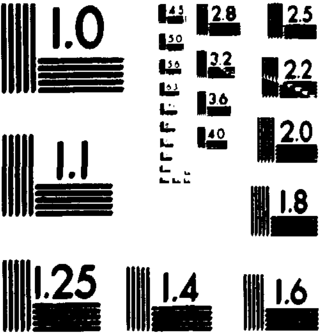

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SPECIFICATION OF FAST NEUTRON RADIATION QUALITY FROM CELL TRANSFORMATION DATA

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Abstract - Experimental data of neoplastic transformation of C3H 10T1/2 cells measured at Casaccia after neutron and X-ray irradiation have been used to determine neutron RBE values for the RSV-Tapiro fast reactor energy spectrum and for monoenergetic neutrons of 0.5, 1, and 6 MeV. In parallel, microdosimetric measurements have provided the actual lineal energy distributions and related mean parameters for the reactor radiation. From these experiments, values of the neutron quality factor were derived for the reactor neutron energy spectrum and, in turn, for the other neutron energies tested. A mathematical expression giving a smooth dependence on neutron energy was also determined for the effective quality factor in the entire energy range examined, and the results have been compared with other proposals.

INTRODUCTION

Specification of radiation quality will continue to represent a crucial aspect in the context of risk assessment, at least as long as the philosophy is retained of referring the radiological risks to a unique quantity, obtained by weighting the absorbed dose by a factor related to the quality of the radiation. This quantity, recently re-named equivalent dose (1), involves the use of radiation weighting factors, w_R, which only assume discrete values specified to be representative of the relative biological effectiveness of the different radiation types and energies in inducing stochastic effects at low doses.

The values attributed to the radiation weighting factors are regarded as broadly compatible with those of the quality factor, which is defined in a mathematical form depending on quantities such as LET or lineal energy. Therefore, ICRP publication 60 (1) recommends the use of the average quality factor at a depth of 10 mm in the ICRU sphere as an approximation for w_R in those cases where the values are not specified. In the case of neutrons, in addition to specific w_R values, ICRP also provides an empirical expression, relating the radiation weighting factor to neutron energy, which should be treated as an approximation. Actually, it has been shown that the w_R values obtained by such a formulation manifest some inconsistency in comparison with the results of effective quality factor calculations, performed using the MCNP code (2,3). In this situation, the possibility of using radiobiological data to gain direct information appeared an attractive potentiality to be exploited.

EVALUATION METHOD AND RESULTS

Data of neoplastic transformation of the C3H 10T1/2 mouse fibroblast cell line, irradiated with various doses of either fission neutrons at the

RVS Tapiro reactor at Casaccia (4) or monoenergetic neutrons at TNO, Rijswijk (5), have recently been obtained by our group. These experiments did not show any significant difference in cell transformation induced by split doses compared to single doses, and therefore the results obtained in both irradiation modes have been combined for the present evaluation. In parallel, microdosimetriy measurements have provided experimental distributions of the relevant microdosimetric quantities and the related average parameters for the Tapiro reactor radiation field (6).

The values of the frequency per unit dose of neoplastic transformation of C3H 10T1/2 cells induced by neutrons of various energies was obtained from a linear fit of the experimental dose-effect data, and are presented in the Table, second column. The lowest neutron energy of 0.23 MeV corresponds to the average energy of the fission spectrum neutrons from the reactor at the irradiation position, as deduced from the neutron fluence spectrum. This value was confirmed by a comparison of the experimental dose averaged lineal energy for the neutron component of the Tapiro reactor radiation field, $\bar{y}_{D,n}$, with the calculated values as a function of neutron energy (7).

On the basis of the microdosimetry measurements, this value of $\bar{y}_{D,n}$ was estimated as 74 keV/μm for a 1 μm spherical diameter. This is in line with the results of single event spectra calculations, in terms of y distributions, assuming the neutron fluence spectrum of the reactor as the primary field characterization (6). From this value the quality factor at Ef=0.23 MeV was obtained using the expression

$$Q(Ef) = 0.3\, \bar{y}_{D,n}$$

which is a good approximation below 100 keV/μm (8), yielding the value Q(0.23)=22.2. By assuming that the quality factor is proportional to the linear coefficient, α, the values of Q at the other neutron energies of the Table were readily obtained as

$$Q(E_n) = Q(Ef)\frac{\alpha(E_n)}{\alpha(Ef)}.$$

and the results are reported as Q (exp) in the last column of the Table, and shown as full circles in the Figure.

As can be seen, these values are in better agreement with the values of the effective quality factor calculated by Leuthold et al (3) using the MCNP code, shown as a dotted line, than with the w_R values obtained using the expression suggested in ICRP 60 (dashed line). Nevertheless, the possibility of constructing a smooth dependence of the radiation weighting factor on neutron energy is interesting from a practical viewpoint. Therefore, a fit of the experimental values was carried out using a similar expression for w_R, namely

$$w_{R,exp}(E) = 5 + 17\, e^{-(\ln(aE))^2/b}.$$

This yielded for the coefficients the values a=3.2 MeV^{-1} and b=4.3, and with this expression the dotted line shown in the Figure was obtained. The results indicate that in the neutron energy range of the experimental points, the $w_{R,exp}$ curve and the results of the MCNP calculations are in substantial agreement, while the ICRP recommended curve is mostly higher by as much as 50%.

CAPTIONS

Table. Experimental values of the linear coefficient for the transformation frequency of C3H 10T1/2 cells exposed to various neutron radiation qualities, and corresponding quality factors (see text).

Figure. Effective quality factor as a function of neutron energy as proposed by different sources. Full circles are from the present work, full line is from the expression in the text, dashed line from ICRP 60(1), dotted line from ref. (3).

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The author is indebted to Dr. G. Leuthold for providing tables of the numerical values of the quality factor calculations performed at GSF, Neuherberg. It is also his intention to acknowledge the interest expressed by Dr. Georg Burger for these aspects of radiation dosimetry in a discussion held just a few days before his tragic departure. Therefore, the author wishes to dedicate this work, though very simple, to the memory of this eminent scientist and very good friend. This study was supported by the Commission of the European Communities, Radiation Protection Programme, Contract Bi6-004-I, contribution n. 2636.

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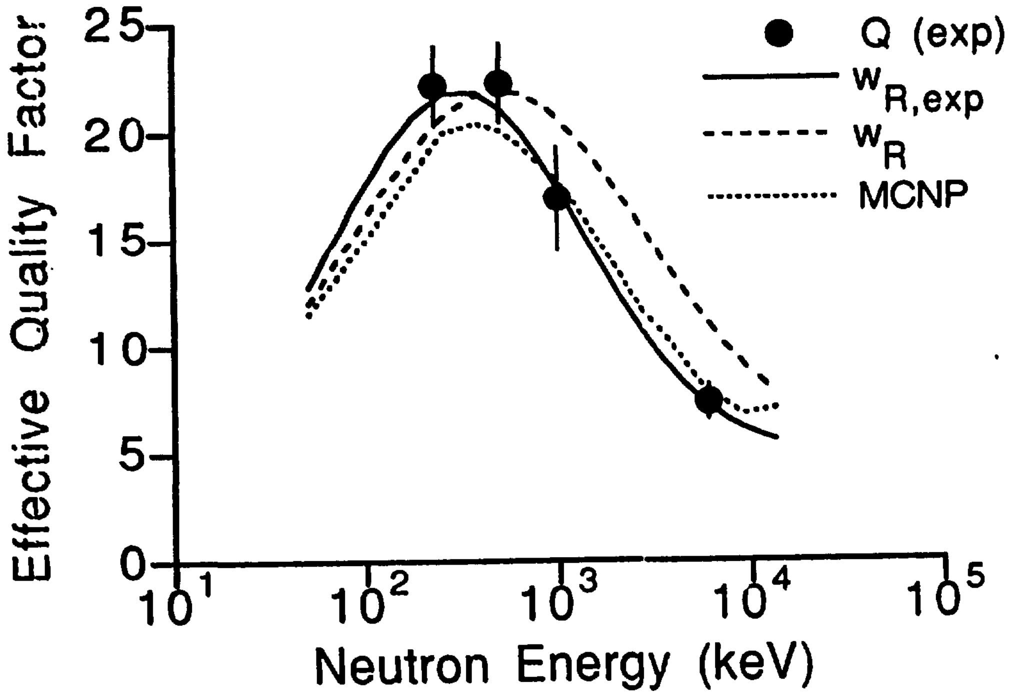
Effective Quality Factor
25
20
15
10
5
0
10^1
10^2
10^3
10^4
10^5
Neutron Energy (keV)
Q (exp)
w_R,exp
w_R
MCNP

Neutron energy [MeV]	Linear coefficient, α [10^{-4} mGy^{-1}]	Q (exp)
0.23	0.294 ± 0.018	22.2 ± 1.8
0.5	0.296 ± 0.019	22.3 ± 1.8
1.0	0.223 ± 0.029	16.9 ± 2.4
6.0	0.098 ± 0.010	7.4 ± 0.8