MEASUREMENT OF NEUTRON DOSE EQUIVALENT IN PULSED AND MIXED RADIATION FIELD AROUND AN ELECTRON LINEAR ACCELERATOR

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ABSTRACT

In order to eliminate false pulses generated by intense burst X-rays in a neutron rem-meter exposed to pulsed and mixed radiations, three techniques have been developed for correction by anti-coincidence counting, pulse height discrimination, and multiplying a correction factor.

INTRODUCTION

In recent years, various types of particle accelerators have been utilized not only in nuclear physics, material science, chemistry but also in medicine such as radiation therapy and diagnosis. Especially, electron linear accelerators have been widely applied to medical purposes. From a viewpoint of the radiation protection, however, the neutron leakage from the machine was reported not to be negligible in spite of low electron energy. Thus, an accurate evaluation of the neutron dose equivalent (DE) around the electron linear accelerator has extensively been carried out.

For neutron measurement are used many types of dosemeters such as an activation detector, a BF_3 counter, a Rossi counter, etc. Among them, an Andersson-Braun type rem-counter[1] is one of the most prevailing dosimeters. However, two important problems still remain in its application to such a mixed field as is generated by the electron linear accelerator. One is the overestimate of the neutron DE due to generation of false pulses by intense burst X-rays, and the other is the underestimate due to the count loss in a high-fluence-rate field. In this report, some countermeasures and the means of solving these problems are discussed.

EXPERIMENTAL APPARATUS

In this experiment, a pulsed and mixed radiation field was generated by the Osaka University Pico-Second Electron Linac.[2] From a tungsten target bombarded by 28 MeV-electrons, bremsstrahlung X-rays and photo-neutrons are emitted. Both the energy spectrum and the angular dependence of the intensity of them has already been evaluated, as reported in the previous paper.[3]

A rem-counter (Studsvik, 2202D) was exposed to the radiation field. General attention in its use should be paid to the deviation of the counter sensitivity from the rem response recommended by ICRP,[4] the accuracy of the constant converting the count rate into the DE rate, and the angular dependence of the sensitivity, etc. But these problems are assumed here to be clarified, for simplicity.

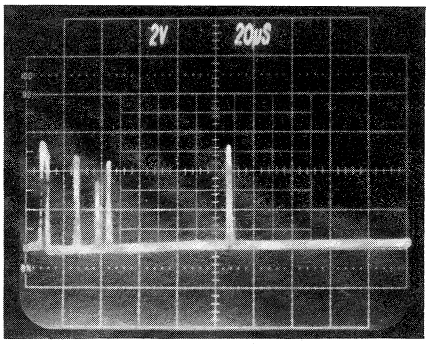

Photo 1. Output waveform of the rem-counter exposed to pulsed and mixed radiations.

SEPARATION OF FALSE PULSES DUE TO BURST X-RAYS

In the rem counter exposed to pulsed and mixed radiations consisting of neutrons and intense burst X-rays, the output signals will be generated not only by α-particles through $^{10}B(n,\alpha)$ reaction, but also secondary electrons ejected by burst X-rays. In order to clarify the difference between two types of signals, the waveform of the counter were observed with a storage oscilloscope. Photo 1 shows a typical form of the counter, which was placed at a distance of about 10 m from the target. A false pulse due to X-rays is produced synchronously with the electron beam and true pulses due to neutrons are generated after some delay. With respect to the pulse height, the former is higher than the latter in case of Photo 1. From the observation of the waveforms, the following techniques for eliminating the false pulses are considered to be promising.

Anti-coincidence counting

In this method, a gate pulse synchronized with the burst X-rays or the electron beam is electronically formed. The width of the gate should be adjusted to be 3 ∿ 4 μs. Thereby the anti-coincidence counting is carried out, after it being confirmed that true pulses does not enter into the gate.

A temporal variation of the counted number of the true pulses is shown in Fig. 1. The count rate reaches its maximum at a delay time of about 20 ∿ 30 μs, and decreases exponentially with two time constants of several tens of μs and about 100 μs.[5] The distribution is probably independent of the neutron energy, because the delay time is determined in most cases by the diffusion of thermalized neutrons rather than the slowing-down and the thermalization. So, the probability of the generation of the true pulses within the gate can be neglected. Namely, this method is effective so long as the expanded time distributions are not superposed on one another.

Pulse height discrimination

The rem-counter is designed to be insensitive to continuous X-rays with an exposure rate lower than 200 R/hr owing to the appropriate bias setting. But the counter generates a false pulse much higher than the level if exposed to intense burst X-rays. A typical of the pulse height spectrum is shown in Fig. 2, where the lower discrimination level corresponds to the 218th channel. A sharp peak in the right side is attributed to the false pulses, and the rest is due to the neutrons. In this case, the former can easily be eliminated by setting the upper discrimination level.

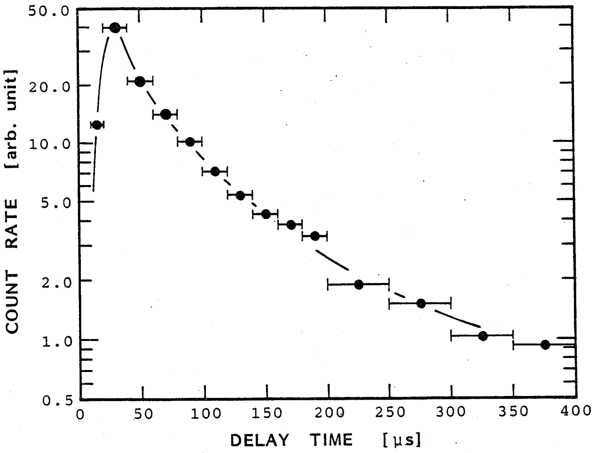

Fig. 1. Temporal variation of the pulse number counted.

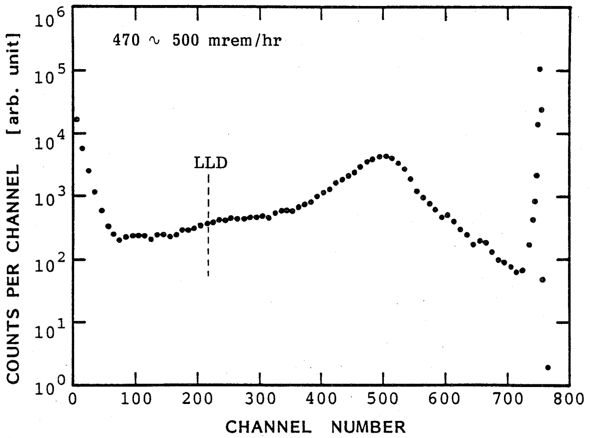

Fig. 2. Pulse-height distribution of the counter. A sharp peak is due to burst X-rays.

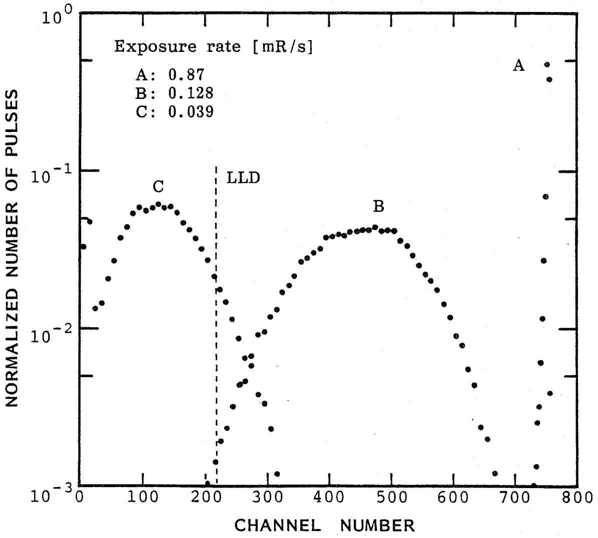

Fig. 3. Distribution of the height of pulses generated by burst X-rays. Spectra for three different exposure rates are shown.

The pulse height of the false signals, however, is not always constant value. With decreasing the exposure rate, the average pulse height of the false signals in general becomes lower as shown in the spectra B and C in Fig. 3. In such cases, the pulse height can never discriminate the true from the false pulse. Namely, in this method exists an application limit of the exposure rate.

Correction factor

If the true signals could not be discriminated from the false by the pulse heights, the correct neutron DE can be obtained by multiplying the readings of the counter by the following factor:

$$F = (R - cfP) / R \quad , \tag{1}$$

where R is the reading in mrem/hr, c is the conversion factor in (mrem/hr)/(cps), and f is the repetition rate. A variable, P, represents the probability that the height of the false pulse exceeds the lower discrimination level. The probability is considered to be a function of the exposure rate, the X-ray energy, etc., but is, for simplicity, assumed here to be determined only by the exposure per pulse. The values of P obtained from the measured spectra shown in Fig. 3 are plotted against the exposure in Fig. 4. In practice, an ionization chamber less sensitive to neutrons, for instance, a graphite chamber is combined with the rem-counter, and the correction factor is obtained from the readings of two dosemeters.

CORRECTION FOR COUNT LOSS DURING DEAD TIME

Although the false-pulse correction becomes negligible with increasing the neutron DE rate, another problem of dead-time correction arises. In general, a true number of pulses, N, generated in the proportional counter is expressed in the following formula:

$$N = \int_0^\infty \frac{n(t)}{1 - \tau n(t)} \, dt \quad , \tag{2}$$

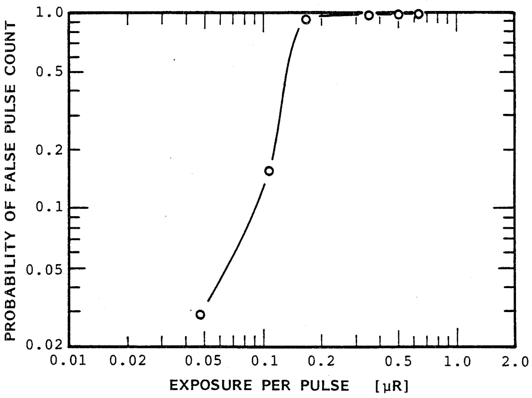

Fig. 4. Probability of the generation of false pulses is plotted against the exposure per pulse.

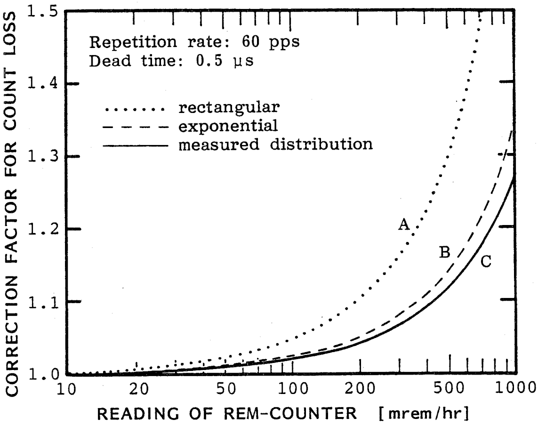

Fig. 5. A factor for dead-time correction as a function of the reading of the counter.

where $n(t)$ is the count rate and τ is the dead time of the counter. In a high-fluence-rate field, it is necessary to correct the count loss during the dead time. Figure 5 shows the calculation results of the correction factor for three temporal distribution of the counted pulses. The curves A,B and C correspond a rectangular form, a single exponential distribution proposed by Ash et al.[6] and the measured one shown in Fig. 1, respectively. The first two curves appreciably deviate from the curve C with 30 % and 6 %, respectively. It is necessary for the accurate neutron DE evaluation to apply the curve C as a factor for dead-time correction.

CONCLUSION

In this report was discussed about two important problems in evaluating the neutron DE with a prevailing rem-counter exposed to mixed radiation field around an electron linear accelerator. One is the overestimate caused by the false pulses due to intense burst X-rays. Three correction techniques based on the anti-coincidence counting, the pulse height discrimination and the calculated factor were proposed. The first technique is considered to be most effective if one can utilize electronic circuits such as a pulse generator and a scaler with a gate. Otherwise, the third one is convenient in practice. The other problem is the underestimate due to the count loss during the dead time of the counter. The correction factor was also obtained by the numerical calculations.

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