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DETERMINATION OF THE QUALITY FACTOR IN A MIXED FIELD OF GAMMA-RAYS AND NEUTRONS BY AN IONIZATION CHAMBER FILLED WITH A DIELECTRIC LIQUID, II

M. LADU, M. PELLICCIONI and M. ROCCELLA

Laboratori Nazionali di Frascati del CNEN, Laboratorio di Dosimetria del CNEN, Sezione di Frascati, Frascati, Italy

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After studying some properties of the response to γ-rays and neutrons relative to an ionization chamber filled with hexane, it has been carried out a method for the measure of the quality factors in the γ-rays and neutrons mixed fields. The precision and the limits of the method are also being discussed in comparison with other measurement systems of the quality factors.

1. Introduction

In order to evaluate the dose equivalent given to a tissue exposed in a radiation field we need the following information: the absorbed energy in the tissue and the radiation effectiveness for causing a certain biological damage.

The absorbed energy in the tissue, which is expressed in rad, can be measured by a tissue equivalent ionization chamber[1]).

In order to take account of the radiation effectiveness to cause a certain damage we introduce the coefficient of the relative biological effectiveness (EBR), that is, for protection purposes, the quality factor (QF).

The EBR, as well as the QF, are functions of the linear energy transfer (LET). After knowing the kind of radiation and its energy, the value of the QF can be obtained from the relationship or from the curves which give the dependence on the LET.

However, when the structure of the radiation field is unknown, the QF is to be measured directly.

This is relative to the scattered radiation around the high energy accelerators, where the radiation field consists of several components, every one with its own energy spectrum.

Under these conditions a direct measurement of the QF becomes indispensable, if we want to avoid to give a precautionary and too large estimation of the dose equivalent, which generally requires big sizes for the shielding or limitations to the experiments.

Rossi and Rosensweig[2]) have measured the neutron dose against the LET with a tissue equivalent proportional counter and being QF dependent on the LET, from the measure of LET of a given radiation or from a certain spectrum of LET they can know the QF.

Sullivan and Baarli[3]) have measured the QF, exploiting the columnar recombination in an ionization chamber filled with a tissue equivalent gas at high pressure.

Zel'chinskii[4]) carried out a measure method of the QF based upon a different recombination regime which was obtained in two ionization chambers with a different polarization voltage.

Distenfeld and Markoe[5]), equally utilizing the columnar recombination, have recently measured the QF by a balanced tissue equivalent chamber.

Finally Pszona and al.[6]) have investigated the possibility of measuring the QF studying the dependences on LET of the organic scintillators effectiveness.

2. On the possibility of measuring the QF by an ionization chamber filled with a dielectric liquid

By the ionization chambers filled with dielectric liquid, Blanc et al.[7]) have found, and we have confirmed[8]), that prolonging the linear portion of the curves, which give the ionization current against the electric field strength, these converge to points of the abscissae axis that depend on the QF of the considered radiation.

However, that is partially justified by the Jaffé's theory on the columnar recombination in the liquids, by which it is possible to foresee the existence of the convergence points and their dependence on the specific ionization of the particles, that is on the LET and, therefore on the QF[9]).

This property, extremely useful for measurements in the mixed fields, is particularly interesting for the mixed γ-rays and neutrons fields, which are the most important components of the scattered radiation around the high energy accelerators.

Herewith we give the results of our study on the possibility of measuring the QF of a mixed γ-rays and neutrons field by a dielectric liquid ionization chamber.

3. Experimental results

The measurements have been accomplished by a plane ionization chamber, having a collecting electrode of a surface equal to about 34 cm^2 and distance between the electrodes variable from 0 to 10 mm.

As filling liquid we used hexane, usually employed in spectral analyses. This was introduced in the chamber, carefully clean, after being distilled very slowly several times. Therefore the liquid was kept under the action of a high electric field until the background current reached a stable value.

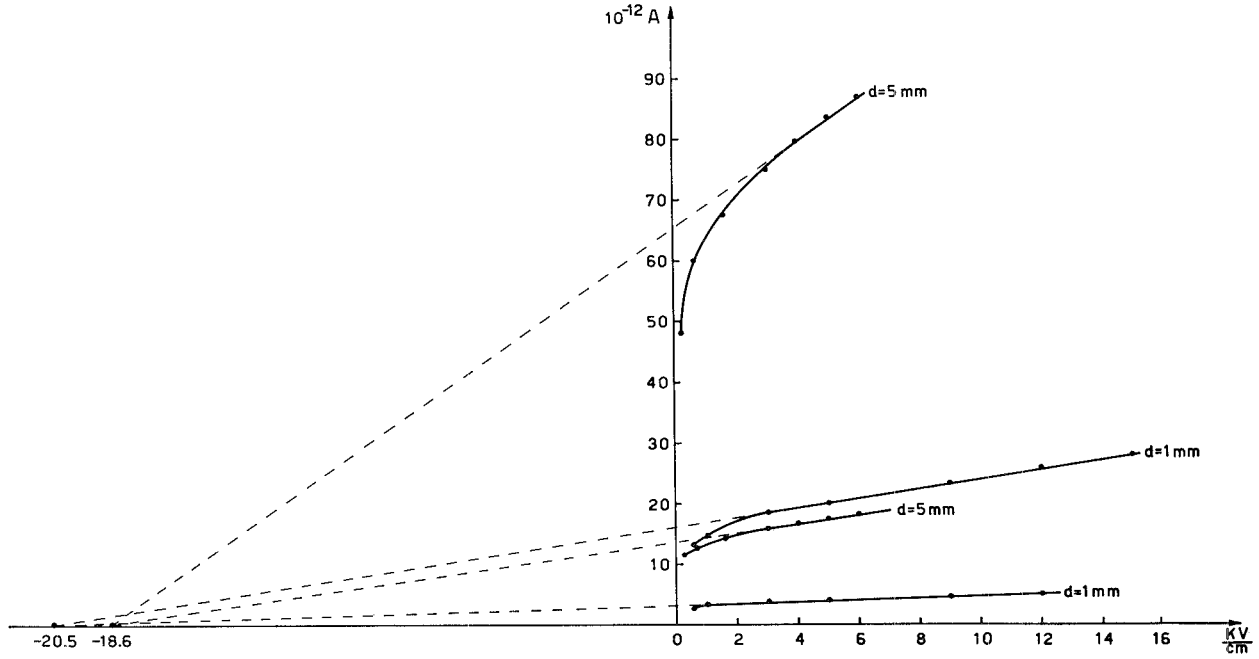

Fig. 1. Ionization current against the electric field strength using interelectrode distances of 1 mm and 5 mm. The curves are obtained using two sources of ^{60}Co of different activity (14 mCi and 2.9 mCi), placed about 11 cm from the center of the chamber.

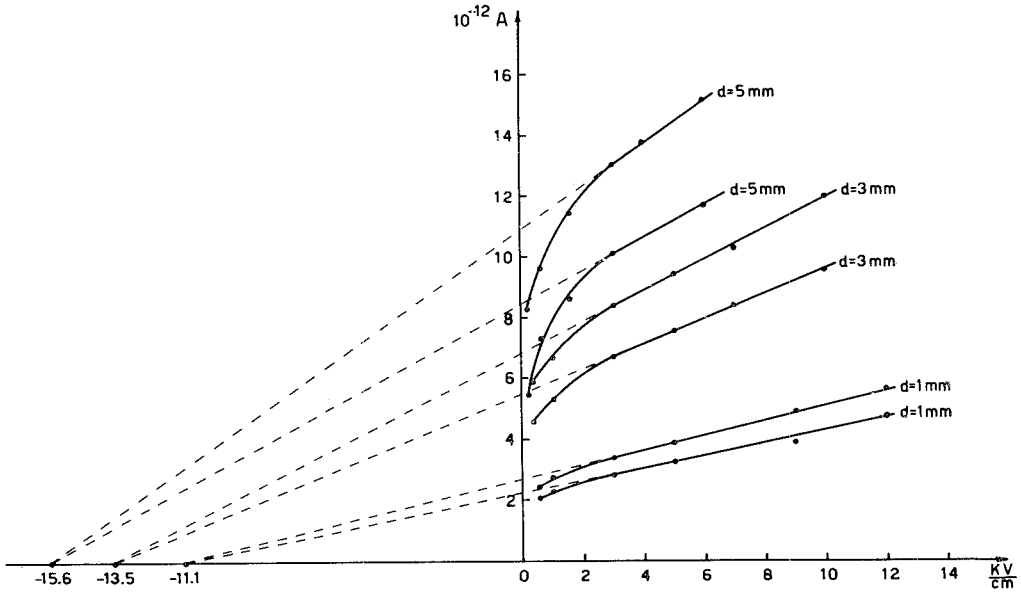

Fig. 2. Ionization current against the electric fields strength for some interelectrode distances for neutron sources of Am-Be ($A = 2.6 \times 10^6$ n/s) and Po-Be ($A = 2.15 \times 10^6$ n/s).

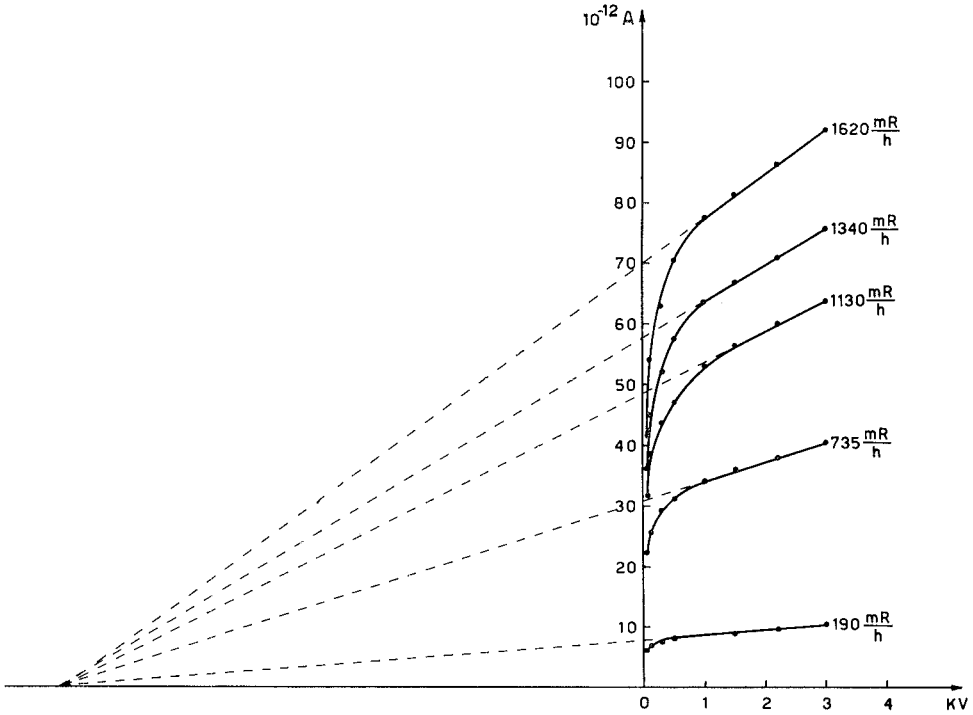

Fig. 3. Ionization current against the voltage for different dose rates. The curves are obtained varying the distance from the chamber of a ^{60}Co source ($A = 14$ mCi).

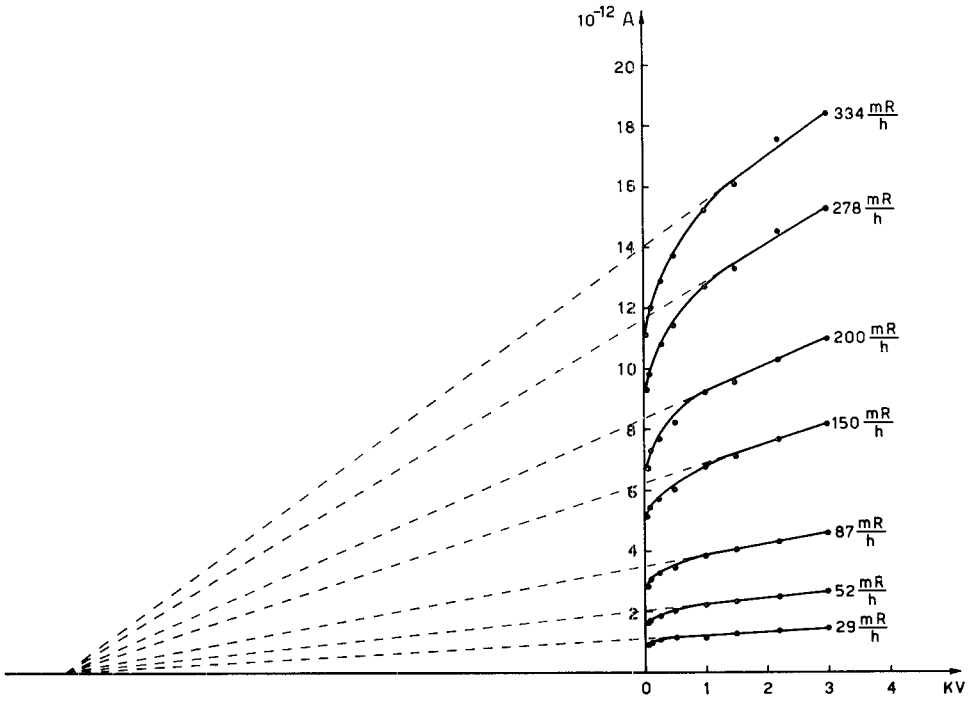

Fig. 4. Ionization current against the voltage for different dose rates. The curves are obtained varying the distance from the chamber of a ^{60}Co source ($A = 2.9$ mCi).

After such a treatment the conductivity of the liquid was about $10^{-18}/\Omega\cdot$cm with an electric field strength of some kV/cm.

During the measurements, the chamber was constantly kept in connection with a container full of an exsiccator ($CaCl_2$ or P_2O_5). The ionization currents measured by an electrometer were also recorded grafically.

For the γ-rays we used two sources of ^{60}Co of different activity (14 mCi and 2.9 mCi). The dose rate could be varied with precision shifting the sources along a graduated axis. For the neutrons we used sources of Po-Be ($A = 2.15\times10^6$ n/s and $A = 4.4\times10^5$ n/s) and Am-Be ($A = 2.6\times10^6$ n/s), which were placed inside the chamber in a suitable holder.

Afterwards we indicate respectively with V_γ and V_n the points in which the curves obtained for the γ-rays and the neutrons intersect the abscissa axis.

Firstly we have studied the position of V_γ and V_n changing the distance between the electrodes, that is the sensitive volume of the chamber.

A part of the obtained results are shown in fig. 1 and fig. 2 respectively for the γ-rays and neutrons and for some values of the interelectrode distance d.

From these curves it seems that the position of V_γ and V_n depends on the value of d.

Similar behaviour has been observed by us also for other values of d between 1 mm and 10 mm.

We have also studied the response of the chamber in a larger range of dose rate, for an interelectrode distance of 5 mm.

The curves showing the ionization current against the applied voltage for the source of ^{60}Co ($A = 14$ mCi and $A = 2.9$ mCi) when these are placed at various distances from the chamber, i.e. with various intensities, are plotted in fig. 3 and fig. 4.

As it can be seen the position of V_γ falls in the range between -9500 V and -9600 V. Then we can assume $V_\gamma = (-9550 \pm 50$ V).

In fig. 5 similar curves are plotted for the neutron sources, from which we have $V_n = (-7500 \pm 50)$ V.

In order to investigate the possibility of calibrating the chamber for measurements of QF in mixed fields of γ-rays and neutrons, we studied also, for $d = 5$ mm the response of the chamber in such fields.

The mixed fields have been realized taking in a fixed position a source of Po-Be ($A = 4.4\times10^5$ n/s) and varying the distance of the sources of ^{60}Co from the chamber. The current so measured has been always equal, within experimental error, to the sum of the currents i_γ and i_n relative to γ-rays and neutrons respectively.

The values of QF for the mixed fields have been empirically determined from the following relation:

$$QF = (i_\gamma QF_\gamma + i_n QF_n)/(i_\gamma + i_n), \qquad (1)$$

where QF_n has been taken equal to 7.6 and QF_γ equal to 1.

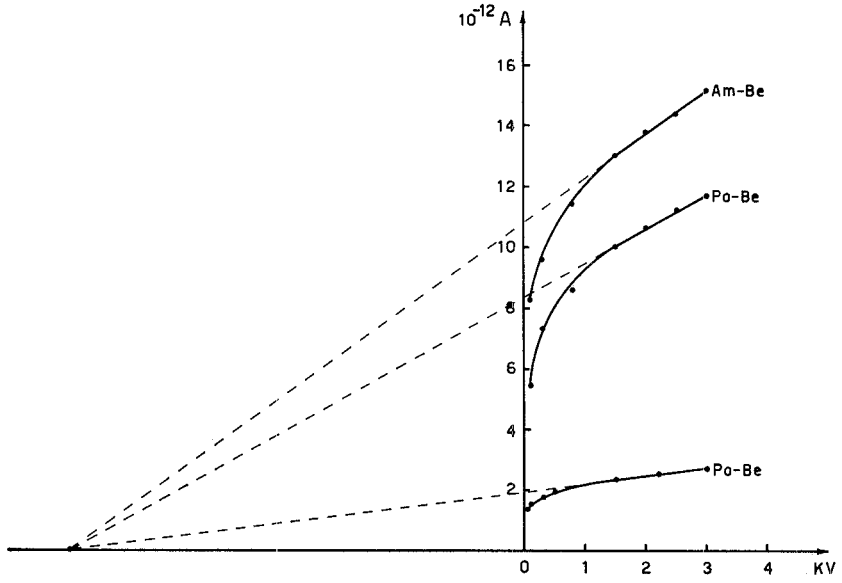

Fig. 5. Ionization current against the voltage with the neutron sources respectively of Am-Be ($A = 2.6\times10^6$ n/s), Po-Be ($A = 2.15\times10^6$ n/s) and Po-Be ($A = 4.4\times10^5$ n/s).

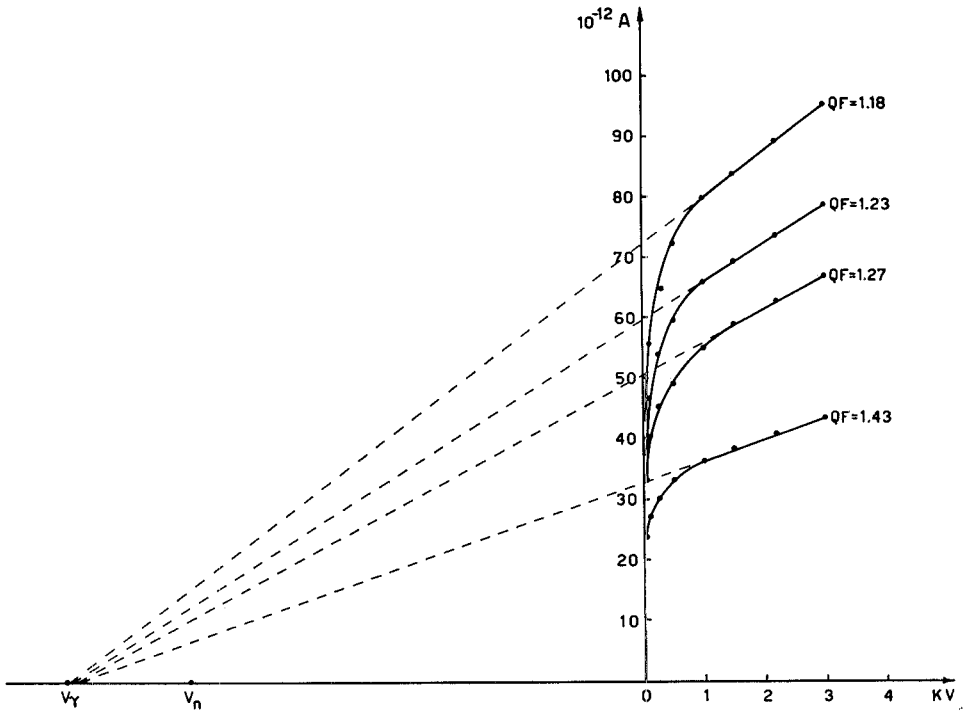

Fig. 6. Ionization current against the voltage for the mixed fields of different QF realized by exposing the chamber to neutrons of the Po-Be source ($A = 4.4 \times 10^5$ n/s) and to γ-rays of ^{60}Co ($A = 14$ mCi), this one placed at various distances from the chamber.

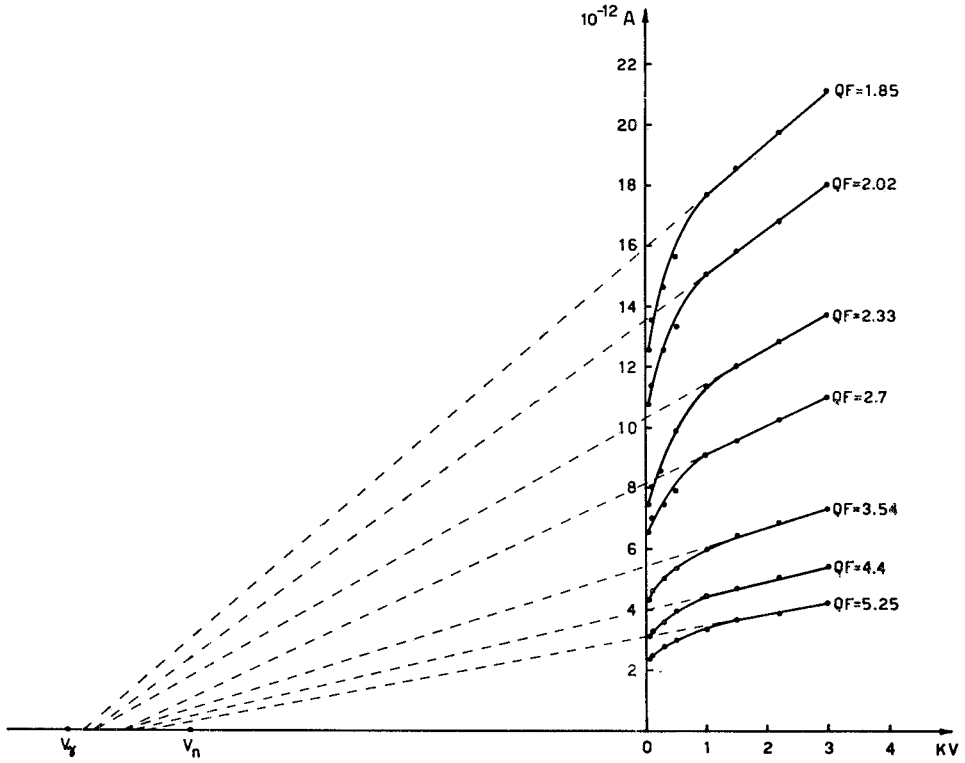

Fig. 7. Ionization current against the voltage for the mixed fields of different QF, realized by exposing the chamber to neutrons of the Po-Be source ($A = 4.4 \times 10^5$ n/s) and to γ-rays of ^{60}Co ($A = 2.9$ mCi), this one placed at various distances from the chamber.

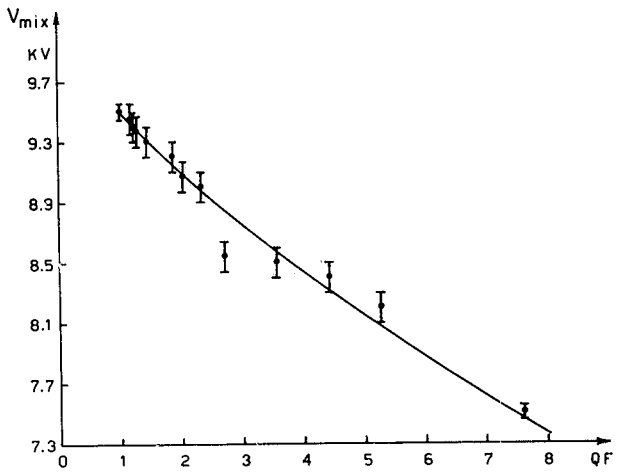

Fig. 8. Abscissae of convergence points against QF and calibrating curve of the chamber.

In fig. 6 and fig. 7 are plotted the curves obtained under the above described conditions. The linear zone has been then prolonged until to the intersect the abscissae axis, in order to investigate the position of the intersection point vs QF. As it can be seen each value of QF corresponds to a different position of such a point, within experimental error, and when QF goes towards 1, the points go towards V_γ.

In fig. 8 the abscissae V_{mix} of intersection points, inferred from fig. 6 and fig. 7 and having changed the sign, are plotted against the values of QF calculated by eq. (1). As it has already been said, the position of V_γ and V_n can be considered known with an incertitude of $\pm$ 50 V. For the other points, because it was not possible to realize fields of different intensity with the same QF, each point has been determined through a single series of measurements with an incertitude of $\pm$ 100 V.

The Jaffé's theory, as already mentioned, foresees the existence of convergence points, which depend on the specific ionization of the incident particles. Because of the dubious knowledge of many parameters which affect the phenomenon (mobility, recombination coefficient, etc.) we cannot make at this moment, a direct comparison between the results of our measurements and the theory.

Rather we have preferred to obtain from experimental data an empirical relation between V_{mix} and QF:

$$V_{mix} = a/(b+\mathrm{QF}), \qquad (2)$$

suitable for the QF values between 1 and 7.6. The line in fig. 8 shows eq. (2) with $a = 2.32 \times 10^5$ V and $b = 2.3.5$.

By eq. (2) it is possible to measure by our chamber the unknown QF in mixed fields of γ-rays and neutrons.

4. Conclusions

The results obtained seem promising, since we have succeeded to determine an empirical relation between V_{mix} and QF which allows us to reach our purposes.

The precision of the method, of order of 20–30% is acceptable for protection purposes.

However, as it is necessary to accomplish the measurements in the zone where the current is a linear function of the electric field strength, it is advisable to work with small interelectrode distances, i.e. small sensitive volumes, in order to use enough low polarization voltages.

This fact reduces the sensitivity of the instrument making its employment difficult in low fields strength. On the other hand it is particularly suitable for measurements in high fields strength as, for example, around pulsed radiation sources.

Another limit of this method is due to the fact that at least two measures of the current are necessary for one measure of the QF. This forbids its employment in fields varying with the time, unless two chambers polarized with different voltages are used at the same time. On the other hand since it is possible to realize a dielectric liquid ionization chamber with response proportional to the absorbed dose in rad[10]), from the two measurements could be determined the QF as well as the dose equivalent.

In future we will extend this study to other types of particles in order to increase the possibility of employment of our instrument.

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