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Intercomparison of gamma dose measurements at the 8 MeV electron accelerator

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Abstract

Measurements of gamma dose with thermoluminescent detectors, Fricke dosemeters and an ionisation chamber were performed in the range of 5 to 70 Gy in the electron bremsstrahlung field with a maximum energy of 8 MeV of the Bucharest linear accelerator. Previous calibration was done with a ^{60}Co source.

The results of the intercomparison were used in dosimetry of the $n - \gamma$ field of the $\Sigma\Sigma$ irradiation facility, with a gamma spectrum similar to the 8 MeV bremsstrahlung field.

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Abstract

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1 Introduction

The ΣΣ irradiation facility [1] is a secondary standard for reactor dosimetry and is suitable for radiation hardness studies of Si detectors for high energy collider experiments, as it has been shown in [2]. For the gamma dose characterization of this environment it was necessary to calibrate the MgF_2(Mn) and CaF_2 thermoluminescent detectors in a similar gamma spectrum.

At the 8 MeV electron linear accelerator of the Institute of Physics and Technology of Radiation Devices (IPTRD) it is possible to obtain several bremsstrahlung spectra. For our measurement a bremsstrahlung spectrum of 8 MeV electrons has been used. The gamma beam was obtained on a 1 mm thick Mo target.

2 The experimental set-up

The linear electron accelerator ALIN-10 works in pulses of 3.5 μs, with a repetition frequency of 100 Hz. The maximum current is 100 mA; the maximum energy can vary between 6 and 10 MeV, and the standard working conditions are at 8 MW [3].

The electron beam of 8 MeV produces bremsstrahlung radiation on a 1 mm thick Mo (Z=42) target. The gamma beam obtained passes through 12 mm of aluminum which absorbs completely the electrons. The gamma spectrum obtained has been computed in the approximation of a thin target [4].

The spread of the beam due to scattering in the target and the absorber determines, in a plane situated at 50 cm from the target, a gamma focal spot of about 11 cm diameter and an approximately constant intensity. This is the plane where the detectors have been positioned. A monitor ionisation chamber type VA-K-253 was situated on the beam axis, at a distance of 60 cm.

The gamma radiation has also been attenuated between the detectors and the monitor, due to the detector holder, made of 10 mm of glass.

The calculated energy spectrum of the bremssstrahlung gammas is given in Figure 1 a. The absorption of the gammas in 12 mm Al has been taken into account in the calculation.

3 The detectors

The thermoluminescent detectors used have been MgF_2(Mn) TLDs, manufactured by INPE Bucharest [5] and CaF_2 detectors, manufactured by INR Piteşti [6].

The MgF_2(Mn) are 0.6 mm thick and 12.5 mm diameter tablets, covered with Sn foils to reduce the low energy response. They have been calibrated previously at 1.25 MeV with a ^{60}Co reference source. The maximum deviation from the calibration curve for individual detectors is 10%. The regression of the signal is about 10% in a week (see [7]).

The TLDs of CaF_2 are 1 mm thick and 3.2 mm diameter tablets; four such detectors being encapsulated in a cylinder of aluminum with a 1 mm thick wall. They have been calibrated at a ^{60}Co reference source in the dose range 2.6 - 972 Gy. The response has a good linearity (χ^2/ndf = 0.5). The uncertainty in the dose measurement for individual CaF_2 detectors is 20%. Signal regression for these detectors is 10% in a month.

Due to the fact that the aluminum absorber attenuates only partially the high sensitivity of the CaF_2 detectors for energies below 100 keV, we expect a deviation of the detection factor in the bremsstrahlung spectrum compared to the ^{60}Co conditions.

The Fricke dosemeters have been standard $Fe(NH_4)_2(SO_4)_2$ + H_2SO_4 0.8 N solution encapsulated in quartz containers, 3 cm high and 1.48 cm in diameter. The wall thickness has been 1.2 mm. The dosemeters have been prepared in INPE and a UV-VIS type VSU-2 spectrophotometer has been used for read-out.

4 Calibration factors for the detectors in the bremsstrahlung spectrum

The absorbed dose in a flux of photons with a continuous spectrum may be calculated as:

$$D = \int_{E_{min}}^{E_{max}} \int_0^t (\frac{\mu_{en}(E)}{\rho}) \Psi_\gamma(E,t) dE dt \qquad (1)$$

with Ψ_γ the energy flux density; and
$\mu_{en}(E)/\rho$ the mass absorption coefficient for the detector material.

For a compound, the mass absorption coefficient is:

$$\mu_{en}(E)/\rho = \sum w_i (\mu_{en}(E)/\rho)_i \qquad (2)$$

where w_i is the mass proportion of element i.

In these calculations we have used the tables of energy dependence of the mass absorption coefficients from [8].

Fig. 1 b shows the energy dependence of $\mu_{en}(E)/\rho$ for the different detectors used.

5 Results

Figure 2 gives the dosemeter response versus the dose measured with the ionisation chamber. The ionisation chamber response has been corrected for the difference in position and the gamma absorption in the glass holder.

The response for CaF_2, MgF_2 and Fricke dosemeters has been corrected, using the respective factors for the dose recalculation estimated corresponding to the bremsstrahlung spectrum [9]:

$$f_{CaF_2} = \frac{(\mu_{en}/\rho)_{CaF_2}}{(\bar{\mu}_{en}/\rho)_{air}} \frac{(\mu_{en}/\rho)^{^{60}Co}_{air}}{(\mu_{en}/\rho)^{^{60}Co}_{CaF_2}} = 1.05364 \quad (3)$$

$$f_{MgF_2} = \frac{(\bar{\mu}_{en}/\rho)_{MgF_2}}{(\bar{\mu}_{en}/\rho)_{air}} \frac{(\mu_{en}/\rho)^{^{60}Co}_{air}}{(\mu_{en}/\rho)^{^{60}Co}_{MgF_2}} = 1.005405 \quad (4)$$

$$f_{Fricke} = \frac{(\bar{\mu}_{en}/\rho)_{Fricke}}{(\bar{\mu}_{en}/\rho)_{air}} \frac{(\mu_{en}/\rho)^{^{60}Co}_{air}}{(\mu_{en}/\rho)^{^{60}Co}_{Fricke}} = 0.998729 \quad (5)$$

where $(\bar{\mu}_{en}/\rho)$ represents the value of the mass absorption coefficient μ_{en}/ρ averaged over the bremsstrahlung spectrum. The μ_{en}/ρ values have been taken from Reference [8] and adjusted for the missing elements in the tables.

In figure 2 we can see that the doses measured with TLDs and corrected with the recalibration factors are in good agreement with the ionisation chamber measurements. The straight line fit gives a slope of Y/X=1.01 with a high correlation factor. The dose measured with Fricke dosemeters is lower, due probably to a systematic error in calibration. A recalibration factor of 1.58 can be applied to correct the results. We should also note that the Fricke method is not very reliable for the low dose region.

6 Conclusions

Thermoluminescent CaF_2 and MgF_2 dosemeters have been recalibrated for dose measurements in a bremssstrahlung gamma spectrum obtained with an electron accelerator of 8 MeV, on a molibdenum target. Fricke dosemeters show systematically lower values of the measured doses, due probably to the fact that in the dose range of 5–70 Gy this type of measurement is not very reliable. A correction factor of 1.58 should be applied for the results obtained with these dosemeters.

The TLD calibration aimed at using these detectors in mixed neutron-gamma fields, for the measurement of the gamma dose inside the ΣΣ facility, an intermediate energy neutron standard environment.

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Figure captions

Fig. 1
a) Bremsstrahlung energy spectrum for 8 MeV electrons
b) Absorption coefficients for the detectors used in this work

Fig. 2
Corrected dose response for different detector types versus dose measured with an ionisation chamber

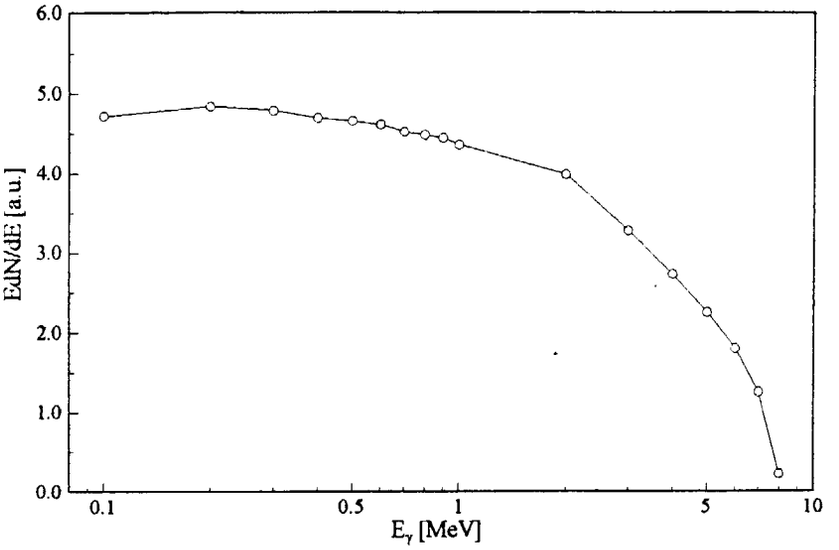

Fig. 1 a) Bremsstrahlung spectrum for 8 MeV electrons

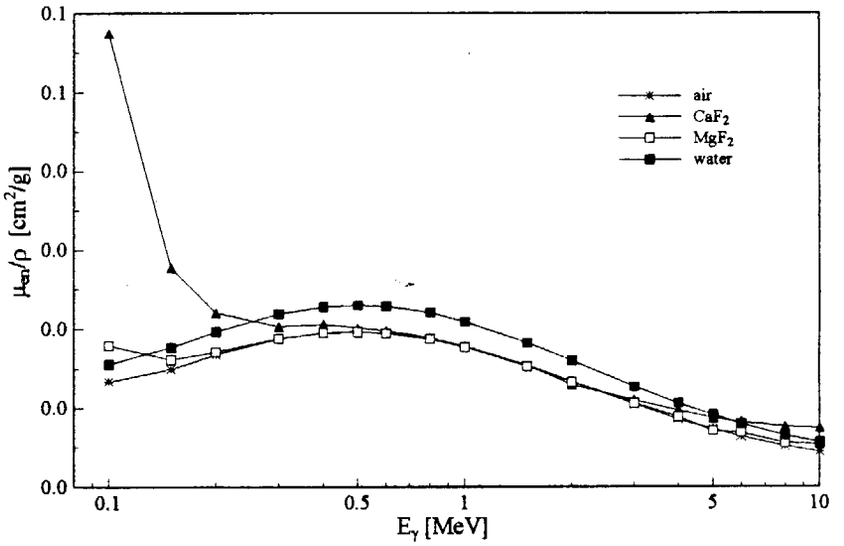

Fig. 1 b) Absorption coefficients for the detectors used in this work

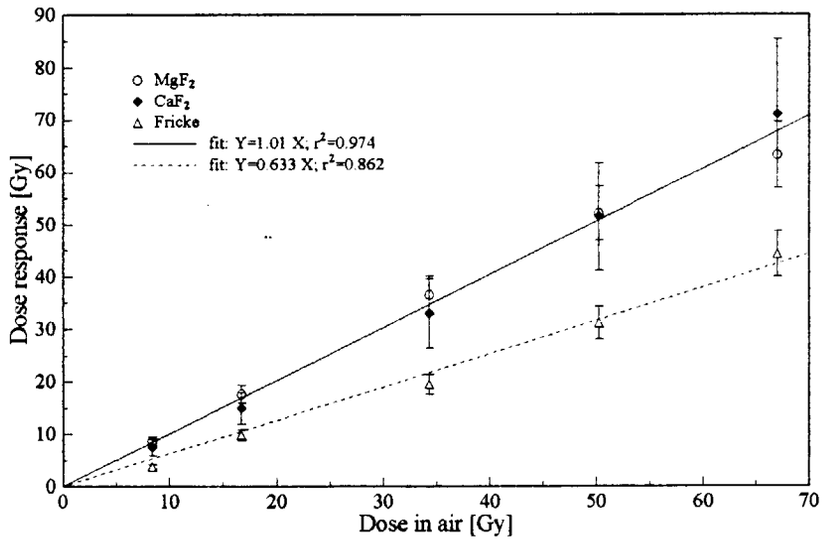

Fig. 2. Corrected dose response of different detector types versus dose measured with an ionisation chamber