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Determination of the Photon-Contribution of a ^{238}Pu-Be Source

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Abstract

Gamma radiation of a ^{238}Pu-Be source at CERN was measured with two neutron insensitive ionisation chambers, i.e. a graphite chamber filled with CO_2 and a steel chamber filled with argon, in order to determine the photon-contribution to ambient dose equivalent. Scattered neutrons and neutrons from (n,γ)-reactions were taken care of by an extrapolation method. These straightforward measurements were confronted with a novel method using a recombination chamber, with which a coarse spectrum in LET of the mixed radiation field can be obtained. The lowest LET part of the spectrum corresponds to the photon-contribution to the absorbed dose of mixed radiation. The comparison of the different methods showed very good agreement within the measurement uncertainties.

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1. Introduction

Dosemeters for the monitoring of ambient or personal dose equivalent need to be calibrated periodically in order to determine a calibration factor (ratio of the chamber reading to the quantity of interest), and also to assure their correct functional status. The calibration of neutron-sensitive monitors is a complex subject due to the influence of scattered radiation. A recently published international standard [1] is dedicated to this problem.

A question that has rarely been treated is the influence of the photon radiation from the neutron source on the calibration results. Photons are emitted by one of the components of the source, e.g. 60 keV photons from ^{241}Am in the recommended ^{241}Am-Be source. In all alpha-Be sources, a second origin of photons is the first excited state of the ^{12}C nucleus, which is formed from the intermediate ^{13}C nucleus, the product of alpha-capture on ^{9}Be. It deexcites under emission of photons with an energy of E = 4.4 MeV.

The photon-contribution can be neglected when calibrating rem-counters or superheated drop detectors with a negligible sensitivity to photons. However, it has to be taken into account when calibrating neutron monitors which have an important photon response as e.g. hydrogen-filled ionisation chambers. It is therefore important to carefully assess the photon-contribution for precise calibrations.

The field of a ^{238}Pu-Be source at CERN was studied with two largely neutron insensitive chambers: a graphite high-pressure chamber type G5 and an argon chamber type IG5 in order to determine the photon-contribution to ambient dose equivalent. The results applying the distance law were evaluated and compared. These straightforward measurements were confronted with a novel method using a recombination chamber REM-2, with which a coarse spectrum in LET of the mixed radiation field can be obtained. The lowest LET part of the spectrum corresponds to the photon-contribution of the absorbed dose of mixed radiation.

2. Material and Methods

2.1. ^{238}Pu-Be neutron source

At CERN, a ^{238}Pu-Be neutron source is used for calibrating neutron detectors and dosemeters. The 1.81 TBq source has a neutron emission of 10^8 n/s [2]. Neutron mean energy is 4.5 MeV and half-life of the source is 87.7 years. The neutron spectrum of ^{238}Pu-Be is similar to the one of ^{241}Am-Be, the source recommended in ISO standard 8529-1. The advantage of the ^{238}Pu-Be source is its higher neutron fluence for the same source mass, allowing a more compact design of

the source and the significantly smaller contribution of photons to the radiation field. The emission of the source has been traced back to international standards by the use of a transfer instrument, a moderated neutron detector (rem-counter) of type EG&G Berthold LB6411. The neutron emission of the ^{238}Pu-Be source is accompanied by a small photon-contribution, on which no information can be found in the literature.

The source is mounted into an automatic calibration bench. It is located behind a 40 cm thick concrete shielding wall with a window of 40x40 cm². In addition to the normal expected scattering from the floor, ceiling and walls there is a scatter contribution from the edges of the beam "window".

2.2. Ionisation chambers

The high-pressure G5 type graphite ionisation chamber used in this work was designed and constructed in the Institute of Atomic Energy (IAE) Swierk (Poland). The chamber is 115 mm long and 18 mm in diameter. The distance between the electrodes is 2 mm. It is enclosed in a 0.3 mm thick aluminium envelope and is filled with carbon dioxide at a pressure of 2.8 MPa. The chamber was used as a "neutron insensitive" detector. In such chambers, especially when they are operated at relatively low collecting voltages, the recombination of ions in tracks of high-LET particles is considerably higher than in tracks of low-LET particles. As the result, the relative neutron sensitivity of the chambers is below 0.03 for neutrons of energies up to 15 MeV [3], provided that the electrical field strength in the chamber cavity does not exceed 200 V/cm.

A gamma ion chamber type IG5 manufactured by CENTRONIC was used as a second largely neutron insensitive ionisation chamber. It is filled with argon gas and has a diameter of 185 mm and a length of 430 mm.

The recombination chamber REM-2 [4] is a high-pressure tissue-equivalent ionsiation chamber, manufactured in Poland by POLON-Bydgoszcz. It is filled with mixture of methane and nitrogen (5%) up to pressure of about 1 MPa. It has a volume of 1800 cm³, a mass of about 6 kg and the effective wall thickness is of about 1 g/cm², when the point source at the distance more than 1 m is used.

Recombination chambers make use of the phenomenon of initial recombination of ions in gases. The difference in ion collection efficiency f_R [5] at two voltages, of which one assures saturation, permits to determine the quality factor of the radiation field. A summary of works and developments in using recombination methods can be found in earlier report [3].

2.2.1 Determination of the low LET dose fraction with the recombination chamber

For practically any mixed radiation field, the ion collection efficiency in a recombination chamber, operating at given voltage U, can be expressed [6] by ion collection efficiency measured in reference gamma radiation field at the same voltage U:

$$f_{mix}(U) = \mathcal{D}_{low} \cdot f_{\gamma}(U) + \sum_{j=2}^{6} \mathcal{D}_j(L) \cdot s_j \qquad (1)$$

Here, $f_{mix}(U)$ and $f_{\gamma}(U)$ are ion collection efficiencies determined at voltage U in mixed and gamma radiation field, respectively, $\mathcal{D}_j$ are the absorbed dose contributions associated with a considered LET numbered by index j and s_j are analytical functions of the ion collection efficiency, averaged over the interval j [3,6].

From the measurements at different voltages, one can obtain a set of equations (1) and then the parameters $\mathcal{D}_{low}$ and $\mathcal{D}_j$ can be fitted, with constrains that they cannot be negative. In case of irradiation with ^{238}Pu-Be, the parameter $\mathcal{D}_{low}$ is a photon-contribution to absorbed dose (the sum of photon dose from the source and from photons generated by neutrons in the chamber).

3. Measurements

3.1. Determination of the photon-contribution using a pen-like chamber of G5 type

Measurements were performed with a pen-like chamber of G5 type at ^{238}Pu-Be source. As a working voltage –20V was chosen. The calibration of the chamber has prior the measurements taken place in the field of a ^{137}Cs source. A calibration factor of –(1.31±0.05) µC/Sv was found. The charge was collected five times in steps of 0.1 m at distances r from 0.8 m to 1.4 m. A simple model assumes a contribution b/r^2 of direct photons and a spatially constant contribution a of scattered photons and photons produced in (n,γ)-reactions in hydrogenous materials in the calibration laboratory to the reading of an instrument. In Fig. 1 the product of the charge times the square of the distance source-detector r is plotted over r^2. The intercept of a linear regression in this presentation delivers the contribution of direct radiation, b, originating predominantly from the Pu-Be source. We obtain an interception value b of –(48.2±2.5) pC/h. Applying the calibration factor and considering the measurement uncertainties, the photon-contribution of the source is H^*_{photon} = (36.8±2.8) µSv/h.

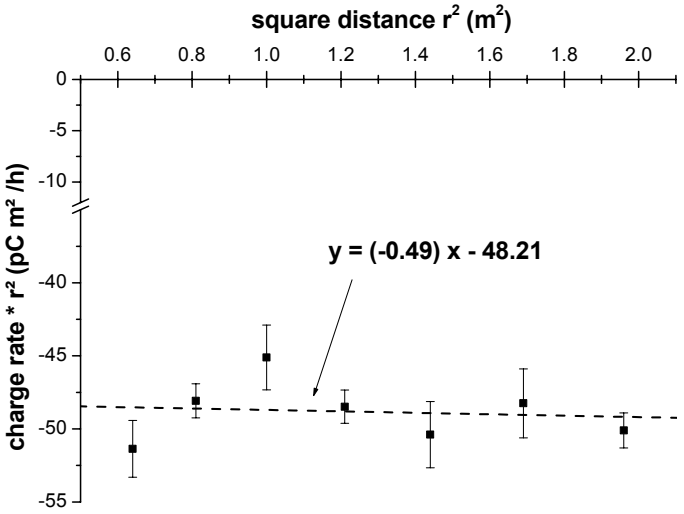

Fig. 1 Product of charge rate and distance (detector-source) as a function of the square distance measured with the G5-chamber. The interception value in combination with the calibration factor delivers the photon-contribution of the ^{238}Pu-Be source.

3.2 Determination of the photon-contribution using an argon chamber IG5

In multiples of 25 cm, at each distance from the ^{238}Pu-Be source 10 measurements over 200 s were made with the argon chamber type IG5. Uncertainties were obtained from the standard deviation in these 10 measurements and adding an overall uncertainty of 5 % assumed coming from several other sources of uncertainty.

From linear extrapolation of the data plotted in Fig.2 we got a value of the axis intercept *b* equal to (11647±50) cts/h. Applying the earlier determined calibration factor of (300±15) cts/µSv leads to a dose equivalent H^*_{photon} = (38.7±1.9) µSv/h.

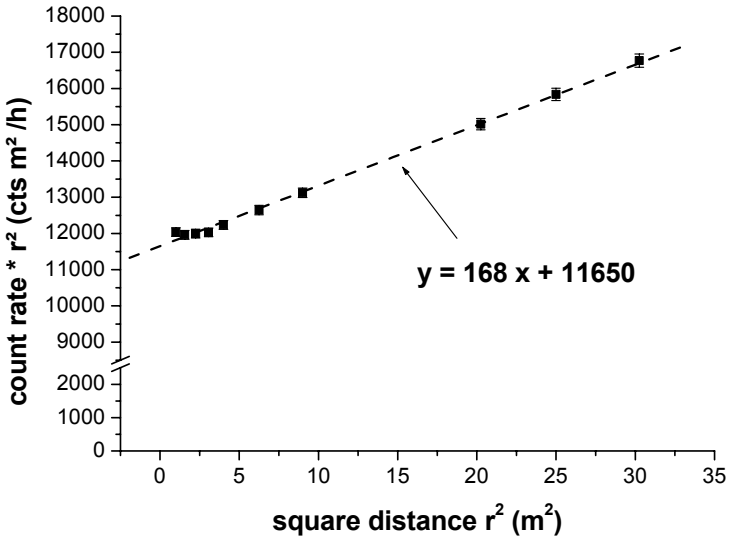

Fig. 2 Product of charge rate and distance (detector-source) as a function of the square distance measured with the argon chamber IG5. The interception value in combination with the calibration factor gives the photon-contribution of the ^{238}Pu-Be source. Note the different scale of the x-axis as compared to Fig. 1.

3.3. Determination with the REM-2 chamber

Complete saturation curve was obtained for the recombination chamber REM-2, in a reference gamma field from a ^{137}Cs source, by applying a succession of voltages in the range 8 to 1300V and measuring the charge collected over 100 s. The chamber was positioned in a distance of 2.17 m with a dose rate of 2 mGy/h. In this procedure a calibration factor of K=348.86 μC/Gy was found. Since former investigations showed that a filling gas based on methane with nitrogen causes a slightly higher sensitivity to neutrons up to 5 MeV, the calibration factor was corrected to the response from ^{238}Pu-Be using a correction factor of 1.18 [3]. This delivered a corrected calibration factor of K_{corr} = 411.4 μC/Gy.

This operating sequence was repeated for the field of the ^{238}Pu-Be source at a distance of (2.18±0.01) m, and a reference neutron dose rate of 300 μSv/h. The saturation curve measured in the ^{238}Pu-Be field is shown in Fig. 3, together with the saturation curve measured in the reference ^{137}Cs field. One can see clearly a faster decrease of the ^{238}Pu-Be saturation curve at low voltages due to greater recombination. After plotting f_{mix} against f_{γ} , Equation (1) was fitted to the experimental results by the least square method, with constraints mentioned above. The

recombination method delivered a photon-contribution of $\mathcal{D}_{low}$ = (17.5±0.9) % at 1m for the ^{238}Pu-Be source within the given geometry including scattered photons. The scattered photon contribution is here neglected, since it is very small as demonstrated in the measurements mentioned before. For the photon-contribution a standard uncertainty of 5 % was estimated. This gives a dose equivalent of H^*_{photon} = (39.9±2.8) µSv/ h.

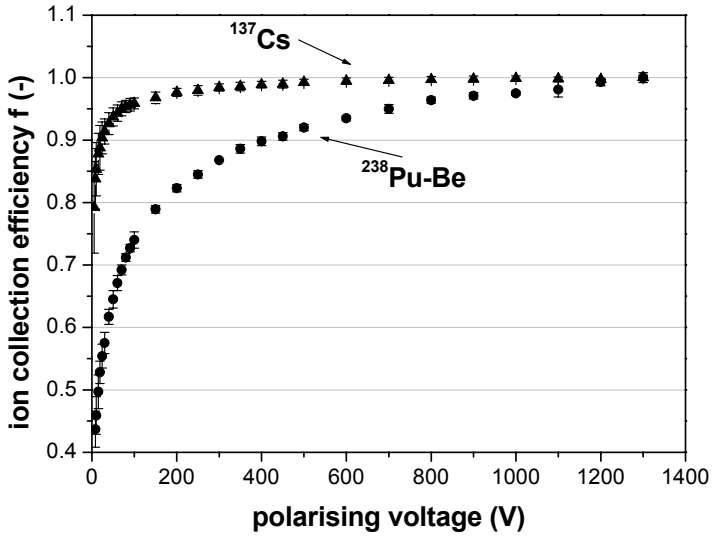

Fig. 3 Saturation curves determined with a recombination chamber REM-2 in the field of a ^{137}Cs source and a ^{238}Pu-Be source.

4. Conclusions

The goal of this study was the evaluation of the photon-contribution of the ^{238}Pu-Be source with different detectors. The knowledge of this contribution is relevant for henceforth calibrations with this source. The more elaborated recombination method was applied to demonstrate the wide possible field of application of the REM-2 chamber and to confirm the measurements done with the neutron insensitive chambers. Table 1 presents the very good agreement between the different detectors.

Table 1
Photon-contribution in 1m distance from the ^{238}Pu-Be source given for different detectors

Detector	Graphite Chamber G5	Argon Chamber IG5	Recombi. Chamber REM-2
Photon-Contribution [µSv/h]	36.8±2.8	38.7±1.9	39.9±2.8

References

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