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RESPONSE OF LiF (TLD-700) THERMOLUMINESCENCE DETECTORS
TO PIONS AND HIGH-ENERGY NEUTRONS

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ABSTRACT

A double readout method for ^7LiF (TLD-700) at 250°C and 300°C was used for dosimetry in pion and high-energy neutron beams in comparison with tissue-equivalent ionization chambers. The LET (linear energy transfer) dependence of the ratio of the readout values can be used as a radiation quality parameter.

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INTRODUCTION

Double readout techniques for LiF thermoluminescence dosimeters have been introduced so far for various applications such as personnel neutron dosimetry^{1,2,3}). It was found that the strong dependence of the LiF glow curve on LET of the radiation can be used to evaluate for example thermal neutron and gamma dose separately from a double readout of ⁶LiF (TLD-600) since the relative contribution of the high temperature glow peaks 6 and 7 strongly increase with increasing LET compared to the glow peaks 3, 4 and 5 usually used for gamma dosimetry.

Recently there has been a growing interest in the use of negative pion and high-energy neutron beams for radiotherapy and radiobiology. Radiobiological experiments have shown⁴) that strong variations in RBE occur at different locations on the central axes of depth-dose curves of negative pion and neutron beams. Therefore the aim of the present study was to show that ⁷LiF (TLD-700) dosimeters can be used to provide a radiation quality parameter by the double readout method and to relate this parameter to the relative response of ⁷LiF compared to ⁶⁰Co gamma radiation.

EXPERIMENTAL METHOD

All TL dosimeters used during this study were ⁷LiF chips (TLD-700) of 3.2 x 3.2 x 0.9 mm annealed for 1 hour at 400°C followed by 17 hours at 90°C. The TL reader used was a Teledyne 7300 B model. The heating cycle of this instrument consists of constant preheat, readout and anneal temperatures with rapid temperature changes in between. The first heating cycle consisted of a preheat of 8 sec at 120°C. After cooling down the dosimeters went through a second similar heating cycle with a readout at 300°C. Recently the instrument has been modified to use the annealing part of the heating cycle for the second readout with a second current integrator.

The TL detectors were irradiated at two facilities :

1. The π -E-3 biomedical pion beams of the SIN accelerator⁴).

Different locations were chosen on the central axes of the depth-

dose curves of two different negative pion beams (~ 4 and 8% momentum spread) and one positive pion beam (4% momentum spread of the initial momentum of $172 \text{ MeV}/c$). In this way the effect of the fractional dose from negative pion stars can be observed.

Pairs of ^7LiF TL detectors were irradiated in small polythene capsules in contact with a 0.1 cm^3 EGG tissue-equivalent ionization chamber : one capsule upstream and one capsule downstream the beam direction surrounded by a block of tissue-equivalent plastic. The depth-dose curves were obtained by means of a variable water absorber.

2. The high-energy neutron beam of the CERN SC.

Neutrons produced by 600 MeV protons incident on a beryllium target under 0° were used. Depth-dose measurements in polythene with ^7LiF detectors were performed in contact with a 1 cm^3 EGG tissue-equivalent ionization chamber.

In both beam facilities the dose received by the TL detectors was kept at or below 10 rad .

RESULTS AND DISCUSSION

The depth-dose distribution as measured with the ionization chamber in the negative pion beam is presented in Fig. 1 in comparison with the TL detector results and the readout ratios. As can be seen the readout ratio reaches a maximum on the back edge of the stopped pion peak where the proportion of the dose from nuclear stars (whence high-LET short-range fragments are created) to the total dose reaches a maximum of $60\%^5$ while in the plateau region it accounts for about 14% only.

In Fig. 1 are also given for comparison some points for positive pions of the same momentum for which the effect of nuclear star production is absent. Consequently the readout ratio is lower due to the absence of high-LET fragments.

The results for the depth-dose distribution in the high-energy neutron beam is shown in Fig. 2 together with the readout ratio variation and relative TL response in comparison with the ionization chamber. The variation in readout ratio in this case can be explained

by the fact that at small absorber depth (where the ratio reaches a maximum) the dose is primarily due to short-range products from nuclear interactions. As the depth increases, the dose due to fast protons produced in the absorber increases. Fast protons may account for more than 75% of the dose at a depth of 20 g/cm² ⁶⁾.

The relative response of the ⁷LiF TL detectors in both types of beams has been presented in Fig. 3 as a function of readout ratio. The results for the pion beams are falling on one curve independent of the momentum spread of the beam. The high-energy neutron beam results are showing a different relationship due to the difference in the LET distribution of the charged particles causing the dose.

Finally the readout ratio measured at positions used for irradiation of *Vicia faba* seedlings with pions to study the 10-day growth inhibition for 50% effects of primary roots is related to the RBE measured at those positions ^{7,8)} in Fig. 4. This curve is similar to the relationship between RBE and fractional dose from nuclear reaction products derived from pion stopping-rate measurements ⁴⁾. It shows that the RBE increases with increasing portion of dose from pion capture processes causing an increase in readout ratio up to a maximum, after which the RBE decreases due to what is called "overkill" arising from too high a local energy deposition.

CONCLUSION

The results obtained with ⁷LiF TL detectors in beams of interest for radiobiological work indicate that the readout ratio as defined in this paper can be used as a radiation quality parameter to predict RBE. Also, the underestimation of the dose from ⁷LiF detectors in pion and high-energy neutron beams can be corrected for by using the readout ratio, which can be of great interest for routine radiotherapy dosimetry.

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FIGURE CAPTIONS

- Fig. 1 Depth-dose distribution for the π -E-3 negative pion beam ($\frac{\Delta p}{p} \approx 4\%$) as measured with a 0.1 cm³ tissue-equivalent ionization chamber compared with the relative response of ⁷LiF TL detectors and their readout ratio.
- Fig. 2 Depth-dose distribution as measured with a tissue-equivalent ionization chamber in the CERN SC high-energy neutron beam compared with the relative response of ⁷LiF TL detectors and their readout ratio.
- Fig. 3 Relative response of ⁷LiF TL detectors (normalized to ⁶⁰Co radiation) versus readout ratio for pions and high-energy neutrons.
- Fig. 4 RBE for 10-day growth inhibition for 50% effects of *Vicia faba* bean roots versus readout ratio.

FIG:1

FIG: 2