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ABSTRACT. -

The possibility of using a trans-stilbene crystal to measure the equivalent dose in a mixed γ-n field has been studied. We have obtained each of γ-rays and neutron signals, separated by pulse schape discrimination, gave a good equivalent dose response to the only radiation component which they were sensible to. For the neutrons we have got a good equivalent dose response in the range of 0.1 ÷ 10 MeV (where the elastic scattering is predominant) by suitable saturation of the pulses produced by recoil protons. For the γ-rays we directly measured the absorbed dose in the scintillator because of its tissue equivalence up to several MeV. In the range of γ-rays exposure up to about 0.2 R/hr, the sum of the two measured contributions was constant, within the experimental errors, when we varied the relative dose intensity, keeping fixed the total equivalent dose rate.

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I. - INTRODUCTION. -

The great differences produced, in the biological effects, by the various ionizing radiations, depending on radiation nature complicates the problem of evaluating the risk in a mixed field. It is well known that the equivalent dose DE has been introduced to take into account these differences. This quantity has been defined as the absorbed dose multiplied by the relative biological effectiveness RBE, which is a modifying factor depending on the considered biological effect, on the radiation nature and on a number of exposure conditions. Since in all pratical situations the exposure conditions are not well known, the ICRU[1], together with ICRP[2], has recomended that, in protetionistic dosimetry, a quality factor QF, depending only on linear energy transfer LET be used instead of the RBE.

In practice almost all problems on the measure of the equivalent dose in mixed radiation fields, concern with γ-n mixed field both for their frequence and for remarkable difference in the QF of γ-rays and neutrons.

It seems the use of organic scintillators can be usefull in dosimetry of such a mixed field because of their good tissue equivalence and because some of them allow discrimination between γ-rays and neutrons[3, 4, 5]. This latter fact, as we shall see in the following, has allowed us to measure separately the contribution to the total equivalent dose due to each radiation component using a single rivelator, a stilbene crystal.

We have chosen a stilbene scintillator instead of the cheaper organic liquid scintillators, now more and more used in γ-n discrimination problems, because it is less critical in the work conditions. This fact is fundamental to obtain a response to neutrons proportional to the equivalent dose in a very simple way.

II. - EQUIVALENT DOSE FROM NEUTRONS. -

In the energy range 0.1$\div$14 MeV, elastic scattering is the most important contributor to the neutron dose. In the following we shall consider only elastic scattering. This approximation is quite crude within 10 and 14 MeV, where non elastic scattering becomes more important and contributes both to the neutron kerma and to the neutron dose for about 20%; nevertless it can be accepted even in this energy range, if used only for protetionistic purpose. Moreover within 0.1 and 14 MeV, the distinction between absorbed dose and kerma is negligible except at volumes so small that the wall effects of recoil nuclei become important.

In Fig. 1 the neutron kerma $K(E_n)$ due to elastic scattering only, calculated from the data of ref. (6), is given versus neutron energy E_n (upper curve) together with the contribution $K_p(E_n)$ due to recoil proton (lower curve). The relative contribution of the hydrogen and the other important elements in tissue, oxigen, nitrogen and carbon, is approximately constant versus neutron energy with the protons contributing, in average, for about 85 ÷ 90%. We can see (dotted line of Fig. 1) that it is possible to obtain a good approximation $K'(E_n)$ of $K(E_n)$ if we put :

$$(1) \qquad K'(E_n) = (1+q)\,K_p(E_n)$$

where $q = 0.12$ is indipendent on neutron energy.

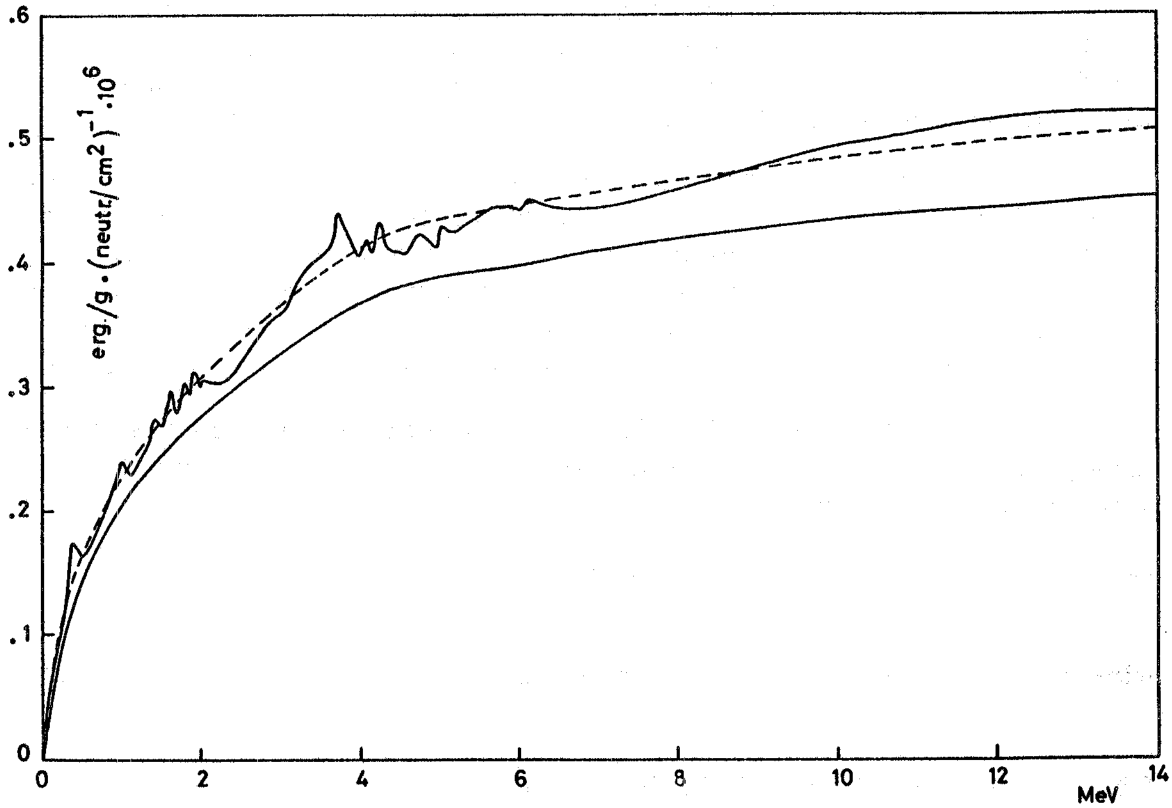

FIG. 1 - Neutron kerma, due to elastic scattering in tissue, versus energy (upper curve); Contribution of recoil protons (lower curve); Contribution of recoil protons multiplied by 1.12 (dotted line).

If we assume this approximation, by eq. (1) one can say that, whenever a proton absorbes an energy E, an energy qE is absorbed in average, by the other elements in tissue. As the quality factor of heavy recoil nuclei in tissue is independent on energy and on type of nucleus, if we indicate its value by $(QF)_o$ ($\doteq 20$) and by $\langle (QF)_p \rangle_E$ the average quality factor of a complitely absorbed proton of energy E, for the equivalent dose $(DE)_n$ from a neutron of energy E_n, we can write :

$$(2) \qquad (DE)_n = (DE)'_n = \int_0^{E_n} dE\, P_H(E_n \rightarrow E)\, E\, \langle (QF)'_p \rangle_E$$

where $P_H(E_n \rightarrow E)$ represents the probability that a neutron of energy E_n has to produce a proton within E and E+dE in one gram of tissue and where

$$(3) \qquad \langle (QF)'_p \rangle_E = \langle (QF)_p \rangle_E + q(QF)_o .$$

In Fig. 2 the equivalent dose, due to a proton completely absorbed in tissue, is given versus the proton energy (full line). This curve has been calculated from Rossi relationship(7) between QF and LET. In the same figure dotted line represents $\langle (QF)'_p \rangle_E$ times the energy E; its meaning is a type of "proton effective equivalent dose" that can be used to take into account the contribution from heavy recoil nuclei, within the approximations discussed above.

In Fig. 3 the neutron equivalent dose (dotted line) calculated by eq. (2) and Fig. 2, is compared with the neutron equivalent dose from elastic scattering (upper curve). From this comparison it will result that, within the precision usually required in the equivalent dose measurements, all the things go as if the neutrons interact only with the hydrogen, being the effective QF of the protons given by eq. (3).

Finally if we call $(DE)_{\gamma+n}$ the equivalent dose in a mixed γ-n field, and D_γ the absorbed dose from γ-rays, neglecting nonelastic scattering, we can write:

$$(4) \qquad (DE)_{\gamma+n} = D_\gamma + (DE)'_n$$

where γ-rays QF has been taken equal to unity.

III. - DESCRIPTION OF THE INSTRUMENT. -

The separation of the contribution of the two kinds of radiation in a mixed γ-n field, using a stilbene scintillator, is feasible by means of the shape difference in the light pulses produced by electrons and protons respectively. Among the numerous techniques used there are some wich use the fact that the spatial charge between dynodes, at low values of polarization voltage, depends on the shape of the pulse(8). Using this fact, since the slow component of the light pulse is comparatively higher for protons than for electrons, by means of a suitable saturation of the phototube, it is possible to obtain clearly separated pulse amplitude in a wide energy range of the two ionizing particles.

With respect to neutrons contribution to the total equivalent dose we shall reach our goal, within the approximation showed in Fig. 3, if we obtain a response to protons versus energy that fits the dotted line of Fig. 2. In this work we have tried to obtain this fitting by suitably varying the saturation of the phototube, compatibly with the need of γ-n

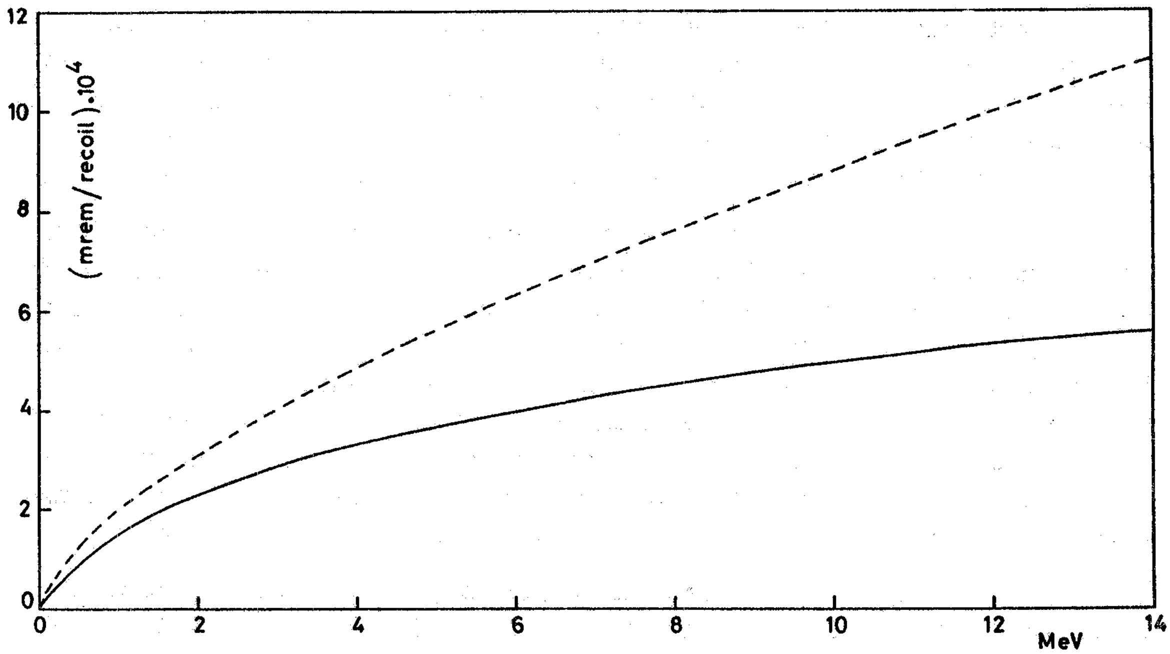

FIG. 2 - Proton equivalent dose (full line) and proton "effective" equivalent dose (dotted line) versus energy.

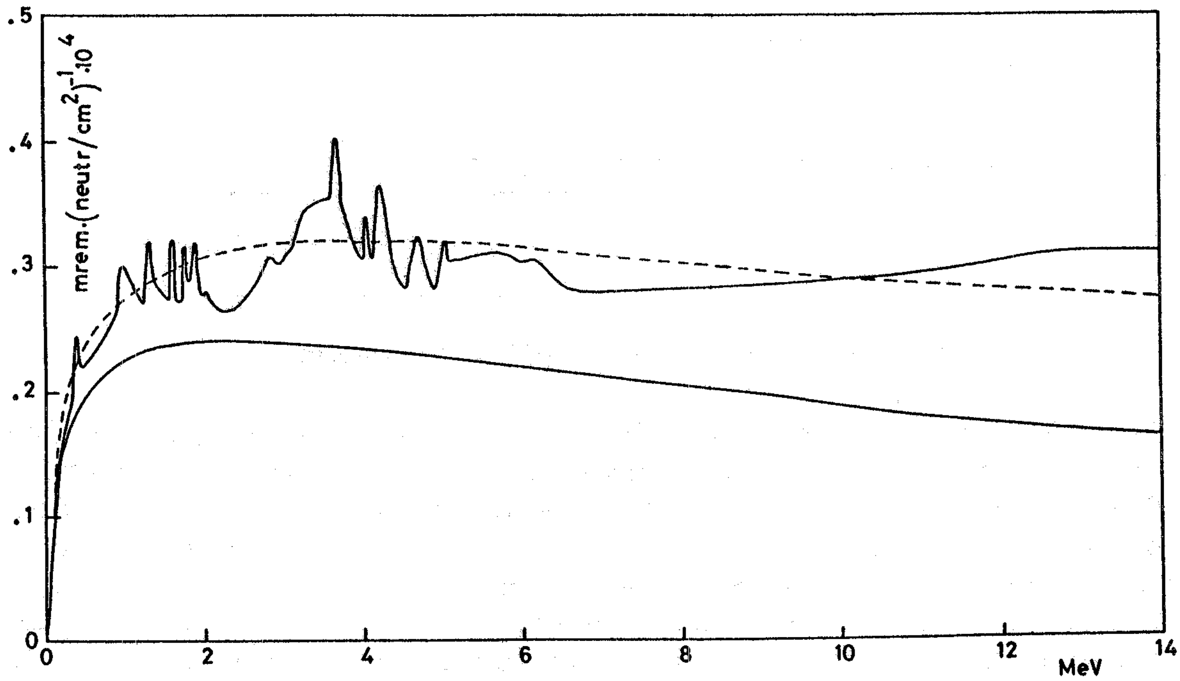

FIG. 3 - Neutron equivalent dose in small element of tissue in free space versus neutron energy (elastic scattering only). Calculated from eq. (2) and Fig. 2 (dotted line); Calculated from ref. (6) (upper curve); Contribution of protons (lower curve).

discrimination. Our hope that this way could be successfull was based on the fact that the ratio between slow and fast components in stilbene light pulse increases with LET[9] and then with QF of ionizing particle. In addition if the saturation is raised, pulse height becomes an increasing function on this ratio for the same light produced. Then we can expect that a suitable saturation give, at the same absorbed energy, a pulse height increasing with QF, as required to fit the dotted line of Fig. 2.

To measure γ-rays dose it is enough to measure the light produced by them; indeed stilbene is tissue equivalent up to several MeV and the light linearly depends on energy of γ-rays. With respect to the contribution to the light coming from neutrons, it can be showed that, for the same contribution to the total equivalent dose, the light from the neutrons, represents in our scintillator only some per cent of the light from γ-rays. However for higher precision or when little scintillator are used, this contribution, can be strongly reduced by anticoincidence with the satured signal after the γ-rays have been discriminated.

In Fig. 4 it is shown the block diagram of our instrument. A 2" in diameter, 1" in thickness stilbene scintillator is assembled on a

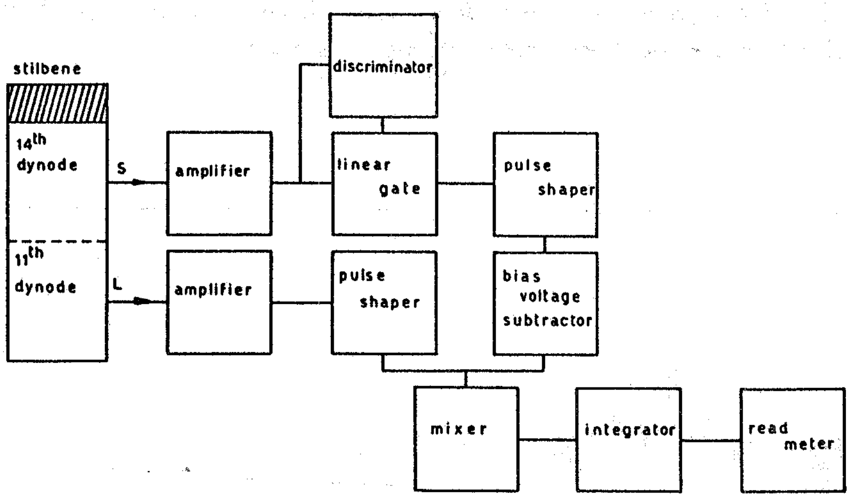

FIG. 4 - Block diagram of the dosimeter.

6810A phototube whose distribution scheme is shown in Fig. 5. Two signals, L and S, have been taken from 11th and 14th dynod respectively. The first is linear with the light and is used to measure the contribution of γ-rays to the total equivalent dose, the second one, suitably saturated and biased to have a better agreement with the dotted curve of Fig. 2, is used to measure neutron contribution. L and S are shaped mixed and finally sent to an integrator for measuring the total equivalent dose rate. The last dynodes of the phototube (see Fig. 5) have been separately feeded to be guaranteed in the stability of the work conditions even at relatively high dose rate.

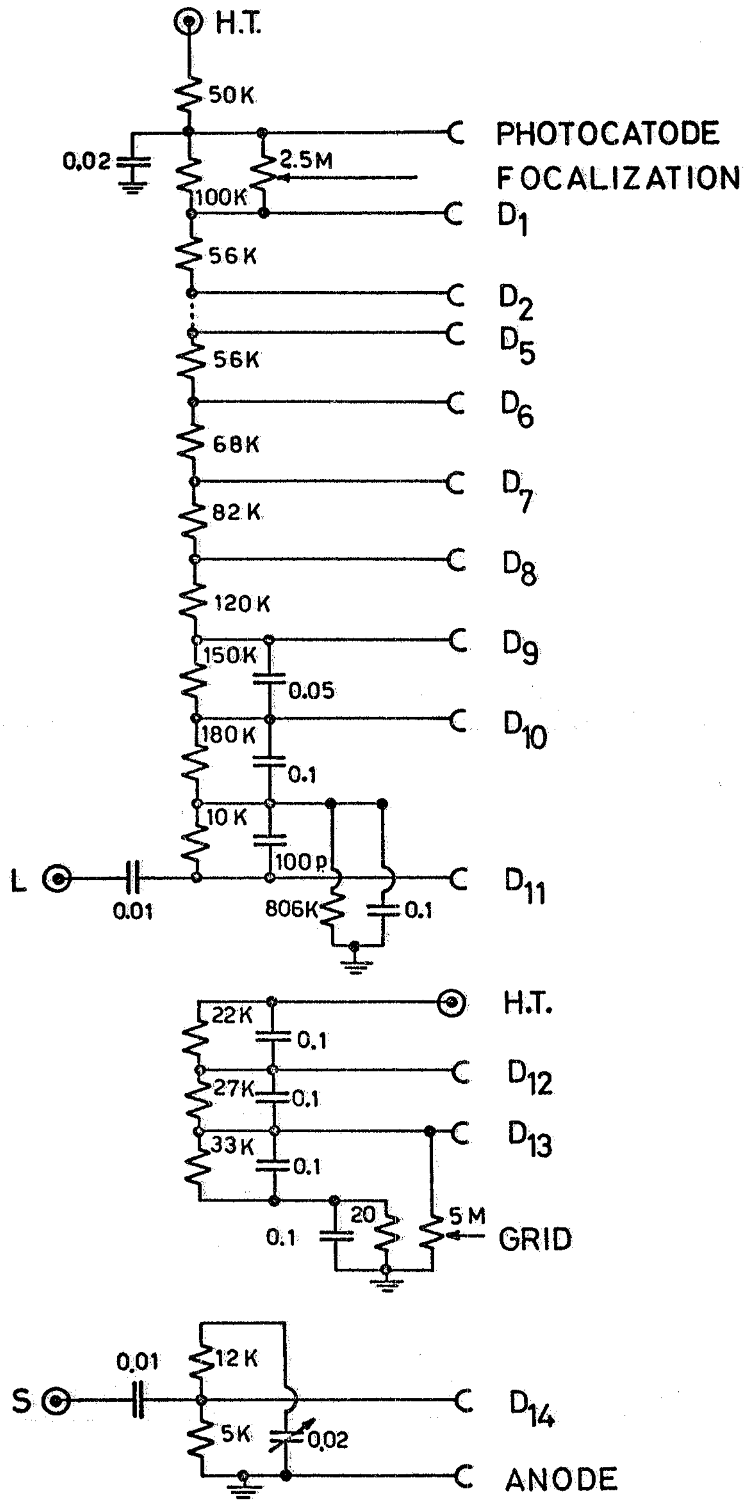

FIG. 5 - Feeding distribution scheme of the phototube.

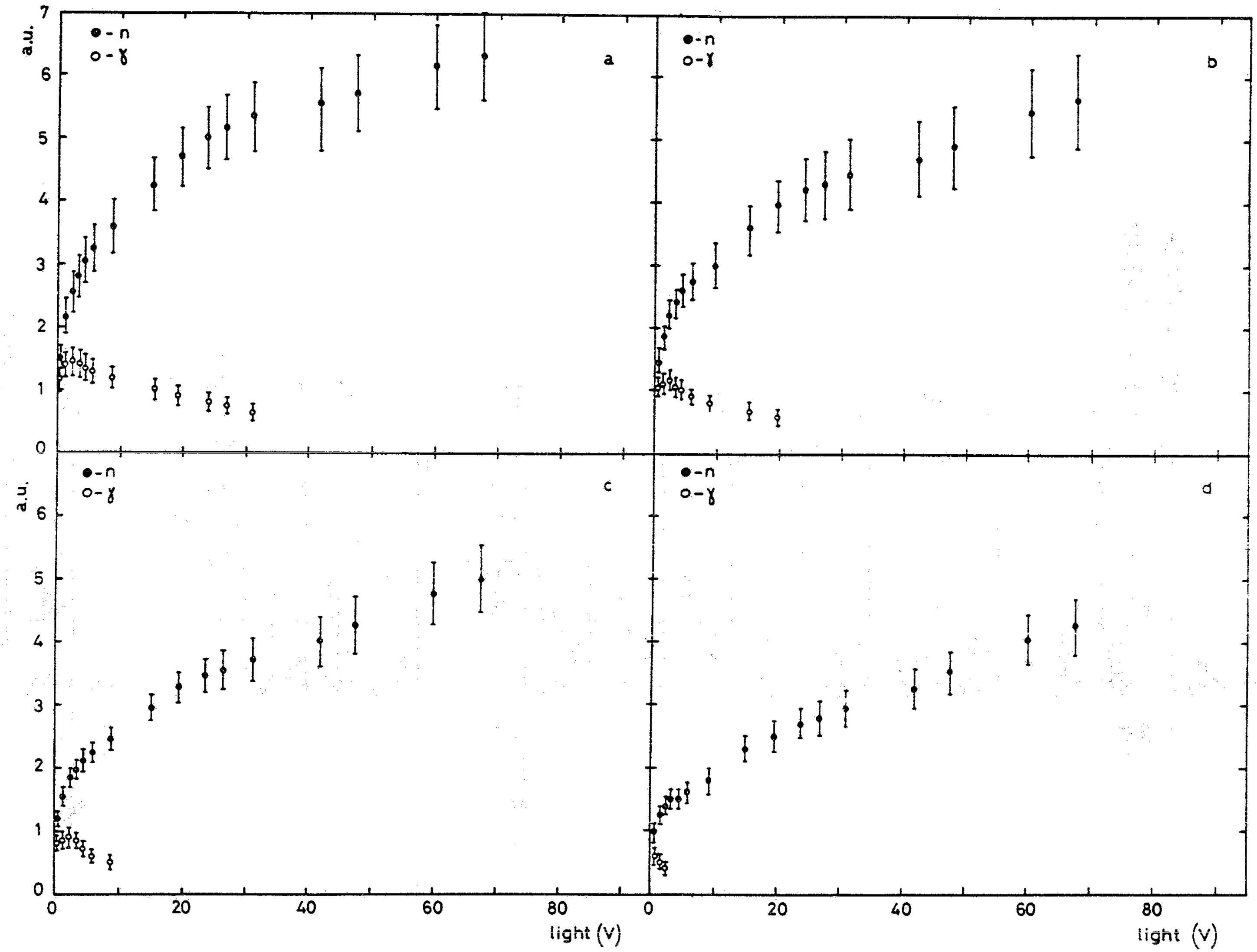

FIG. 6 - Neutron and γ-rays saturated pulse height versus light. Experimental points of a), b), c) and d) are relative to different voltages between last dynode and anode, corresponding to 17, 15, 13 and 11 V respectively.

IV. - PERFORMANCES. -

The amplitude of the saturated pulse has been analysed versus the correspondent amplitude of the linear one by means a 512 multichannel LABEN. A Po-Be source, that has a broad neutron energy spectrum from 0 to about 10 MeV, has been used to this purpose. The Fig. 6 gives results obtained at a phototube voltage supply of about 2.000 V, at various voltages between the last dynode and anode. In Fig. 7 the experimental data are compared with the theoretical curve of proton "effective" equivalent dose (Fig. 2 dotted line). The experimental

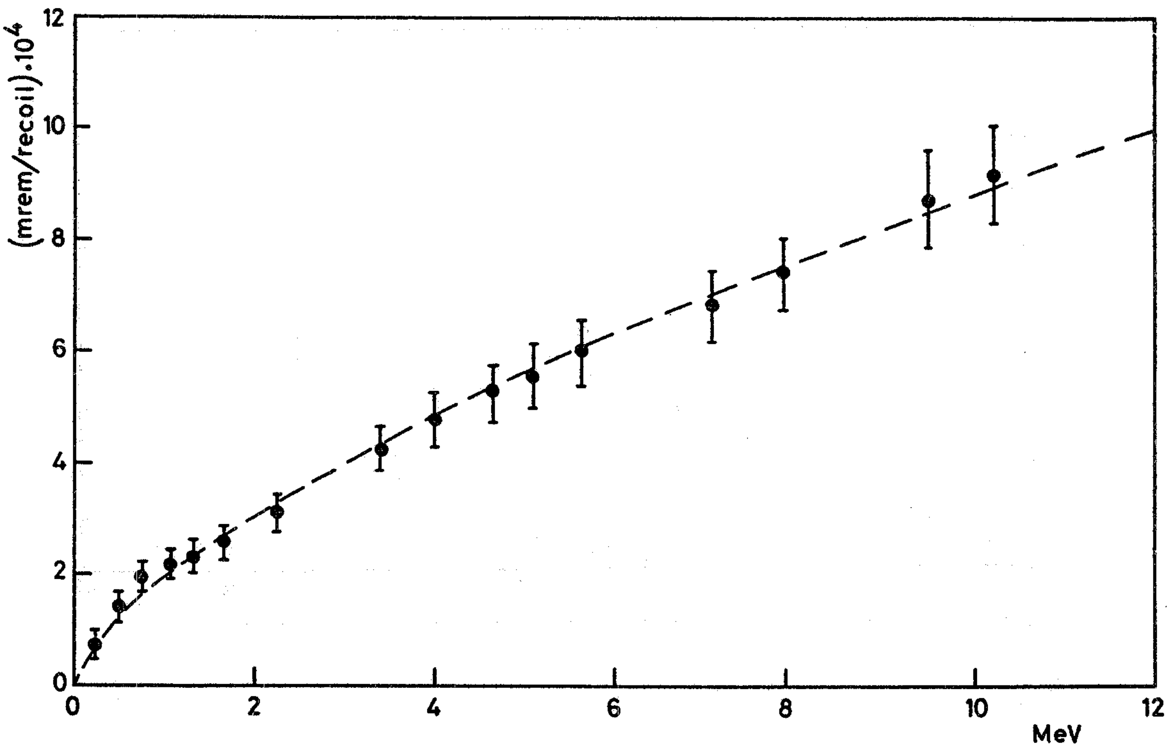

FIG. 7 - Theoretical curve and experimental points of protons "effective" equivalent dose versus energy.

data are those corresponding to the Fig. 6(d), and the comparison is made starting from a bias equivalent to about 80 keV-proton, subtracted from saturated signal in order to obtain a better agreement. This data are reported versus the proton energy using pulse height to energy relationship of ref. (8).

Fig. 8 (a, b, c) shows the amplitude of the integrated and saturated signal versus the equivalent dose due, separately, to γ-rays and neutrons at different values of the discriminating threshold corresponding to 0.35, 0.45 and 0.6 MeV-proton respectively. In these trials the mixed γ-n field has been obtained by means of a Po-Be and a ^{60}Co source and the contribution of γ-rays from Po-Be source has been neglected.

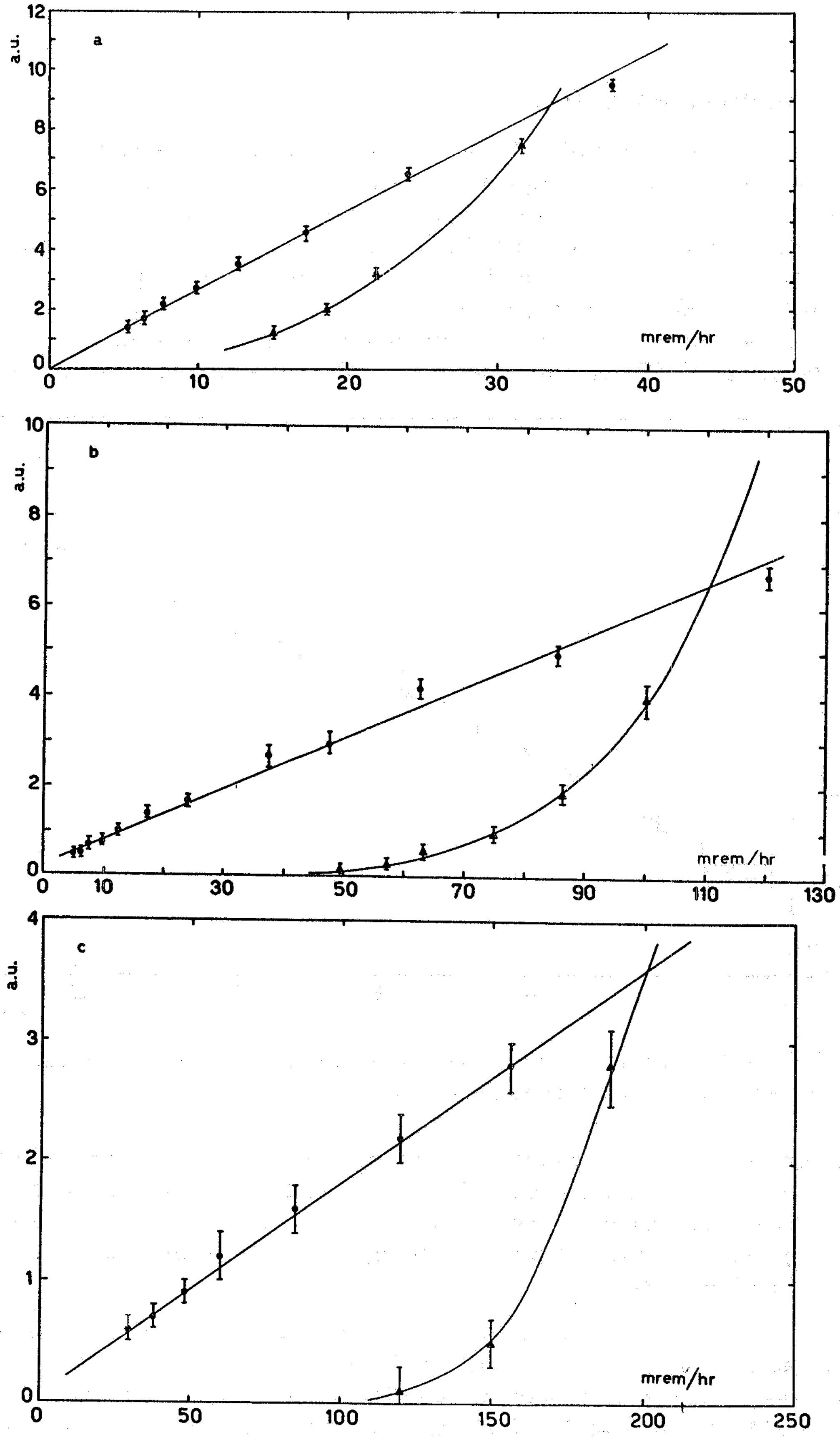

FIG. 8 - Saturated signal versus equivalent dose: ▲ from γ-rays, ● from neutrons; curves a), b) and c) correspond to 0.35, 0.45 and 0.6 MeV-proton of discriminating treshold respectively.

The sum of the linear and saturated signals resulted to be indipendent on the relative contribution of the γ-rays and neutrons to the total equivalent dose up to exposure rate of about 0. 15 R/hr. Fig. 9 gives the results of this sum versus the equivalent dose rate at the treshold value of 0. 6 MeV-proton and for different compositions of the mixed field.

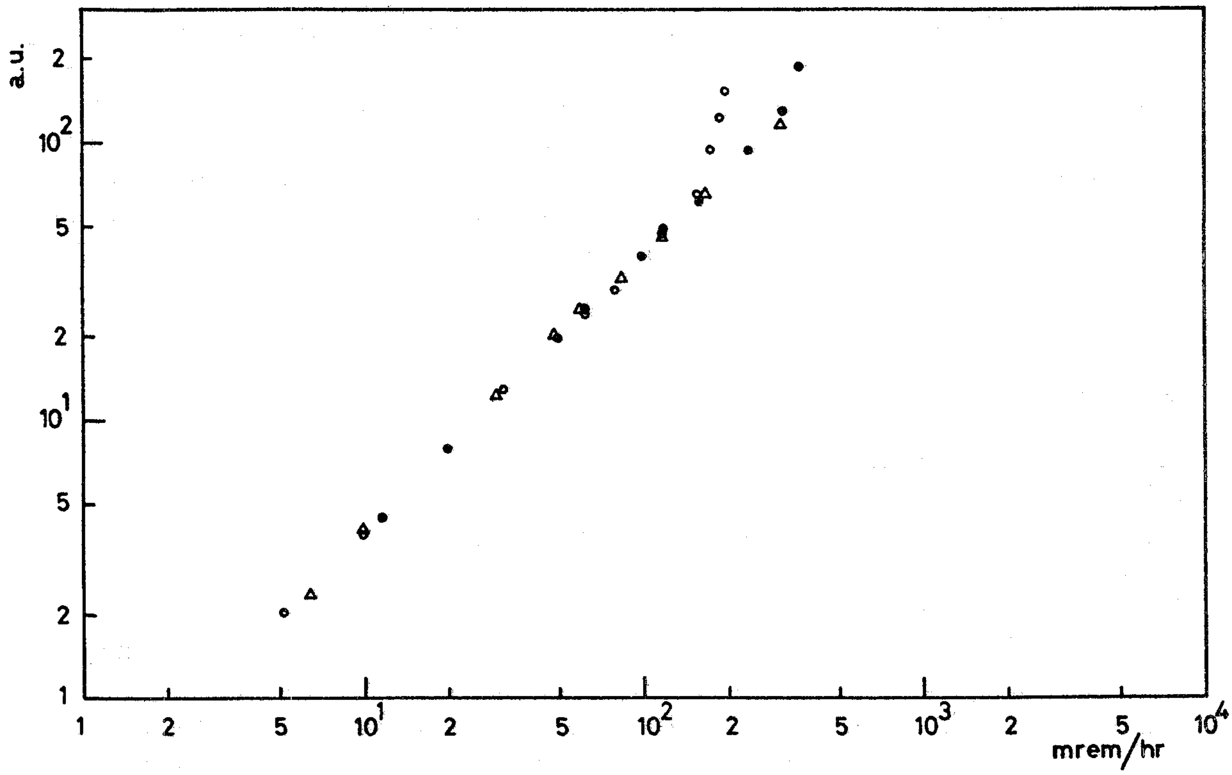

FIG. 9 - Response of our dosimeter versus equivalent dose in mixed field of different composition: △ neutrons only, o γ-rays only, ● γ-rays and neutrons contributing about in equal ratio to the total equivalent dose.

V. - CONCLUSIONS. -

It can be seen (Fig. 8) that the γ-rays contribution to saturated signal raises versus D_γ, about as D^2_γ at low discriminating treshold and faster at higher threshold values. This is a characteristic effect of overloading of the electronics. Indeed counting rate capability of our electronics is of about 10^5 counts/sec and this rate is of the same order of that one produced by γ-rays exposure rate of 0. 1 R/hr in a 2" x 1" stilbene scintillator. This effect can be strongly reduced both using faster electronics and smaller scintillators. It must be noted that a electronic equipment whose count rate capability were better than 10^6 counts/sec could not be fruitfully used owing to the fact that the slow component of the light pulse is several hundreds of nanosec of constant time decay. However it can be easily argued that a stilbene scintillator of 1 cm x 1/2 cm could be used up to exposure rate of several R/hr even with our electronic.

Owing to the relatively small sizes and to the fact that it is possible to have measurements of DE by means only one rivelator, the use of our dosimeter seems very promising both for protectionistic and for research purposes. In fact it can allow DE measures even in small regions (embodied for example in phantoms or in shielding materials) with negligible disturbance.

Moreover it seems of interest to use this instrument for measuring QF of γ-n mixed field when it is employed together with a tissue equivalent chamber. Within the limitation in energy range and γ-rays dose rate discussed before, we think this fact could be of utility near high energy accelerators, where remarkable variations of the quality factor of the mixed field are possible related to the avrious shielding configurations and to the different work conditions of the machines.

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