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USE OF IONIZATION CHAMBERS FILLED WITH A DIELECTRIC LIQUID IN RADIATION DOSIMETRY

M. LADU and M. PELLICCIONI

Laboratori Nazionali di Frascati del CNEN, Frascati, Italy

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The response to γ-rays and neutrons of an ionization chamber filled with hexane in function of various parameters (inter-electrode distance, collecting voltage, dose rate) has been studied in order to realize a dosimeter which would take advantage from the ionization in liquids. It has also been made a comparison with the response of the same chamber filled with air.

From the results obtained, the employ of ionization chambers filled with a dielectric liquid seems particularly promising in dosimetry.

1. Introduction

In some measurements of dosimetry the ionization chambers filled with a dielectric liquid seem preferable to gas ones for the similarity of ionizing radiations effects in the liquids and in the tissues[1]). The composition and density of organic liquids is actually very similar to those of the tissues.

Moreover, under the same conditions, the ionization current is greater in liquids than in gases. However, the ratio of the currents in practice is not as high as it could be foreseen from the ratio of the respective densities, since the radiation absorption in liquids is very high, whereas it is rather negligible in gases[2]).

Another advantage of the employment of liquids instead of gases consists in the possibility of reaching the conditions of equilibrium by the use of smaller chambers[2]).

The proportionality of ionization current with the dose rate has been since long evidenced[3]). It has also been shown that for an ionization chamber filled with hexane the response against X-rays energy has the same behaviour as the absorbed dose in a fat tissue[4]). More recently at last a dosimeter has been designed which uses hexane as filling liquid[5]).

Amongst other applications of these detectors in dosimetry there is also the possibility of measuring the quality factors of ionizing radiations[6]) and of determining the two components of a mixed field of radiation[7]). These properties are extremely interesting for the mixed fields of γ-rays and neutrons, which constitute the principal components of scattered radiation around the high energy accelerators.

However, the use of liquids instead of gases causes some inconveniences which we wish to examine below.

The most important problem is the purification of the liquid, since in liquids the natural conductivity is always added to the one of impurities.

This current, other than limiting the sensitivity of the detector, may compromise its precision, i.e. measurements taken with liquids of different purity may give different values. In fact this seems to be the cause why sometimes the results of various investigators do not coincide.

The background current can, however, be reduced at such a level as not to influence the measurements, if special care is taken in the preparation of the liquid, particularly by removing every trace of water.

As far as the use of gases is concerned there is the disadvantage, generally, of needing very high polariza-

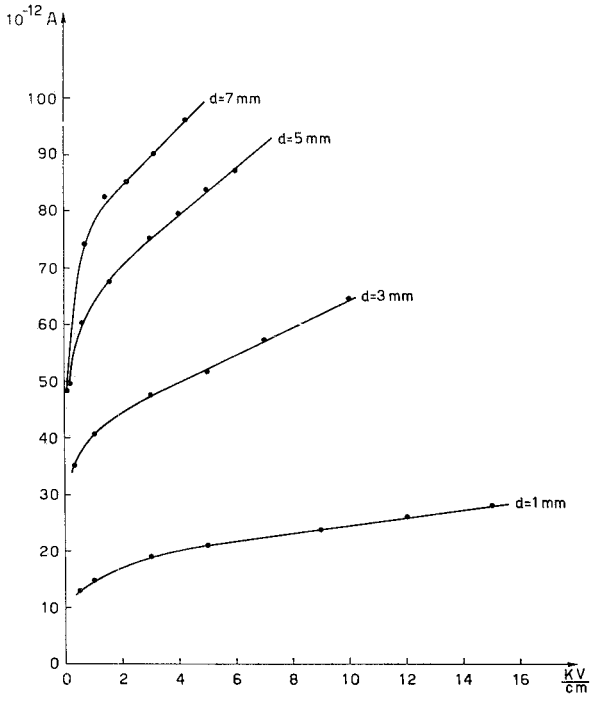

Fig. 1. Ionization current against the electric field strength for some values of the interelectrode distance d, when the chamber is exposed to a source of ^{60}Co ($A = 14$ mCi) placed at about 11 cm from its center.

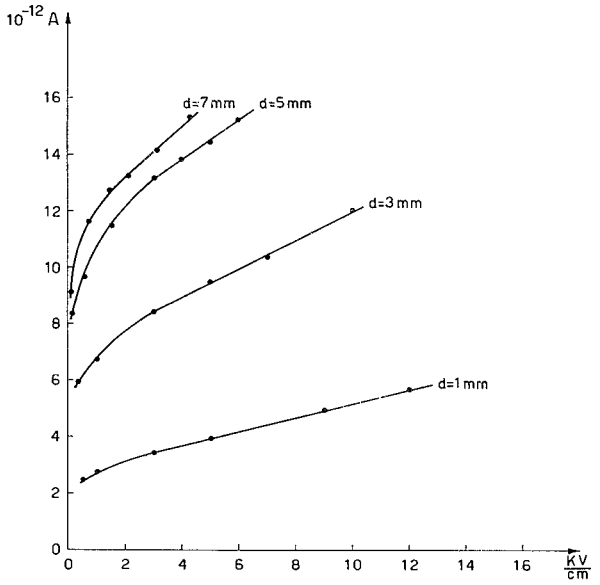

Fig. 2. Ionization current against the electric field strength for some values of the distance d, when the chamber is exposed to neutrons of a source of Am-Be.

tion voltages, even of the order of various thousand V[5]).

While the problem of the purification of the liquid can be considered at least partially solved as a conductivity of the order of $10^{-18}-10^{-19}/\Omega\cdot$cm has been reached, the problem of the high polarization voltage is still unsolved.

In order to realize a dosimeter based on the ionization of organic liquids, we have studied the behaviour of an ionization chamber filled with hexane, referring particularly to the low voltages.

2. Experimental results and their interpretation

The ionization chamber used by us has already been described in a previous paper[8]). After careful cleaning, it was filled with hexane distilled several times very slowly. In order to lessen the value of the background current, the liquid was then put under the action of a high electric field.

After such a treatment the conductivity of hexane was reduced to about $2.2\times10^{-18}/\Omega\cdot$cm with an electric field strength of 6 kV/cm. This conductivity is equivalent to that produced by an exposure of about 8 mR/h, when the sensitive volume is about 17 cm^3.

During the measurements the chamber was constantly kept in communication with a container filled with an exsiccator ($CaCl_2$ or P_2O_5).

The ionization current was measured by an electrometer and in the same time also recorded graphically.

We have used sources of ^{60}Co of various activities as γ-rays sources. The dose rate was varied with precision, removing the sources along a graduated axis. The sources of neutrons (Po-Be and Am-Be) were instead placed inside the chamber in a suitable holder.

For example fig. 1 shows, for various interelectrode distances, some curves obtained placing a source of ^{60}Co ($A = 14$ mCi) at about 11 cm from the center of the chamber. Fig. 2 shows similar curves for the neutrons of Am-Be.

The ionization current of fig. 1 and fig. 2, as it is known[2,4]), can be expressed by:

$$i = i_1 + i_2,$$

where i_1 varies with the electric field strength E quite similarly to the ionization current in gases until reaching a saturation value i_0, while i_2 is always increasing according to the law:

$$i_2 = Ci_0E,$$

therefore for high electric fields strength we have:

$$i = i_0(1+CE). \qquad (1)$$

The values of i_0 can be obtained by extrapolating the linear portion of the curves up to zero field. These values are proportional to the dose rate. This is shown in fig. 3, where i_0 is plotted against the dose rate for two different values of the interelectrode distance d.

In fig. 4 the ionization current is plotted against d for

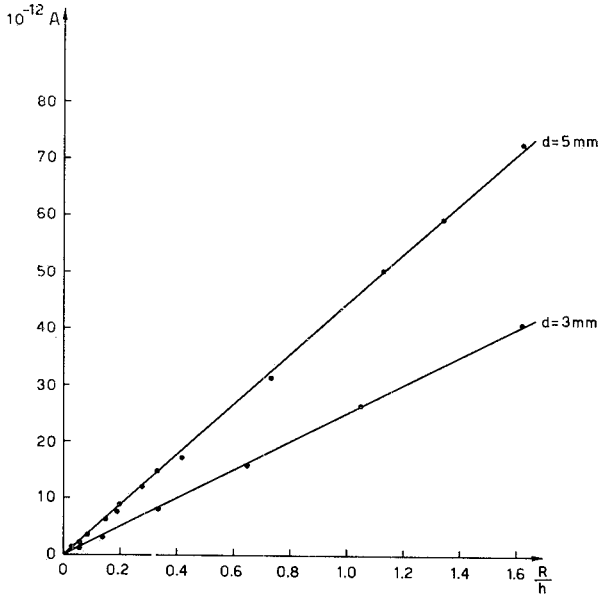

Fig. 3. Current i_0 against the dose rate for two values of the interelectrode distance d.

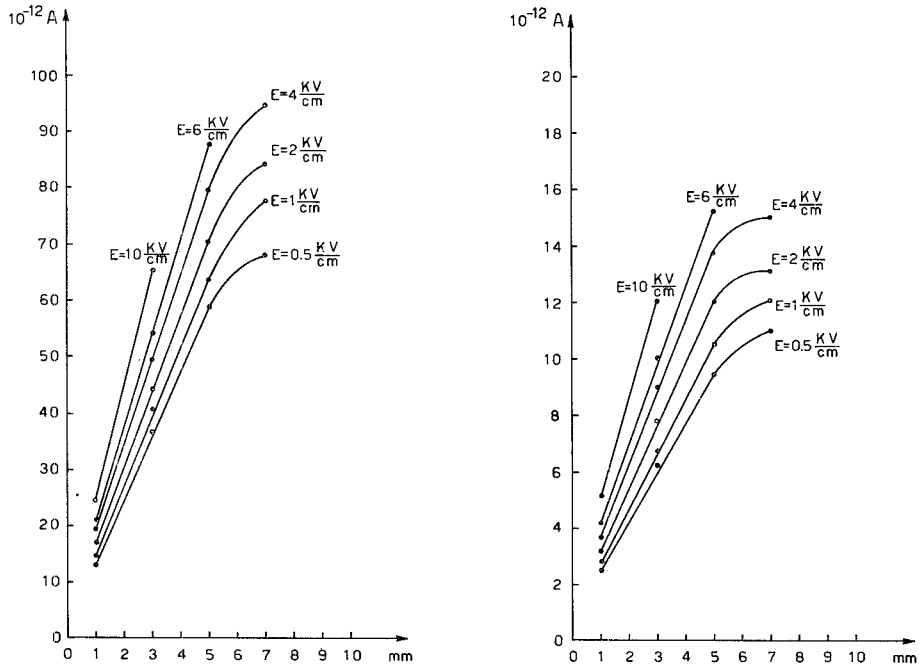

Fig. 4. Ionization current against the interelectrode distance for some values of the electric field strength. The curves on the left side are referred to γ-rays, and those on the right side to neutrons.

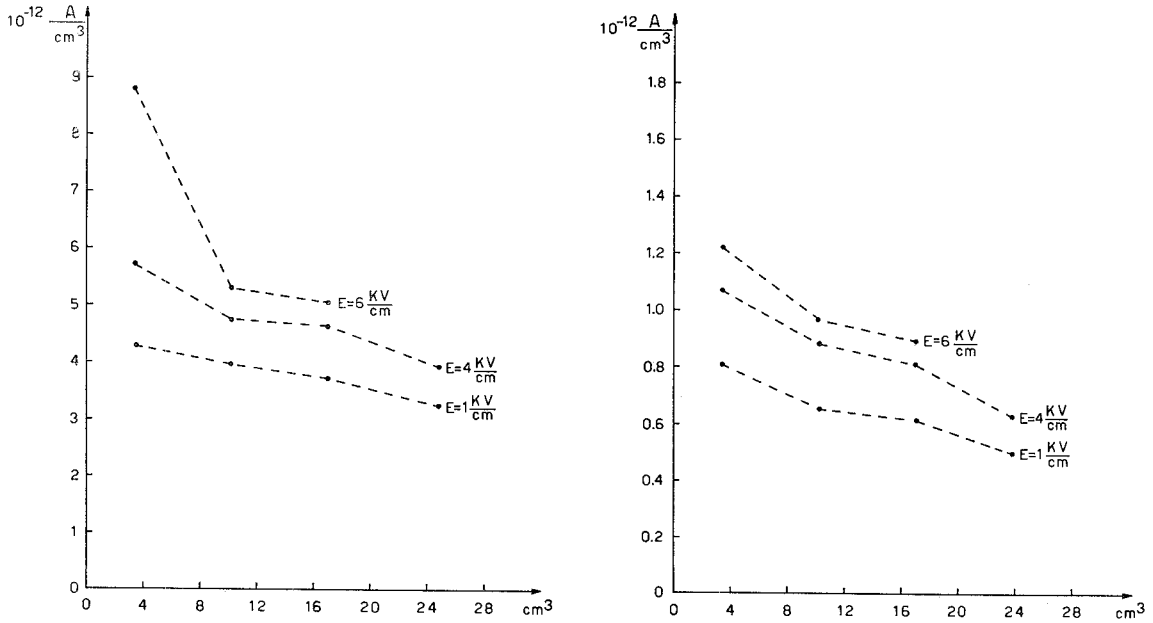

Fig. 5. Ionization current per unit volume against the sensitive volume for some values of the electric field strength. The curves on the left side are referred to γ-rays and those on the right side to neutrons.

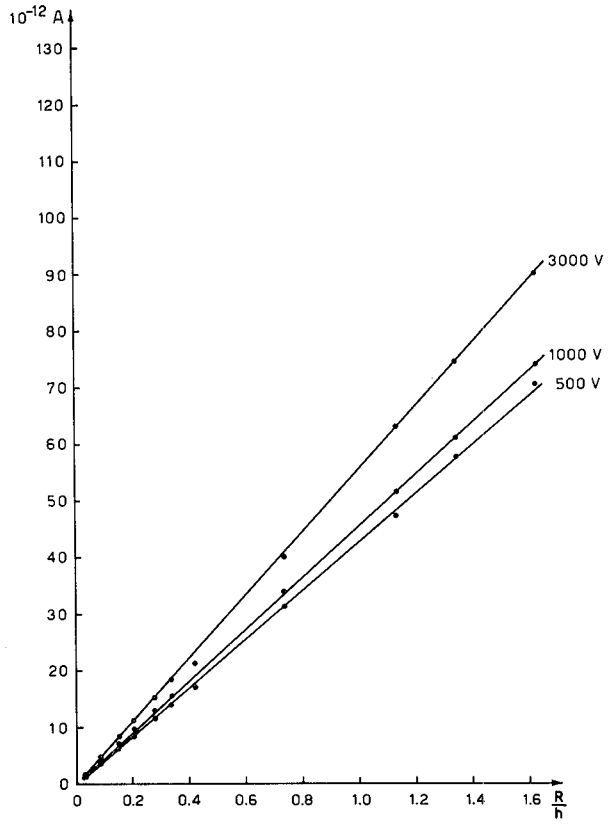

Fig. 6. Ionization current against the dose rate at various voltages for $d = 5$ mm.

some values of the electric field strength for γ-rays and neutrons. As it can be seen, for distances between 1 mm and 5 mm, the current varies linearly with d whatever the value of the electric field strength, whereas the measurements made at 7 mm do not seem to be in line with the others and the displacement from the linear part seems greater for neutrons than for γ-rays.

In fig. 5 the ionization current is plotted for γ-rays and neutrons per unit volume against the sensitive volume of the chamber, for some values of the electric field. A decreasing behaviour is noted as compared to the increasing of the sensitive volume, more accentuated for higher values of the electric field strength. Probably this behaviour is due to influence of the radiation absorption inside the liquid, which we have not considered in these measurements. Such a justification could also explain the behaviour of the curves of fig. 4 for distances of more than 5 mm.

The ionization current against the dose rate is plotted in fig. 6 and fig. 7 with respect to $d = 5$ mm, and in fig. 8 and fig. 9 to $d = 3$ mm.

At $d = 5$ mm, the response is linear for voltages higher than 100 V, that is an electric field strength of 200 V/cm, while at lower voltages a progressive displacement from linearity is shown for increasing values of the dose rate. At $d = 3$ mm linearity is noted until 60 V, i.e. until 200 V/cm, and also in this case the linearity fails at lower voltages for increasing values of the dose rate.

It seems, then, at least in the range of our measurements, that the ionization current is proportional to the dose rate even out of the zone where it is a linear function of the electric field, provided this latter results greater than 200 V/cm. At lower electric fields strength, again there is proportionality with the dose rate, but in a more reduced range. For example at $d = 5$ mm, with a voltage of 50 V, a linearity until about 400 mR/h is shown.

The progressive displacement from the linearity at low voltages and high dose rate could be explained according to our opinion, by admitting that in such a condition in addition to the columnar recombination is present also the volume recombination.

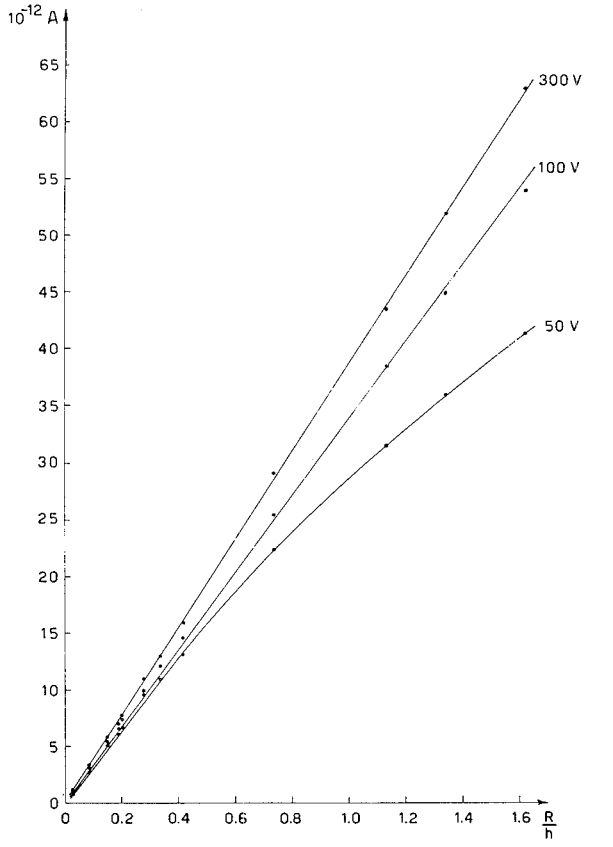

Fig. 7. Ionization current against the dose rate at various voltages for $d = 5$ mm.

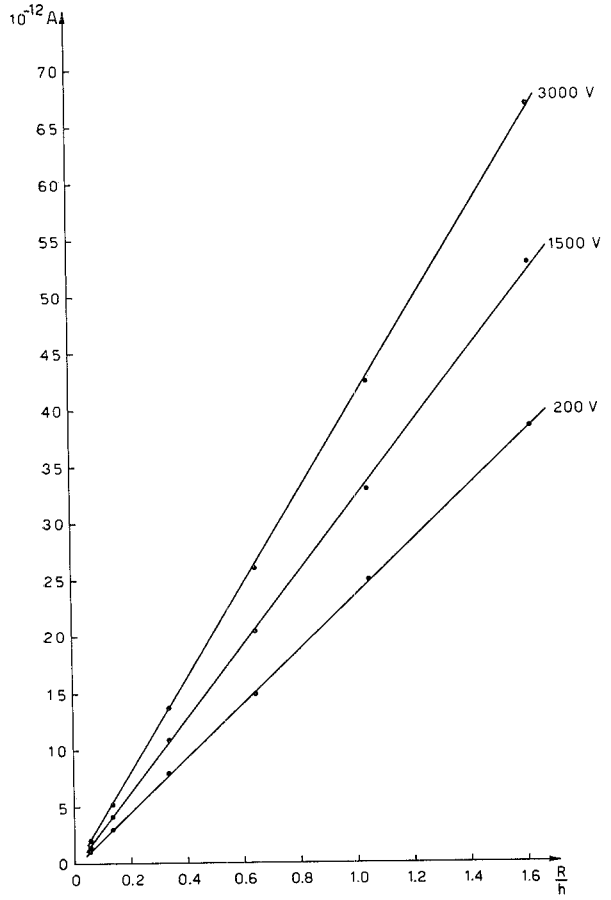

Fig. 8. Ionization current against the dose rate at various voltages for $d = 3$ mm.

Fig. 10 at last, shows the ratio of the ionization current in hexane and in air, measured in the same conditions, for γ-rays and neutrons in function of the distance between the electrodes. The comparison has been made with a collecting voltage of 500 V, which did guarantee the saturation in air for all values of the distance between the electrodes. As it can be seen, the advantage of using hexane instead of air is so much greater as the sensitive volume is smaller, and is greater with neutrons than γ-rays.

3. Conclusions

From the above measurements it seems to us that it is possible to work in dosimetry by detectors based on the ionization in liquids, without high polarization voltages. With electric field strengths greater than 200 V/cm, the ionization current seems to be linear with the dose rate in all range of our measurements, i.e. from about 30 mR/h until about 1600 mR/h. With electric field strengths lower than 200 V/cm we have again linearity, but for a smaller range of the dose rate.

Moreover the employment of an ionization chamber using an organic liquid seems to us particularly promising in all applications when it is essential that the sizes of the detector are small. In fact for very small sensitive volumes, the employment of a liquid instead of a gas seems to produce greater advantages.

From our measurements for example we have seen that, with a sensitive volume of 3.4 cm^3 the ionization current in hexane results greater than that in air respectively 26 times for neutrons and 17 times for γ-rays. With a sensitive volume of about 23.8 cm^3, such ratios are reduced respectively to 19.3 and 10.5.

However, we intend to carry on further comparions for greater and smaller sensitive volumes than those already examined.

On the basis of these results we are now designing a dosimeter of small sizes to employ with low polarization voltages, giving particular attention to the conditions of electronic equilibrium in order to obtain directly the response in rad.

In order to increase the sensitivity of the instrument it will be suitable to improve still the purification of the liquid. To our purposes it seems to us sufficient to reduce the background current by a factor of five or ten.

The employ of a dosimeter realized in such a way

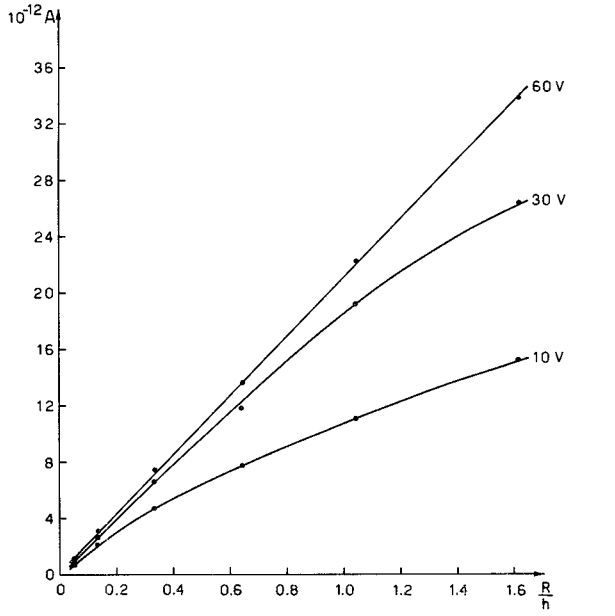

Fig. 9. Ionization current against the dose rate at various voltages for $d = 3$ mm.

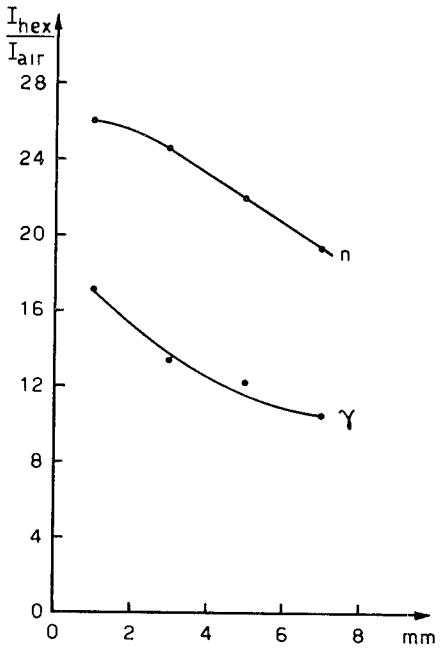

Fig. 10. Ratio of the ionization current measured in hexane and air against the interelectrode distance for γ-rays and neutrons.

should be very practical and suitable for all the dosimetric measurements where small sizes of the detector are essential on account of the sharp gradients of radiation fields used.

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