a cavity chamber should be measured in order to evaluate the dose equivalent experimentally. Then, the charges are collected as an ionic current by applying an electric voltage between the electrodes and considerable amount of ions disappear through recombination of positive and negative ions during encounter. It is known that the higher is

the fluence rate, the more ions disappear, and hence it must be careful to estimate the generated ionic charges accurately under the field of such high fluence rate as would be considered here.

We have already established a method to obtain the ionic charges generated in an ionization chamber placed in an unknown radiation field [2]. An abreast-type ionization chamber, twin chamber with different applied voltages as shown in Fig. 1, has been developed to observe the responses to the pulsed radiation simultaneously. In Fig. 2 is shown an example of the output current shapes. Integrating the current, we obtain the collected charges with respective collection efficiency, f-value, which differs with different applied voltages. The true f-value can be determined from the graphs obtained numerically beforehand [2] by taking a ratio of those collected charges and the true generated charges can also be obtained.

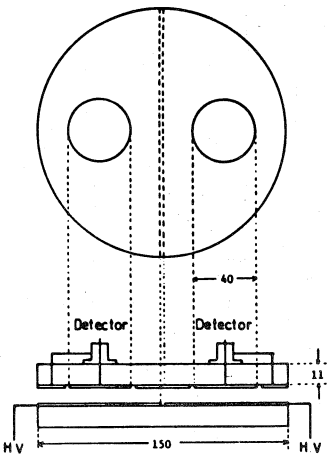

Fig. 1. Abreast-type ionization chamber.

The total fluence Ψ can approximately be obtained without applying an electric voltage to the chamber. Then, integrating the primary current consisting mainly of photo- and Compton-electrons due to pulsed X-rays, we can obtain the primary electron fluence, which is nearly equal to Ψ. Then it is assumed that the recoil proton current is negligible compared with the electron current. Accordingly, this method cannot be applied to the neutron-rich mixed radiation field, where the primary electron current becomes cancelled by the recoil proton current.

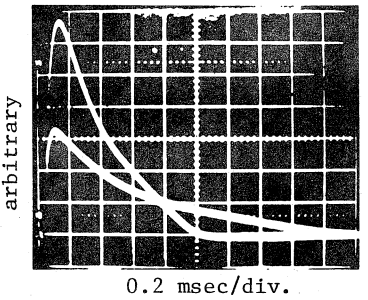

Fig. 2. Output current shapes of the abreast-type ionization chamber.

After all, the effective stopping power $\overline{L}$ and the dose equivalent H could approximately be obtained if the primary charged-particle fluence Ψ and the total number density Q is measured with an ionization chamber.

In fig. 3 is shown an example of observed mixed field with a chamber, where the angular dependence of the generated charge is shown. In general, the high-energy X-rays are almost generated in the forward direction, but neutrons are generated isotropically. Accordingly, if both radiation yields are controlled, the angular dependence would become different each other. In case of Al-target the neutron yield is low and the signal is undetectable more than 45 degrees in the forward direction. When W-target is used, the signal is detectable even at 90 degrees because lots of neutrons are generated isotropically.

In Fig. 4 is shown the effective stopping power as a function of the electron beam energy. It remains nearly constant in case of Al-target, where the neutron yield is very low, but increases with the beam energy in case of W-target, where the neutron yield is high enough for the recoil proton to contribute to the ionization in the cavity chamber though the proton current is still much less than the primary electron current.

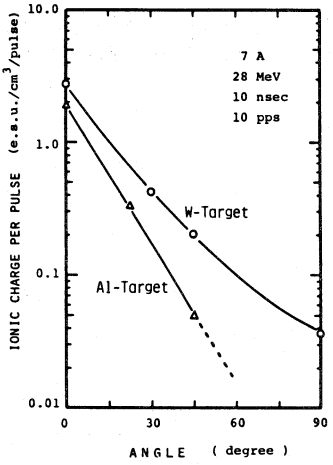

Fig. 3. Angular dependence of the charges generated by a mixed field in the chamber.

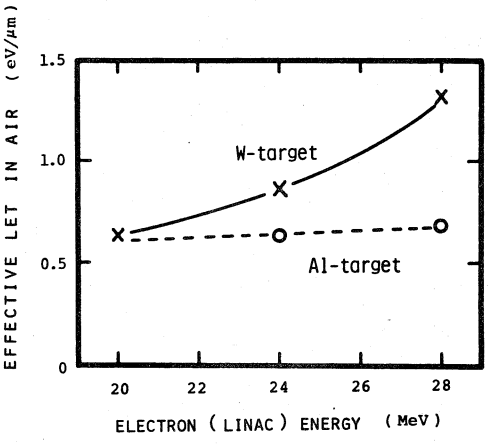

Fig. 4. Effective stopping power as a function of electron energy.

4. Conclusion

The present experiments have been made with an air-equivalent ionization chamber and only the effective stopping power of a mixed field of neutrons and X-rays in air-equivalent material has been obtained. It is, however, necessary to prepare a tissue-equivalent ionization chamber to evaluate the dose equivalent practically.

In order to express the intensity of a mixed field in one word, it might be possible to introduce, for example, mixed air-kerma from the total generated charges with proper modification of Attix' method [3].

Acknowledgements

The authors would like to express their sincere thanks to all the staffs of Radiation Laboratory of Osaka University, especially to Mr. K. Tsumori, for their efforts in stable operation of the electron linear accelerator. Thanks are also due to Mr. H. Kobayashi (Power Reactor and Nuclear Fuel Development Corp.) for his contribution to this work when he was one of the collaborators.

References

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