ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-76/63

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Nuclear Instr. and Meth. 138, 209 (1976)

Servizio Documentazione
dei Laboratori Nazionali di Frascati
Cas. Postale 13 - Frascati (Roma)

NUCLEAR INSTRUMENTS AND METHODS 138 (1976) 209–212; © NORTH-HOLLAND PUBLISHING CO.

MEASUREMENTS OF DOSES PRODUCED BY HIGH ENERGY BEAMS ON THICK TARGETS

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Received 1 June 1976

A 1000 MeV bremsstrahlung beam was sent on Pb and W targets of various thicknesses.

The resulting doses were measured by LiF thermoluminescent dosimeters at various depths in polyethylene phantoms. Measurements were carried out at various angular positions with respect to the beam direction. The results are presented and discussed.

1. Introduction

When a high energy beam interacts with matter a large number of secondary particles is produced. Their energy can be as high as that of the primary particles. The angular distribution of the secondary particles depends on various parameters, including the kind of incident particle and its energy. If the primary beam is made up of electrons or if it is a bremsstrahlung beam, a number of particles, mainly photons and neutrons, is created around the target. Knowledge of the doses around such a target is obviously of high interest from various respects, including shielding calculations and dose estimates for accidental overexposures.

The dose distribution as a function of the tissue depth and of the angle has been measured by Wyckoff et al.[1]) for electron beams of energies between 20 and 100 MeV on heavy material targets.

Doses produced directly by incident electron beams have also been measured on phantoms made up of equivalent tissue[2]).

However so far no similar data to the ones measured by Wyckoff et al.[1]) are available for beam energies greater than 100 MeV or for bremsstrahlung beams. Therefore we decided to measure the dose distribution in equivalent tissue at various angles with respect to the direction of a bremsstrahlung beam of maximum energy 1000 MeV.

Since in these conditions the dose is mainly due to the electromagnetic component, on our measurements the neutron contribution was ignored. However, while such a contribution can be neglected as far as dosimetry is concerned, it can be relevant or also in some cases dominant for shielding calculations.

2. Description of the measurements

The experimental arrangement is shown schematically in fig. 1. The 1000 MeV bremsstrahlung beam from the L.N.F. electrosynchrotron was directed on W and Pb targets of various thicknesses. Phantoms realized using polyethylene ($\rho = 0.91$ g/cm^3) sheets ($15 \times 15 \times 2.5$ cm^3) were placed at various angles around the target. LiF thermoluminescent dosimeters (Harshaw Co., type TLD 700) were inserted between the polyethylene sheets to measure the electromagnetic component of the dose. The detector housings were spread out around the center of the sheets to prevent the measurements in one point to be influenced by the previous dosimeters.

The target thicknesses were 0.4 mm, 3.4 mm, 9.2 mm, 11.8 mm, 14.8 mm and 25.6 mm for the tungsten, 86 mm and 123 mm for the lead case. Their lateral dimensions were always 5×5 cm^2.

The dosimeters were calibrated and selected by exposures to ^{60}Co γ-rays. It has been shown that the response of LiF TLD to γ-rays from ^{60}Co is equivalent within 5% to the response to 15 MeV electrons[3]), and within 15% to 20 GeV electrons[4]). The dosimeters used were selected to give equal response to ^{60}Co γ-rays within 4%.

In principle the measured values must be corrected

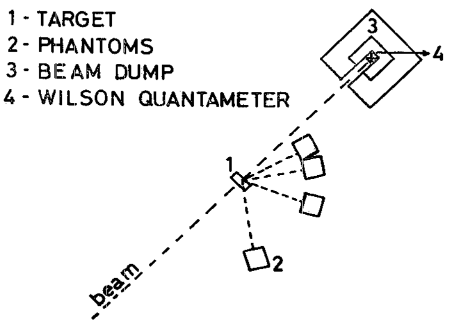

Fig. 1. Schematic illustration of the experimental arrangement.

for the effect due to the presence of the dosimeter. In practice this correction is irrelevant as can be proved using the Bragg–Gray relation, which is certainly valid in our conditions. In fact the results of a Monte Carlo calculation by Völkel[5]) show that, for targets whose thicknesses correspond to the maximum shower development and for monochromatic 1 GeV photon beams, only a fraction of about 1% of the total energy is carried by photons and electrons of energy less than 1 MeV. Therefore the particles emitted by the target with energies less than 1 MeV can be disregarded. The range of 1 MeV electrons in LiF is 1.5 mm, to be compared to the thickness of the dosimeter, which is only 0.889 mm. Therefore the small cavity hypothesis is verified in our case, so that we can use the Bragg–Gray relation.

The value $(S/\rho)_{\text{pol}}/(S/\rho)_{\text{LiF}}$ appearing in this relation has been calculated as a function of energy and its values, as was predictable, are practically equal to 1 (see fig. 2).

The quantametry was carried out by the induced activity technique, using the $^{27}\text{Al}(\gamma,2\text{pn})^{24}\text{Na}$ reaction as monitor reaction. The method was directly calibrated against a Wilson quantameter, and a cross section per equivalent quantum of 0.71 mb was found, which is in good agreement with the values reported by several authors[6]).

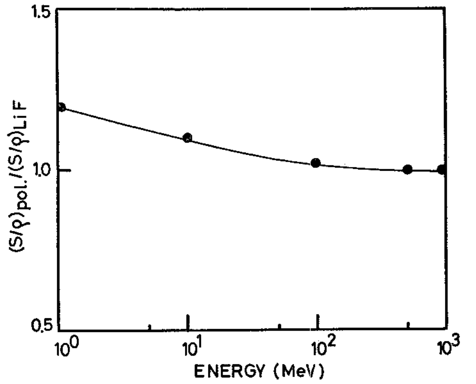

Fig. 2. Ratio of the collision mass stopping power of the poly-ethylene to that of the LiF, vs the electron energy.

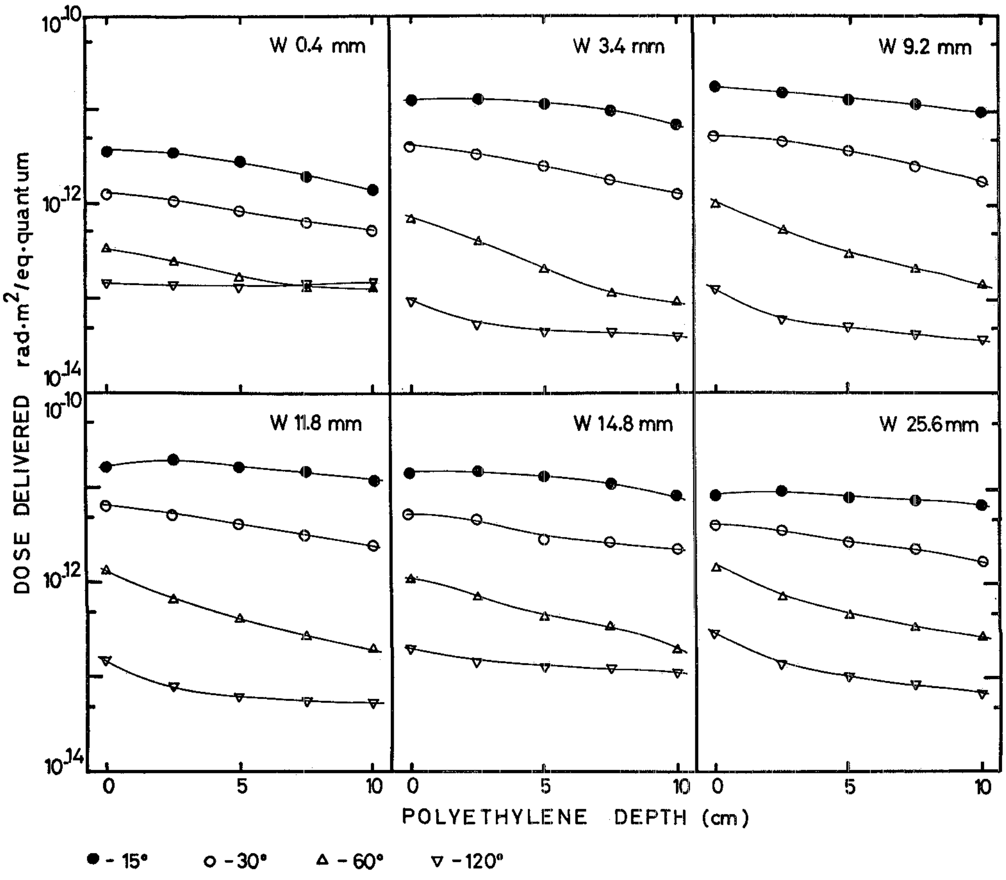

Fig. 3. W results. The data are presented as depth dose curves in polyethylene for some fixed angles relative to the beam direction.

3. Results and discussion

All measurements have been performed using the 1000 MeV bremsstrahlung beam incident on the described W and Pb targets. Of course the results will be expressed as a function of the number of equivalent quanta ($N_{eq} = E_{tot}/E_{max}$).

The doses have been measured at depths of 0, 2.5, 5.0, 7.5 and 10 cm in polyethylene, at angles of 15°, 30°, 60° and 120° with respect to the direction of the beam. Each exposure lasted about 4 h, corresponding to about 10^{12} equivalent quanta incident on the target.

The results for W targets are shown in fig. 3. The results for the two Pb targets are shown in fig. 4. The data include background contamination which is due essentially to backscattering from the beam dump placed at 2–3 m from the polyethylene phantoms. The amount of this contamination has been found to be unimportant except for the measurements performed using thin targets. For example, for a W target 0.4 mm thick, the doses measured at angles of 60° and 120° coincide with the background while the data at 15° and 30° show a contamination of about 15%. Increasing the target thickness the background contamination decreases. We can estimate that, for the 2.4 mm target, only the measurements at 60° and 120° are affected, while for greater thicknesses the background can be disregarded.

The main characteristic of the experimental curves is the strong dependence of their behavior on angle. In fact the small angle curves show a broad maximum and then decrease with increasing phantom depth, while the large angle ones are always decreasing. This can be explained assuming that the high energy particles' contribution dominates in the forward direction, while the low energy particles are predominant at large angles.

Of course, for a fixed depth, the dose decreases strongly for increasing angles.

For thick targets this angular anisotropy is less evident, because the fraction of the shower absorbed in the target increases, thus decreasing the dose at small angles. While the wide angle contribution, which is due mainly to the limited transverse dimension of the target (the same for all thicknesses), stays practically constant.

The data for zero depth are also shown, in fig. 5, as function of the target (W) thickness expressed in radiation length. The figure shows that the maximum dose normally corresponds to a thickness equal to the maximum shower development (≈ 3.36 r.l.), as foreseen by the shower theory.

Qualitatively our curves are similar to those found by

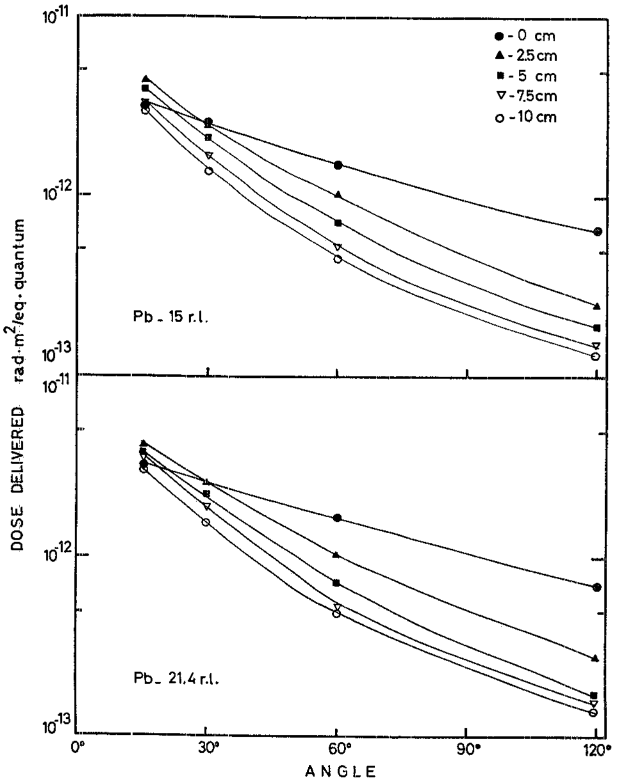

Fig. 4. Pb results. The data are presented as angular distribution of doses measured at various polyethylene depths.

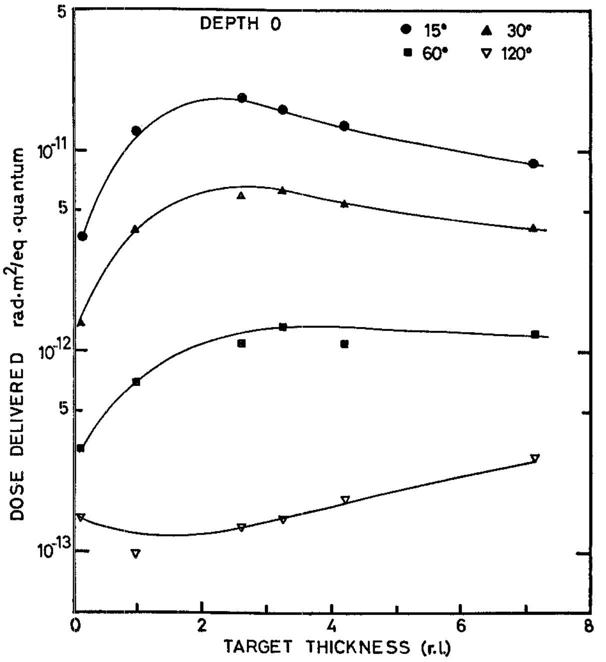

Fig. 5. Doses at zero depth measured at the angles considered, vs the target thickness (W data only).

Wyckoff with 100 MeV electrons. A quantitative comparison is not possible because the two experiments use different particles and energies. However, one can note that the order of magnitude of the doses is not so different as the different experimental conditions would suggest. In detail, our small angle values, if normalized to the total energy incident on the target, are about 10 times higher than those found by Wyckoff at 100 MeV, while the two experiments give similar values at large angles. The first observation can be explained with the higher energy of our beam. On the other hand, the similarity of the wide angle results can be related to the transverse dimension of the targets expressed in Molière lengths which were quite similar in both cases.

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