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LiF:Mg, Cu, P vs LiF:Mg, Ti : A COMPARISON OF SOME DOSIMETRIC PROPERTIES

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1. INTRODUCTION

The most widely used technique in radiation dosimetry is thermoluminescence (TL), which makes use of materials, commonly divided into two groups:

(a) tissue equivalent phosphors, which generally exhibit low sensitivity to ionizing radiation, e.g. LiF:Mg, Ti , $Li_2B_4O_7$ with Cu or Mn as impurities or Be_2O_3 with different impurities.

(b) phosphors with high sensitivity but poor equivalence to organic tissue, e.g. CaF_2 with Mn, Dy or Tm as impurities or $CaSO_4$ with Mn or Tm as impurities.

For a TL dosimeter used in personnel or environmental dosimetry, both tissue-equivalence and high sensitivity are required.

Lithium fluoride doped with magnesium and titanium, known commercially as TLD-100 (Harshaw), is still the most commonly used radiation dosimeter. It has become popular because of several properties, such as tissue equivalence, relative low fading, adequate sensitivity for personnel dosimetry and the possibility to manufacture the material with acceptable reproducibility.

The LiF:Cu, Mg, P phosphor has several important advantages compared to LiF:Mg, Ti. The extended range of linearity, lack of supralinearity and the more nearly ideal tissue equivalence response to low energy photons gives a significant advantage in clinical dosimetry. The higher sensitivity, improved signal to noise ratio, and shorter monitoring periods lead to greatly improved performance in environmental dosimetry. The ultra low relative TL response to neutrons is another important advantage in mixed field neutron/gamma dosimetry.

The LiF:Mg, Cu, P does suffer from several of the disadvantages associated with TLD-100, especially its complex glow curve, and its greater sensitivity than TLD-100 to heating procedures. A comparison of some main properties of the two phosphors is presented in this work.

2. GLOW CURVE, ANNEALING AND HEATING PROFILES.

In this section we present the glow curve of the LiF:Mg, Cu, P compared to that of LiF:Ti, Mg, and different proposed annealing and heating profiles. The most popular LiF:Mg, Cu, P phosphor is the GR-200 (produced in China or by Bicron/Harshaw); another phosphor is the MCP-N (produced in Poland).

The LiF:Mg, Ti (TLD-100) has a complicated glow curve, including about 10 glow peaks, vastly overlapping (see figure 1). The first five peaks are received when the phosphor is heated to a temperature of 250-300°C. Peaks 6 and 7 are received at high doses of electromagnetic irradiation or neutrons. Peaks 8, 9 and 10 are received when the phosphor is heated to higher temperatures (up to 400°C). The main peak (and the most important for dosimetric applications) is the peak 5, overlapping with peak 4 (and with other peaks as well, e.g. 3, 6 and 7).

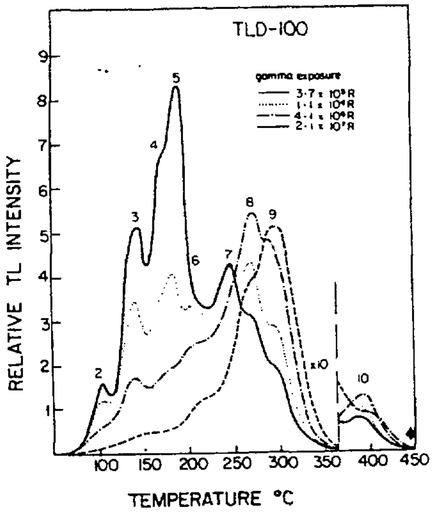

Figure 1. Glow Curve of TLD-100

The LiF:Mg, Cu, P has a glow curve which is more simple, but its shape is strongly influenced by the annealing and heating profiles. It exhibits five temperature peaks at temperatures 90, 120, 180, 220 and 275°C (NIE90). Peak no. 4 is the dosimetric peak and peak no. 5 is the high temperature peak.

Mostly, a pre-heat to 140°C is performed, and a reading up to 240°C. Oster and Horowitz (OST93) described an improved method of annealing/reading the GR-200 chips: pre-irradiation annealing at 240°C/10min and reading at a heating rate of 2.5°C/s up to 240 - 270°C. An example of the resulting glow curve of LiF:Mg, Cu, P including CGCD analysis is presented in figure 2.

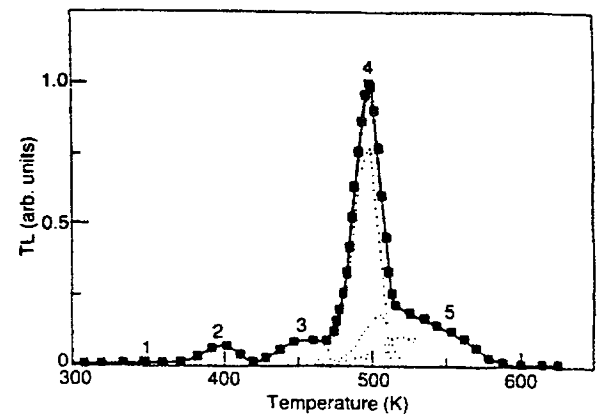

Fig 2. Glow curve of LiF:Cu, Mg, P irradiated with 0.4 Gy ^{60}Co gamma rays at room temperature (OST 93).

Delgado et al. (DEL95) used a heating rate of 6°C/s up to 250°C followed by a 10s heating at this temperature. This temperature profile permitted work to be done using only reader annealing in a dose range of two orders of magnitude, for ultralow doses.

3. THE LOSS IN SENSITIVITY AND THE RESIDUAL DOSE

The main drawback of the LiF:Mg, Cu, P phosphor is the well- documented transformation and loss in sensitivity of the material when annealed at temperatures above approximately 240°C. The manufacturer's recommendations have been to pre-irradiate and anneal the material at 240°C for approximately 10 s. These recommendations have been widely accepted. Unfortunately, the presence of a high temperature peak extending in temperature to approximately 270°C - 300°C leads to a significant residual signal (HOR93A) - approximately 5%-10% of the first readout dosimetry signal when the material is read at 240°C for 12 s. By comparison, the total residual signal of TLD-100, read at 300°C, is no more than a few-tenths of per cent, and this has led to the widespread use of "unannealed" TLD-100 in personal dosimetry. Considerable effort has been invested in the development of a LiF:Mg, Cu, P material without the high temperature structure (and consequently with a greatly reduced residual signal following 240°C readout).

The issue of reproducibility was handled by Oster and Horowitz (OST93). The results of the response of GR-200 chips during 40 successive re-use cycles at different temperatures, as well as the total residual signal as a function of number of readouts, clearly illustrate that the GR-200 chips can be read at temperatures as high as 270°C without any significant loss in sensitivity. Readout at 270°C for 12 s reduces the total residual signal (HOR93B) to an acceptable level of 0.6%, over an order of magnitude improvement over readout at 240°C. The residual signal becomes comparable to the residual signal of TLD-100, thus GR-200 can be used, in "unannealed" form, without any high temperature pre-irradiation annealing between readouts.

4. LINEARITY.

The LiF:Mg, Ti, as well as the LiF:Mg, Cu, P are linear in their dose response at the low dose levels. The supralinearity of TLD-100 above a gamma dose level of approximately 1 Gy and its non-universality and dependence on a great number of experimental and radiation field parameters has been documented in many works (HOR84). The linearity behaviour is considerably simplified in LiF:Mg, Cu, P where the dose response is known to be linear up to a dose level of approximately 10 Gy (GON95).

5. ENERGY DEPENDENCE.

Even though the Zeff of LiF:Mg,Ti and LiF:Mg,Cu,P are essentially identical, their relative response to X rays below about 100 keV is significantly different. In TLD-100, peaks (4+5) are known to over-respond at low energy X rays (i.e. the relative response is greater than that predicted by the mass energy absorption coefficients, approximately 1.4 instead of 1.3 at 30 keV). Peak 7 has an even greater over-response (as high as 2 instead of 1.3 at 30 keV). In the LiF:Mg,Cu,P the energy dependence is less pronounced and more stable (HOR93B). The material under-responds to low energy X rays: the relative TL response at 30 keV is approximately 0.9, and at 100 keV is approximately 0.8, instead of 1.4 as in TLD-100. LiF:Mg,Cu,P is thus closer by approximately a factor of two to tissue equivalence than LiF:Mg,Ti for this energy range.

6. CONCLUSIONS.

The LiF:Cu, Mg, P phosphor has several important advantages compared to LiF:Mg, Ti - higher sensitivity, extended range of linearity, lack of supralinearity and more nearly ideal tissue equivalence response to low energy photons. The LiF:Mg, Cu, P does suffer from several disadvantages, especially its complex glow curve and its greater sensitivity than TLD-100 to annealing procedures.

The main dosimetric peak of LiF:Mg, Cu, P is peak no. 4 (at about 220°C). This peak can be separated from the low temperature peaks of the glow curve by using the CGCD technique. It is very important to perform an optimal annealing and heating profile, otherwise an irreverssible loss in sensitivity and changes in the glow curve will occure, which leads to high residual dose.

The linearity behaviour is considerably simplified in LiF:Mg, Cu, P where the dose response is known to be linear up to a dose level of approximately 10 Gy, while TLD-100 has supralinear effects above a gamma dose level of approximately 1 Gy.

The energy dependence of LiF:Mg, Cu, P is less pronounced and more stable. Not as TLD-100,this material under-responds to low energy X rays (up to 100 kev) and is closer by approximately a factor of two to tissue equivalence than LiF:Mg,Ti for this energy range.

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