VARIATION OF RADIATION DOSES ESTIMATED ON TIME RESOLVED PHOTON ENERGY SPECTRA OF PULSED RADIATION FIELDS

Itsumasa Urabe[1], Masayasu Nagayasu[1],
Tadashi Tsujimoto[2], Katsuhei Kobayashi[2], Taka-aki Yoshimoto[2],
Yoshiyuki Nakashima[3] and Keiji Oda[4]

[1]Faculty of Engineering, Fukuyama University, Hiroshima, Japan
[2]Research Reactor Institute, Kyoto University, Osaka, Japan
[3]Suzuka University of Medical Science and Technolgy, Mie, Japan
[4]Kobe University of Mercantile and Marine, Hyogo, Japan

INTRODUCTION

Since the dose and dose rate effectiveness for low LET radiations became evident by experimental results in animals as well as theoretical considerations, determination of radiation dose due to time resolved energy spectra of low dose and high dose rate radiation fields such as pulsed radiation fields has become important for radiation protection practice(1). From this point of view, scintillation spectrometer that can be used for analysis of photon energy spectra in the energy region from 0.1 MeV to 100 MeV has been developed for estimation of radiation doses due to X- or gamma-rays induced by operation of nuclear facilities. The main purposes of this paper are: to determine the time resolved photon energy spectra of pulsed radiation fields and to describe the differences between the mean dose rates averaged over total measuring times and the dose rates averaged over pulse duration periods during which radiations are emitted by the accelerator.

EXPERIMENTAL

1.Scintillation detector and its response function

Scintillation detector was constructed with a 7.6 cmΦ x 7.6cml BaF_2 crystal and a HTV R594 photomultiplier tube with breeder resistances. A 30 x 30 response matrix of the detector was constructed by modifying energy deposition spectra calculated by the EGS4 Monte Carlo code(2) into response functions whose energy resolution was experimentally determined by using radioactive sources. Fundamental properties of the spectrometer and an accuracy of unfolded spectra were investigated by using mono-energetic gamma-rays from radioactive sources and neutron capture gamma-rays from the E-3 beam facility of the Kyoto University Research Reactor. Photon energy spectra could be estimated within an error of about 8 % of the incident photons(3).

2.Measurements

Measurements of the time resolved photon energy spectra were carried out in the workplace around the electron linac facility of the Kyoto University Research Reactor Institute. A measuring point in the experimental room was about 1.1 m away from the wall of 2.7 m in thickness which was situated between the target room and the experimental room. A Ta target of the linac was placed in the target room at 2.6 m away from the wall and, as a result, the total distance between the target and the detector was about 6.4 m. The measurements was also performed outside the experimental room near the entrance for sending in experimental equipments. The second point was situated at about 8 m away from the first measuring point.

The linac was operated with the beam energy of about 30 MeV and the beam width of about 10 ns. The repetition frequency of a bunch of electrons(an electron pulse) was 300 pulses s^{-1}. Photon energy spectra were measured in the two time regions of time interval between successive electron bunches, from 0 to 10 μs and 10 μs to 3.3 ms, by coincidence counting method using a ORTEC Digital Delay & Gate.

RESULTS AND DISCUSSION

1.Time resolved photon energy spectra

A time spectrum of photons (time series variation of photon counting rate) observed by the scintillation detector was shown in Fig.1. The abscissa of the figure shows the elapsed time (62.5ns /channel) from the incidence of a bunch of electrons into the Ta target. As is evident from the figure, most of photons were observed within a few microsecond and the maximum counting rate was approximately 10 counts s^{-1} and the total counting rate during 0 to 10 μs was almost 30 counts s^{-1}. This means that approximately one photon/ 10 electron bunches could be detected in this time period and that the distortion of energy spectrum due to chance coincidence of incident photons would be scarcely occurred here.

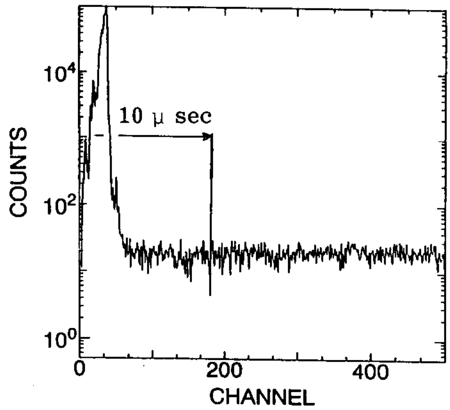

Figure 1. Time spectrum of photons observed by BaF_2 spectrometer.

Examples of photon energy spectra observed in the experimental room are shown in Fig.2. The solid and the broken histograms in Fig.2 represent the spectra measured during the former and the latter periods of the time interval between electron bunches from the linac, respectively. Since high energy photons and neutrons are considered to be generated in a few tens of nanosecond after incidence of electron bunches into the target, the photon energy spectrum shown by solid histogram seems to be mainly originated in high energy photons and their scattered ones and partly due to photons generated by neutron inelastic scattering in the wall. On the other hand, the result by broken histogram in the figure shows the energy distribution up to the energy of about 8 MeV. The higher energy part of this spectrum seems

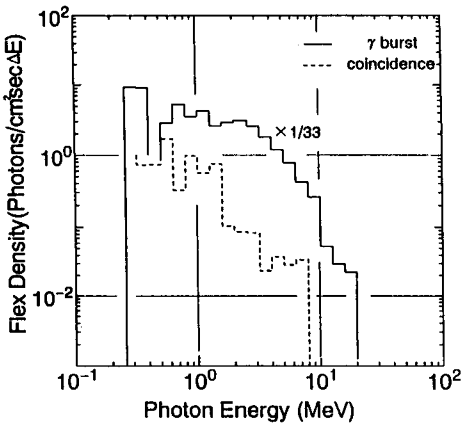

Figure 2. Time resolved photon energy spectra in the experimental room.

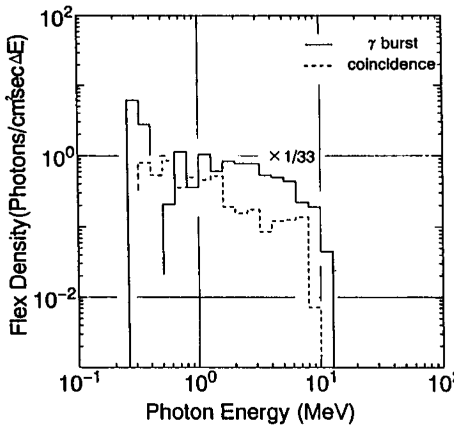

Figure 3. Time resolved photon energy spectra near the entrance of ex. room.

to be caused by neutron capture gamma-rays emitted from the surroundings of the spectrometer.

Photon energy spectra observed near the entrance to the experimental room are shown in Fig.3. It is evident from the solid histogram that the intensity of photons below 5 MeV becomes weak compared with that shown in Fig.2 and the photons more than 15 MeV do not have enough intensity to be detected by the present method. On the contrary, the broken histogram reveals us that the energy spectrum around 7 MeV which would be caused by neutron capture by the iron shutter of the entrance becomes more intensive than that in the experimental room.

2.Variation of dose rates within the interval of electron pulses

Air absorbed dose rates calculated on the energy spectra illustrated in Figs.2 and 3 are shown in table 1. The second and the third columns of the table show the absorbed dose rates given by the first intensive high energy photons and fast neutrons and those by gamma-rays from naturally occurring radionuclides and photons by slow neutron capture reactions, respectively. The mean dose rates during measurements are shown in the last column of the table. As is evident from the table, the dose rates in the former period (0 to 10μs of the pulse spacing time) are more than hundreds of times than those obtained in the later period (10μs to 3.3ms of the pulse spacing time). And, furthermore, the dose rates in the former period will show values by several times as much if the realistic high intensity pulse duration time shown in Fig.1 is taken into consideration.

Table 1. Variation of dose rates within the interval of electron pulses.
(unit:nGy/h)

time interval	0 to 10 μs	10 μs to 3.3 ms	mean
inside exp room	2.7×10^4	7.8×10^1	1.7×10^2
near entrance	8.3×10^3	8.5×10^1	1.1×10^2

In radiation protection practice, total doses are usually determined using personal dosimeters and dose rates are often interpreted as the mean doses illustrated in the last column of the table. But it is to be noted that the total doses are originated in repeated irradiation of extremely high intensity photons momentary emitted. So it may be concluded that dose rate effectiveness for irradiation by pulsed radiations with a duration less than a few nanoseconds must be investigated to get definitive information on the DDREF, though the ICRP has already recommend that the value 2 be used for the factor.

CONCLUSIONS

From the investigation stated above, conclusions are as follows:

(1) Energy spectra of pulsed photons determined by using the BaF_2 spectrometer changed remarkably with time. High intensity and high energy photons were observed within a few nanosecond after incidence of electron bunches into the target.

(2) The maximum dose rate caused by pulsed radiations became more than a thousand of times the mean dose rate averaged over the total measuring period.

REFERENCES

1. ICRP;Annals of the ICRP, ICRP Publ.60,Pergamon press,(1991)
2. W.R.Nelson and H.HIrayama;SLAC-265,(1985).
3. I.Urabe et al.;to be published.