P-3b-209

Radiation Weighting Factors for High Energy Neutron, Proton, and Alpha Particles

N. Yoshizawa[1], O. Sato[1], S. Takagi[1], S. Furihata[1], J. Funabiki[1], S. Iwai[2], T. Uehara[2], S. Tanaka[3], and Y. Sakamoto[3]

[1] Mitsubishi Research Institute Inc., Otemachi, Chiyoda-ku, Tokyo, 100-8141, Japan

[2] Nuclear Development Corporation, Kitabukuro-cho, Omiya-shi, Saitama-ken, 330-0835, Japan

[3] Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken, 319-1195, Japan

INTRODUCTION

Estimation of radiation exposure against high-energy neutron above 20 MeV is very important to radiation protection around high energy and large intensity proton accelerators. For aircrew of high-altitude flight, radiation exposure from high-energy neutron and proton has come to be an important problem (1). High energy neutron, proton, and alpha exposure must be also estimated for radiation protection concerning the astronauts staying for a long time in a space station(2).

In ICRP 60(3), the organ equivalent dose is defined as the averaged organ absorbed dose multiplied by a radiation weighting factor appropriate for the external radiation type and incident energy on the body rather than the radiation type and energy distributions in the body. The introduction of the radiation weighting factor for high energy radiation was discussed(4). For high energy neutron, proton, and alpha irradiation, several different types of radiations are produced from nuclear interaction in the body. National Council on Radiation Protection and Measurements (NCRP) defined the value of w_R for proton as 2 (5). This value is less than the half of recommended value of 5 in ICRP 60.

We have reported dose conversion coefficients about two different types of effective doses, one was the effective dose using w_R and the other one is the effective dose using $Q-L$ relationship(6,7). In this paper, we propose modified radiation weighting factors for high energy neutron, proton, and alpha particles.

EFFECTIVE DOSE AND MEAN QUALITY FACTOR FOR THE WHOLE BODY

In ICRP60, the effective dose is defined as a summation of the equivalent doses for organs, with the term for each organ multiplied by an appropriate tissue weighting factor:

$$E_{w_R} = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R} \tag{1}$$

where H_T : equivalent dose in organ T

w_T : tissue weighting factor for T (values recommended in ICRP 60)

w_R : radiation weighting factor for radiation R (also recommended in ICRP 60)

$D_{T,R}$: absorbed dose of radiation R averaged over T .

We call the above E_{w_R} calculated using w_R "the effective dose using radiation weighting factor" to distinguish from E_{Q-L} , defined later.

In the same ICRP60, it is recommended to replace the relationship given in ICRP 26(8) with a new $Q-L$ relationship (Q : quality factor, L : unrestricted linear energy transfer in water). The effective dose calculated using the $Q-L$ relationship is given by

$$E_{Q-L} = \sum_T w_T \hat{H}_T \tag{2}$$

where $\hat{H}_T$: dose equivalent averaged over organ T (diacritic mark ^ added to distinguish organ dose equivalent from equivalent dose). In order to obtain the organ dose equivalents, the energies deposited in the regions were weighted with the averaged quality factor in accordance with the methodology described in **Ref.6**.

In this study, the mean quality factor for the whole body is given by

$$\overline{Q}_{body} = \frac{E_{Q-L}}{\sum_T w_T D_T} \quad (3)$$

The difference between $\overline{Q}_{body}$ and w_R can be considered the factor that distinguishes E_{Q-L} from E_{w_R}.

METHOD OF CALCULATION

In this study, an adult hermaphroditic anthropomorphic phantom——modified MIRD5——was adopted for calculating the mean absorbed dose and the mean dose equivalent of an organ. Calculations were performed on whole-body irradiation with parallel broad monoenergetic beams incident on an anthropomorphic phantom placed in vacuum. Organ absorbed doses and organ dose equivalents were calculated by the HETC-3STEP(9) and the MORSE-CG/KFA(10) in the HERMES code system(10). In **Ref.6**, detailed method of calculation is described.

RESULTS AND DISCUSSION

Effective Dose Conversion Coefficients for high energy neutron, proton, and alpha particles have been already reported in Ref.6,7. Figure 1 plots the ratios E_{w_R} / E_{Q-L} for neutron, proton, and alpha particles. It is found large differences between E_{w_R} and E_{Q-L}.

As shown in Figure 1, E_{w_R} overestimates E_{Q-L} for neutron, proton, and alpha above 20 MeV. In ICRP60, w_R for neutron is defined as a continuous function of neutron energy as follows:

$$w_R(E_n) = 5 + 17\exp\left(-(\ln(2E_n))^2/6\right) \quad \text{(in ICRP 60)} \quad (4)$$

Siebert et al.(11) described modification of w_R to reconcile a difference between w_R and $Q-L$. Pelliccioni (4) also proposed radiation weighting factors for high energy neutron, proton, negative pions, positive pions, negative muons, and positive muons. For neutron above 20 MeV, the adjustment of w_R as a function of neutron energy E_n given by Eq. (5) will make an agreement between E_{w_R} and E_{Q-L} within 40%.

$$w_R(E_n) = 4 + 26\exp\left(-(\ln(2E_n))^2/6\right) \quad 20MeV \le E_P \le 10GeV \quad (5)$$

In Eq. (5), only two coefficients in Eq. (4) are adjusted from 5 to 4 and from 17 to 26, respectively. Modified w_R given by Eq. (5) was shown in **Fig. 2**. comparing with $\overline{Q}_{body}$.

Differences between E_{w_R} and E_{Q-L} for proton and alpha are larger than those for neutron. The main reason is that w_R for proton is 5 and alpha is 20 in ICRP 60 independent on incident energy. For proton above 20 MeV, the adjustment of w_R as a step function of proton energy E_p given by the equation (6) will make an agreement between E_{w_R} and E_{Q-L} within about 70%.

$$w_R(E_p) = \begin{cases} 2.5 & 20MeV \le E_P < 30MeV \\ 2 & 30MeV \le E_P \le 10GeV \end{cases} \quad (6)$$

Modified w_R given by Eq. (6) was shown in **Fig. 3** to compare with $\overline{Q}_{body}$. NCRP 116 (5) recommends that w_R is 2 for proton independent on its energy. Above 30 MeV, adjusted w_R in this study is equal to the value in NCRP 116. However, E_{Q-L} will underestimate E_{w_R} for proton with $w_R = 2$ below 30 MeV.

For alpha above 20 MeV, the adjusted w_R as a step function of alpha energy E_a is given by the equation (7).

$$w_R(E_a) = \begin{cases} 5 & 20MeV \le E_a < 30MeV \\ 3 & 30MeV \le E_a \le 10GeV \end{cases} \quad (7)$$

Modified w_R given by Eq. (7) was shown in **Fig. 4** to compare with $\overline{Q}_{body}$. Proposed radiation weighting factors are summarized in **Table 1.**

Table 1 Proposed Radiation Weighting Factors for High Energy Neutron, Proton, and Alpha particles

Radiation	Radiation Weighting Factor	
	ICRP60	Proposed Radiation Weighting Factor
Neutrons	5+17exp(-(ln(2En))^2/6) En: neutron energy (MeV)	4+26exp(-(ln(2En))^2/6) 20MeV≦En≦10GeV En: neutron energy (MeV)
Protons	5	2.5 20MeV≦Ep<30MeV 2 30MeV≦Ep≦10GeV Ep: proton energy(MeV)
Alpha Particles	20	5 20MeV≦Ea<30MeV 3 30MeV≦Ea≦10GeV Ea: alpha particle energy (MeV)

SUMMARY

Effective doses using w_R and effective doses using $Q-L$ relationship were compared. It was found that effective doses using w_R overestimate effective doses using $Q-L$ relationship for neutron, proton, and alpha. Modifications of w_R were proposed.

REFERENCES

1. J.W.Wilson, et al. *NASA Technical Paper* 3524, (1995).
2. National Council on Radiation Protection and Measurements *NCRP Symposium Proceedings No.3,"Acceptability of Risk from Radiation – Application to Human Space Flight,"* NCRP Publ., Bethesda, (1997).
3. International Commission on Radiological Protection *"1990 Recommendations of the International Commission on Radiological Protection,"* ICRP Publication 60, Pergamon Press, Oxford, (1991).
4. M. Pelliccioni., *Radiat. Prot. Dosim.,* **80**, 371 (1998).
5. National Council on Radiation Protection and Measurements *"Limitation of Exposure to Ionizing Radiation,"* NCRP Report No.116 NCRP Publ., Bethesda, (1993).
6. N.Yoshizawa, et al. *J. Nucl. Sci. and Technol.*,**35**, 928(1998).
7. N.Yoshizawa, et al. "*Fluence to Dose Conversion Coefficients for High-Energy Neutron, Proton and Alpha Particles*," Proc. of the 9th International Conference on Radiation Shielding, Oct.17-22,1999 Tsukuba, Japan(to be published).
8. International Commission on Radiological Protection *"Recommendations of the International Commission on Radiological Protection,"* ICRP Publication 26, Pergamon Press, Oxford (1977).
9. N.Yoshizawa et al. *J. Nucl. Sci. and Technol.,***32**,601(1995).
10. P.Cloth, et al. *KFA-IRE-EAN* 12/88(1988).
11. B.R.L.Siebert *Radiat. Prot. Dosim.*, **54**[3/4], 193 (1994).

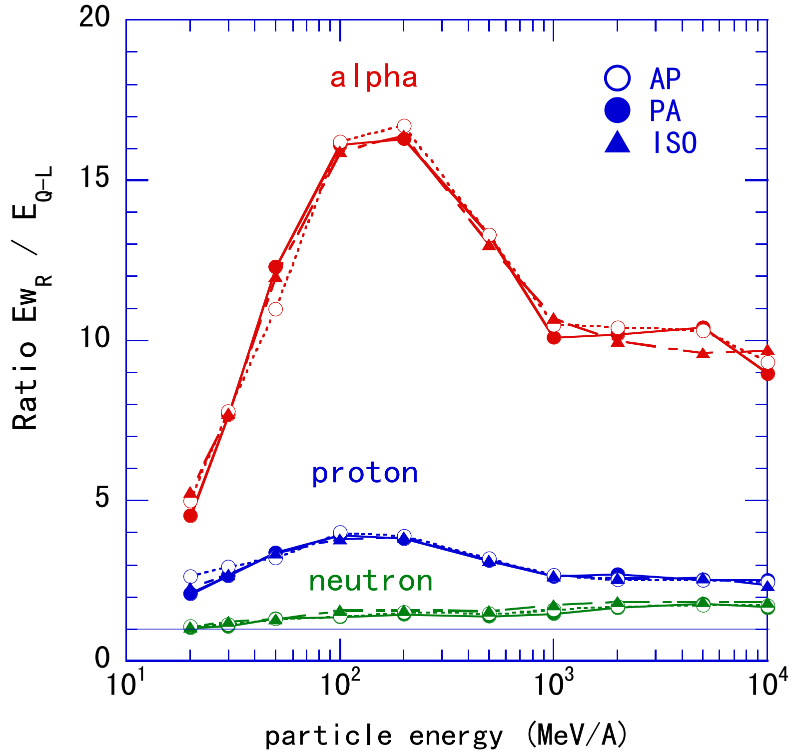

Fig.1 Ratio between Ew_R and $E_{Q\text{-}L}$ for neutron, proton, and alpha particle incident energy

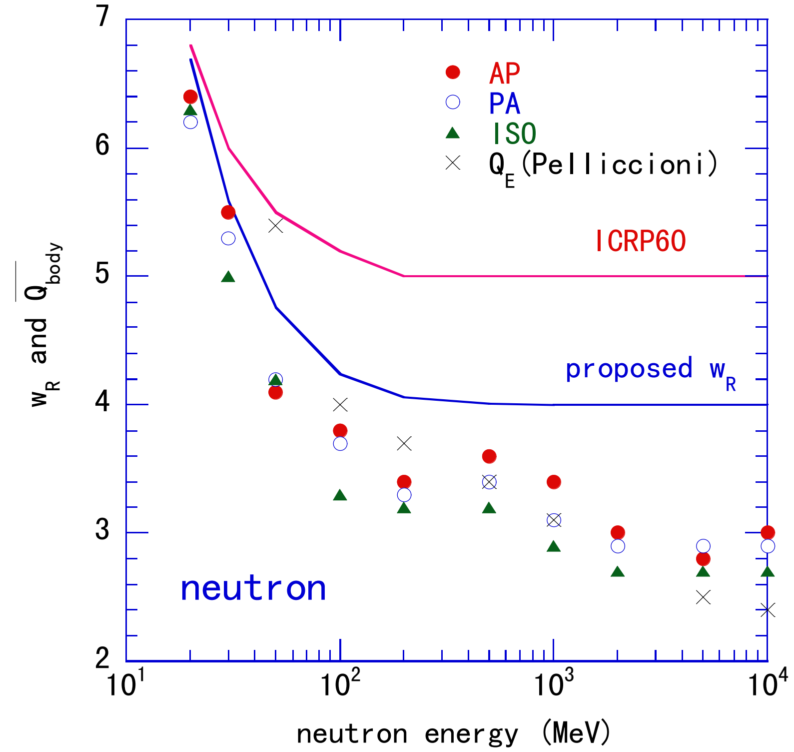

Fig.2 Mean quality factor for whole body irradiated by neutron and proposed w_R

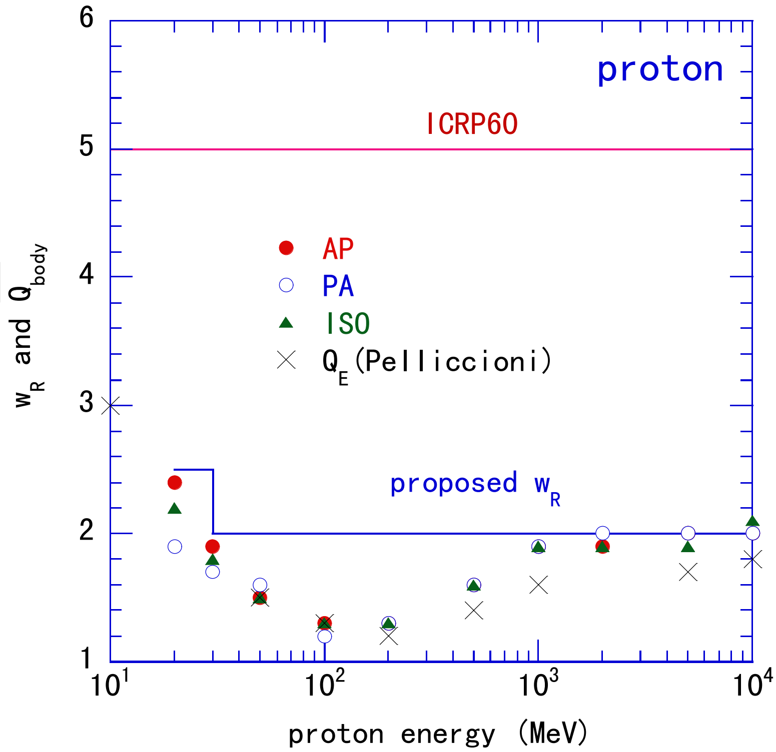

Fig.3 Mean quality factor for whole body irradiated by proton and proposed w_R

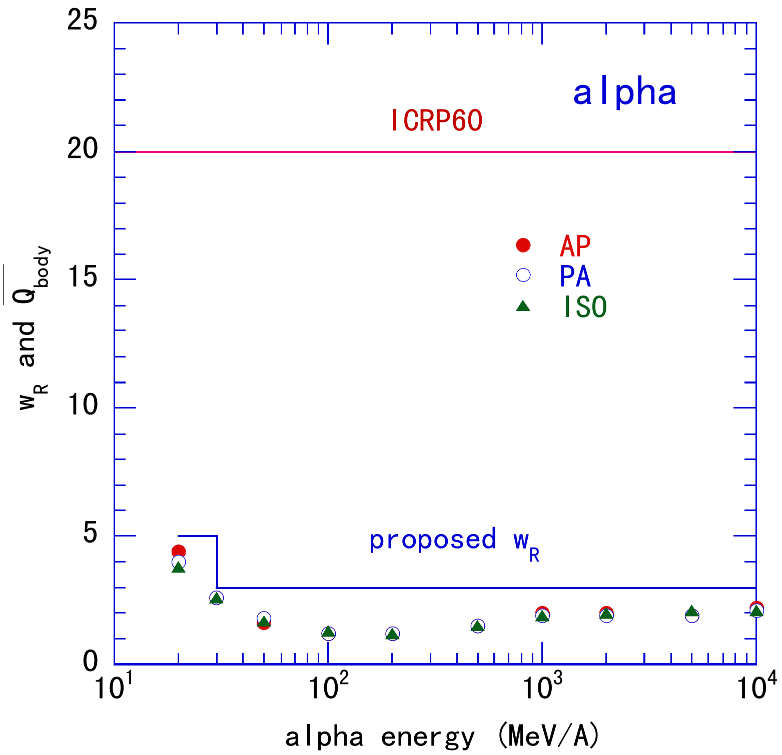

Fig.4 Mean quality factor for whole body irradiated by alpha and proposed w_R