PHYSICAL ASPECTS OF USING ROSSI-PROPORTIONAL COUNTERS FOR RADIATION PROTECTION MEASUREMENTS AND PRACTICAL DEVELOPMENT

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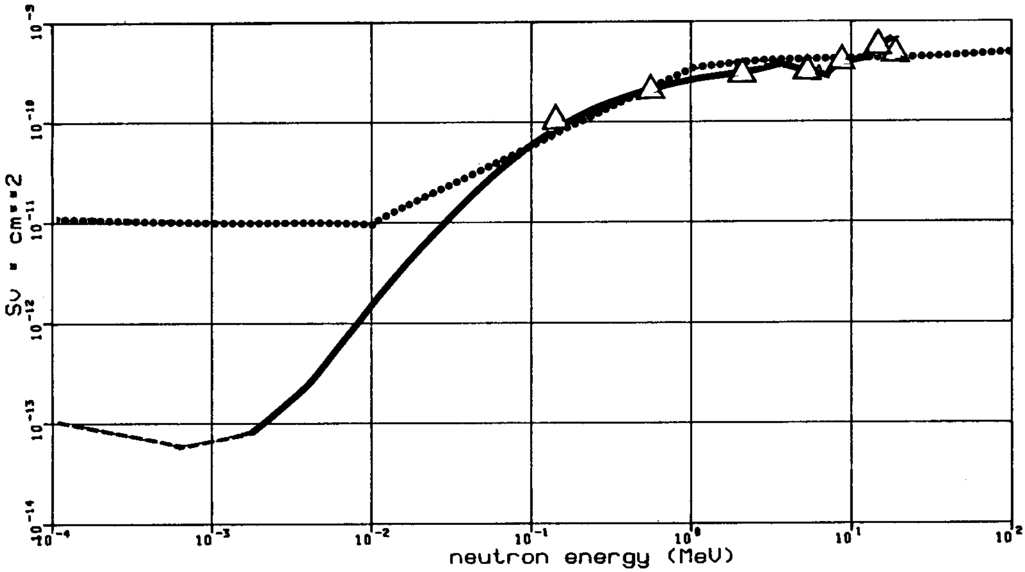
Introduction

Radiation protection measurements require the determination of dose equivalent, H. This quantity was introduced by ICRU /1/ and ICRP /2/ to account for the fact that the correlation of a given biological effect with absorbed dose will change in general when the type of radiation is varied. Dose equivalent H at a point of interest in tissue is defined as the product of the absorbed dose, D, and the quality factor, Q. The latter factor has values of between 1 and 20 and has been specified as a function of linear energy transfer, LET, because it is assumed that differences in biological effectiveness are related to differences in the microscopic distribution of absorbed dose delivered by the charged particles. The quality factor is unity for X, beta and gamma rays. In practice neutrons constitute the most important radiation for which Q is greater than one. Usually an average quality factor has to be applied because the dose is delivered over a range of values of LET. This holds in particular for complex radiation fields.

Low pressure tissue-equivalent proportional counters ("Rossi-counters") are cavity-chambers and present therefore, similar to ionization chambers, a very accurate method for measuring absorbed dose in most practical situations. The gas amplification of the proportional counter enables to measure in addition the energy deposition for single primary particles yielding energy imparted spectra ("microdosimetric spectra"). These spectra and the LET distribution of the charged particles delivering the dose are closely correlated for a wide range of radiations so that this type of instrument enables the simultaneous determination of absorbed dose and in approximation the average quality factor and thus dose equivalent also in unknown radiation fields. Furthermore, the spectral information can be used to evaluate the contribution of photons and neutrons to dose equivalent.

Physical Aspects

For the purpose of radiation protection dose limitations are stated as limits of dose equivalent in organs or tissue of the body. However, the value of the dose equivalent in an organ can rarely be determined directly and therefore a hierarchy of primary, secondary and derived limited quantities have been introduced. They include measurable or so called operational quantities which are supposed to provide a sufficiently conservative estimate of organ and tissue dose equivalents. The operational quantities thus permit to relate results of radiation protection monitoring to dose equivalent limits. An example for a quantity of this type is the maximum dose equivalent in a cylindrical phantom for a uniparallel beam (MADE) /2/. The Figure shows the fluence-to-MADE conversion function for neutrons for several decades of neutron energy as given by ICRP publication 21 /2/. For actual measurements of MADE (or other measurable quantities) detectors must have a response function proportional to the conversion function.



Fluence-to-MADE conversion function /2/ (dotted line), calculated response function for a Rossi counter (solid line) and experimental results as function of neutron energy.

The method of determining dose equivalent from Rossi-counter measurements has been described /3,4,5,6/ and is straightforward. Using the computer code for calculating microdosimetric distributions by Caswell and Coyne /7/ the response function of a Rossi counter was determined for monoenergetic neutrons between 1 keV and 20 MeV (below 1 keV the results are very preliminary) (Fig.). The simulated irradiation condition are idealized in the sense that modifications of the radiation field by interactions with the detector material are ignored. In particular, spectrum degradation and photon production in the detector wall are not considered. The Figure includes several results of measurements with Rossi-counters for monoenergetic neutrons between 144 keV and 19 MeV. The experiments were performed at the Physikalisch Technische Bundesanstalt (PTB), Braunschweig and the Gesellschaft für Strahlen- und Umweltforschung (GSF), Munich. The spherical counters used have an inner diameter of 12.7 mm and the thickness of the wall made of A-150 tissue-equivalent (TE) plastic is

2.5 mm. The propane based TE-gas mixture pressure was set at 8.9 kPa (67 torr).

Conversion function and calculated response function agree well above 50-100 keV and also the experimental points do not differ significantly. This agreement shows the principal suitability of this type of detector to determine dose equivalent in this energy range. The agreement between the two functions and the experimental points permit the conclusion that neutron scattering in the phantom or detector wall is not important for the value of MADE above 100 keV. The discrepancy between conversion function and response function at lower energies, however, has to be attributed mainly to the photon contribution to MADE. The photons are produced in capture processes of neutrons degraded in the phantom to thermal energies. In fact, for neutrons below 10 keV about 50% of the conversion function is due to gamma rays from (n,γ) processes /8/.

A real counter, i.e. a counter with finite wall-thickness which implicitly includes the effects of neutron interactions in the wall is expected to have a response function which agrees better below 50 keV than the calculated function in the Figure. This is confirmed by preliminary results of measurements with 2 keV neutrons. The use of additional wall material (300 cm^3 polyethylene) yielded an additional contribution to dose equivalent of about 6 10^{-12} Sv cm^2 in terms of gamma rays. This value corresponds to about 60% of the conversion function at this energy. These results support the assumption that it is possible to match the response function of Rossi counters to fluence dose equivalent conversion functions for the entire energy range between 1 keV and 20 MeV by choosing the wall thickness appropriately. It is anticipated that a far better proportionality can be obtained than with other types of monitors including REM-counters /9/. Therefore the use of this detector is promising not only in practical radiation protection dosimetry but also as a reference method.

Practical Development

The development of a practical dose equivalent meter based on a Rossi-counter in our laboratory foresees a counter with a diameter of about 5 cm. Equivalent dose rates of interest in radiation protection range from about 0.1 μSv h^{-1} to values in excess of 3 10^3 μS h^{-1}. For a mixed radiation field with about 50% contribution of photons to absorbed dose pulse frequencies were found to range from about 1 s^{-1} at 0.75 μSv h^{-1} to 4 10^3 s^{-1} at 3 $10^3$$\mu$Sv h^{-1}. This range of dose equivalent rates is of interest for radiation protection. The real count rates depend on the type and spectrum of the radiation field. In a pure photon field they may be two orders of magnitude higher than in a pure neutron field.

For the highest count rates fast pulse processing is required. If a portable battery operated instrument is to be constructed this requirement is opposed to the need to use low power consumption electronic components which in general are relatively slow. Our concept is based on the principle of using a minimum number of channels in the pulse height analysis. This allows an optimum compromise between the two requirements. The digital analogue conversion is achieved by use of comparators /10/. The conversion of the pulse height information into dose equivalent (rate) and absorbed dose (rate) will be performed by a simplified method permitting single signal processing. A maximum count rate of 10^4 s^{-1} is anticipated.

An instrument based on this concept and covering the above range of count rates and displaying dose equivalent rate and absorbed dose rate can be built with a power consumption of 3 to 4 Watt. This means that the use of rechargeable batteries is reasonable and that portable instruments can be realized. If requirements for the performance of the instrument are further reduced personal dosimeters are feasible /11/. It has already been shown that non portable and portable instruments can be built /12,13,14/.

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Acknowledgement: This work has been financially supported by the Commission of the European Commission.