To be submitted to
Radiation Protection
Dosimetry

ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-81/52(P)
15 Settembre 1981

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ABSTRACT.

Measurements have been made of mass attenuation coefficients for some thermoluminescent dosemeters using low-energy photon in the range 5-12 keV. Some of the results are compared with existing theoretical calculations when available.

1. - INTRODUCTION.

A good knowledge of the X-ray mass attenuation coefficients (μ/ϱ) at energies below 20 keV is very important in many applications. For instance, the recent utilization of synchrotron radiation in various storage rings results in the availability of very intense soft X-ray beams. For a correct dosimetry of the beam itself it is useful to extend the knowledge of the response of the most common dosemeters at energies lower than 15 keV. In this energy range the measurements of the mass attenuation coefficients are very poor and refer essentially to the materials used in experimental radiation physics[1] (as Al, air, CO_2, perspex, etc.) or to the various human tissues (muscle, lung, breast, etc.)[2]. Until recently no measurements have been performed for the materials normally used as dosemeters. In particular do not exist any experimental data for the thermoluminescent dosemeters (TLD).

In theory the values of the mass attenuation coefficients are available for all the elements with Z = 1 to Z = 100 in the energy range from 1 to 100 keV[3]. Using these data it is possible to calculate the values of the mass attenuation coefficients of any material if the weight percentage of the elements constituent is known. Following this line the mass attenuation coefficients for a variety of tissue compositions and for some TLD materials have been calculated[4]. However, due to the uncertainty of the composition, it is impossible to do such calculation for most of the TL dosemeters.

In this paper we present the results of the mass attenuation coefficients measurements for the most used TLD in the energy range from 5 to 12 keV.

2. - EXPERIMENTAL LAY-OUT.

Since 1953 extensive studies have been done on the possibility of practical applications of the synchrotron radiation produced by high-energy accelerators. In fact, using the electromagnetic energy from a large number of electron running on a circular orbit, it is possible to obtain well collimated intense X-ray beams.

In the last ten years, with the electron-positron storage rings of maximum energy up to 18 GeV, X-ray beams have been obtained with critical energies up to 67 keV and with an intensity 10^6-10^7 times larger than the bremsstrahlung continuum of the X-ray tubes. Using a Si crystal monochromator it is possible to obtain soft X-ray beams with a well defined energy (usually 10^{-3}-10^{-4} per cent).

At the 1.5 GeV storage ring ADONE of the Frascati National Laboratories it is recently operating a synchrotron radiation facility. The synchrotron radiation emerges tangentially from the ring and is sent to the experimental area through high-vacuum channels. In the X-ray channel the beam is monochromatized by a single Si crystal; then it enters the collimator C and the ionization chamber IC as shown in Fig. 1.

A dosemeter of thickness x, posed in front of the collimator C, changes the beam intensity I_0 to I_1 following the law:

$$\ln(I_0/I_1) = (\mu/\varrho)\varrho x . \tag{1}$$

If I_0 and I_1 are measured by the ionization chamber, the value of μ/ϱ can be deduced from the eq. (1).

Due to the monochromator used, the X-ray beam has an energy definition better than 10^{-3} per cent. But, for each energy E, the beam contains higher harmonics of the fundamental wave length which are also diffracted by the monochromator. However the intensity of the harmonics which have an energy greater than 12 keV is negligible. The relative amount of the second harmonic has been measured: it is about 5% at 6 keV and 1% at 5 keV. At these energies the 3E

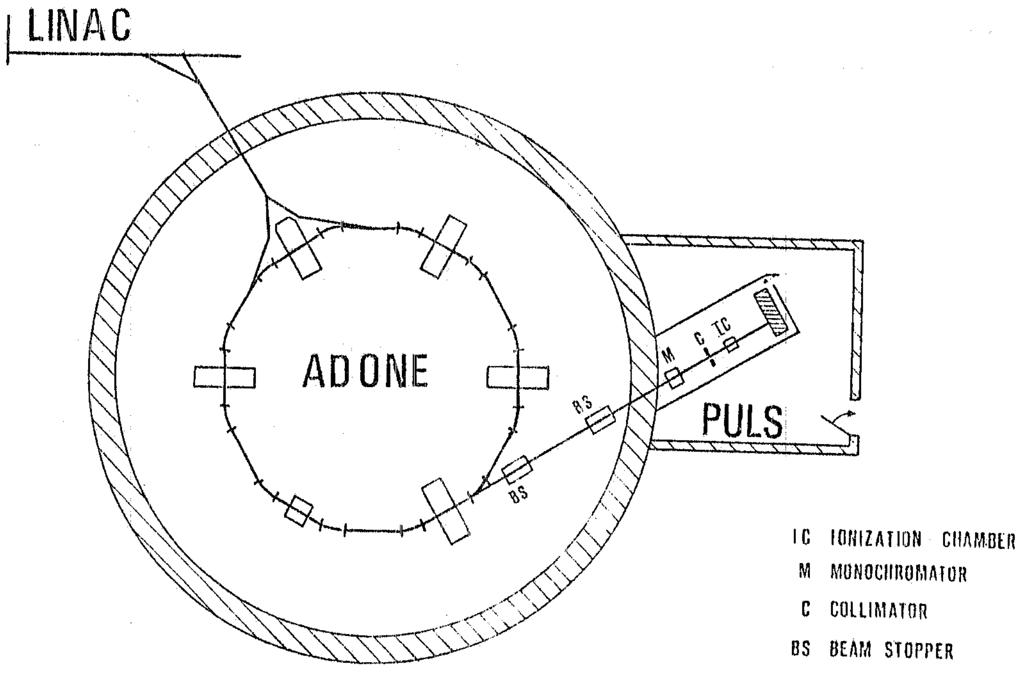

FIG. 1 - Experimental lay-out.

component is negligible. At energies $E \leq 4$ keV while the 2E component increases in per cent, the 3E component also becomes important. This produces some uncertainties when we have to measure the mass attenuation coefficients at these energies and restricts us to energies ≥ 5 keV.

3. - EXPERIMENTAL RESULTS.

The TLD used in this measurements are listed in Table I. In some cases we have not considered the densities quoted by manufacturer because very different from the values we measured. The results are presented in Table II and in Fig. 2, where the measured values of mass attenuation coefficients for the various TLD is shown against the photon energy.

As already stated, there are not previous measurements or calculations on the mass attenuation coefficients for these materials at energies lower than 10 keV. In fact only some theoretical calculation on the mass energy absorption μ_{en}/ϱ is available. Since the difference $(\mu/\varrho - \mu_{en}/\varrho)$ is less than 10-15% for all the materials at 10 keV[5] and decreases at lower energies, we can try to compare our results with these theoretical calculations. For instance it has been quoted for $Li_2B_4O_7$:Mn the value $\mu_{en}/\varrho = 4.09\ cm^2/g$ at 10 keV[6] to be compared with our value of $\mu/\varrho = 4.2 \pm 0.3\ cm^2/g$.

A. R. Reddy and S. C. Mehta[4], using photon cross section data[3, 7] and the values of (μ_{en}/ϱ)[8] available, calculated for some TLD the fraction:

TABLE I - TLD used.

Manufacturer	Type	Thickness (cm)	Density (g/cm^2)
Harshaw	$Li_2B_4O_7$:Mn (TLD 800)	0.089 ± 0.002	2.4 ± 0.1
Harshaw	LiF:Mg, Ti (TLD 600)	0.089 ± 0.002	2.64 ± 0.01(x)
Teledyne	$CaSO_4$:Dy (Pellets)	0.037 ± 0.002	2.06 ± 0.01
Harshaw	CaF_2: Mn (TLD 400)	0.036 ± 0.002	3.18 ± 0.01(x)
Teledyne	LiF-7	0.038 ± 0.002	1.90 ± 0.06
Teledyne	BeO	0.076 ± 0.002	2.85 ± 0.01
Harshaw	LiF: Mg, Ti (TLD 700)	0.089 ± 0.002	2.64 ± 0.01(x)
Harshaw	LiF:Mg, Ti (TLD 700)	0.038 ± 0.002	2.64 ± 0.01(x)

(x) Values quoted by the manufacturer.

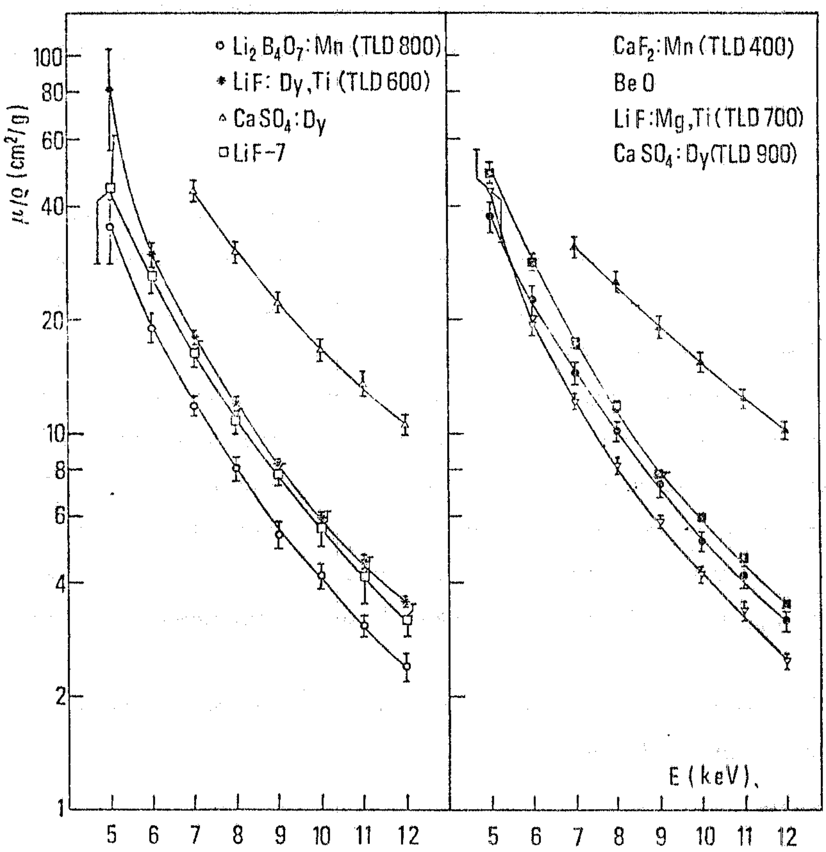

FIG. 2 - Mass attenuation coefficients vs energy for the analysed TL dosemeters.

TABLE II - Experimental mass attenuation coefficients (cm^2/g) for different type of TLD.

E (keV)	LiB_4O_7Mn (TLD 800)	LiF:Mn, Ti (TLD 600)	$CaSO_4$: Dy Teledyne Pellets	CaF_2:Mn (TLD)	LiF-7 Teledyne	BeO	LiF:Mg, Ti (TLD 700)	$CaSO_4$:Dy (TLD 900)
5	35.5 ± 7.2	81.1 ± 27.4		37.8 ± 3.2	45.1 ± 17.5	45.1 ± 12.7	48.2 ± 2.8	
6	19.2 ± 1.6	29.8 ± 2.1	68.8 ± 3.7	22.4 ± 1.8	26.0 ± 2.6	19.6 ± 1.0	28.2 ± 1.1	
7	11.9 ± 0.8	18.0 ± 0.5	43.7 ± 2.5	14.5 ± 0.9	16.4 ± 1.4	12.1 ± 0.4	17.3 ± 0.2	31.1 ± 1.9
8	8.1 ± 0.5	12.0 ± 0.3	30.8 ± 1.8	10.1 ± 0.6	10.9 ± 1.0	8.2 ± 0.3	11.9 ± 0.2	25.5 ± 1.6
9	5.4 ± 0.4	8.3 ± 0.2	22.4 ± 1.3	7.3 ± 0.5	7.8 ± 0.7	5.8 ± 0.2	7.6 ± 0.1	19.2 ± 1.2
10	4.2 ± 0.3	6.0 ± 0.2	16.7 ± 1.0	5.2 ± 0.3	5.6 ± 0.6	4.2 ± 0.2	6.0 ± 0.1	15.7 ± 1.0
11	3.1 ± 0.2	4.6 ± 0.2	13.7 ± 0.9	4.2 ± 0.3	4.2 ± 0.5	3.4 ± 0.2	4.6 ± 0.1	12.7 ± 0.8
12	2.4 ± 0.2	3.6 ± 0.1	10.4 ± 0.7	3.2 ± 0.2	3.2 ± 0.3	2.5 ± 0.1	3.5 ± 0.06	10.1 ± 0.6

$$f(E) = \frac{(\mu_{en}/\varrho)_{TLD}}{(\mu_{en}/\varrho)_{air}}(E) \Big/ \frac{(\mu_{en}/\varrho)_{TLD}}{(\mu_{en}/\varrho)_{air}}(CO^{60}) . \qquad (2)$$

For the sake of comparison we have normalized our data as follows :

$$R(E) = \frac{(\mu/\varrho)_{TLD}}{(\mu/\varrho)_{air}}(E) \Big/ f(10\ keV) . \qquad (3)$$

The results of the comparison, when possible, are shown in Table III. The values of R(E) and f(E) agree substantially, at least in the experimental uncertainty of our measurements.

TABLE III - Comparison between experimental μ/ϱ and theoretical μ_{en}/ϱ.

E	Li		$CaSO_4$:Dy		LiB_4O_7:Mn	
(keV)	f(E)	R(E)	f(E)	R(E)	f(E)	R(E)
5	1.37	1.3 ± 0.5			0.899	0.86 ± 0.20
6	1.36	1.3 ± 0.1	4.59	4.9 ± 0.3	0.871	0.87 ± 0.07
8	1.35	1.3 ± 0.1	5.37	5.3 ± 0.3	0.873	0.83 ± 0.05
10	1.34	1.3 ± 0.1	5.69	5.7 ± 0.3	0.857	0.86 ± 0.06

4. - CONCLUSIONS.

Due to the availability of a monochromatic X-ray beam it is possible, at present, to measure directly the mass attenuation coefficients in the energy range 5-12 keV. The data obtained for different types of TLD are consistent with previous theoretical calculations and could represent a useful tool for the dose measurements at very low energies.

ACKNOWLEDGEMENTS.

We are greatly indebted to A. Savoia, F. Comin, L. Incoccia and S. Mobilio for their help in the data taking and for the useful discussion.

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