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FAST NEUTRON DOSIMETER USING COOLED OPTICALLY STIMULATED LUMINESCENCE (COSL)

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ABSTRACT

Data is presented that demonstrates the concept of a fast neutron dosimeter using Cooled Optically Stimulated Luminescence. CaF_2:Mn powder, compounded with polyethylene, was injection molded and pressed into 0.1-cm-thick sheets. The sheets were then cut to form dosimeters with dimensions, 1.25 cm by 1.25 cm. After a laser anneal, the dosimeters were exposed to various amounts (from 10 mSv to 100 mSv) of fast ^{252}Cf neutrons. The exposed dosimeters were cooled to liquid nitrogen temperature, stimulated with laser light, and then allowed to warm up to room temperature whereupon the dose dependent luminescence was recorded with a photon counting system. When the control and gamma components were subtracted from the ^{252}Cf response, a dose-dependent neutron response was observed.

The design, construction, and preliminary performance of an automated system for the dose interrogation of individual CaF_2:Mn grains within the polyethylene matrix will also be discussed. The system uses a small CO_2 laser to heat areas of the cooled dosimeter to room temperature. If the readout of very small grains within the plastic matrix is successful, it will enhance the neutron to gamma response of the dosimeter.

INTRODUCTION

In the Cooled Optically Stimulated Luminescence (COSL) readout procedure, standard thermoluminscent CaF_2:Mn (supplied by Solon Technologies) is cooled to liquid nitrogen temperature, whereupon light stimulation moves the electrons populating high temperature traps to lower than room temperature traps.(1) As the stimulated dosimeter is warmed to room temperature (either with contact with ambient or by warming from a small CO_2 laser), light evolves which is proportional to the amount of absorbed ionizing radiation. Because the COSL process operates at low rather than high temperature, the luminescent material can be compounded with hydrogen-rich plastics (polyethylene) that do not withstand the high temperatures generated in a traditional thermoluminescent readout process. The polyethylene itself does not suffer any damage from the low liquid nitrogen temperatures nor does the CaF_2:Mn. Because the CaF_2:Mn is surrounded by a hydrogen-rich matrix, incident neutrons generate knock-on protons which deposit their energy in the CaF_2:Mn grains. We present the fast neutron response from dosimeters composed of 90% polyethylene and 10% CaF_2:Mn powder.

EXPERIMENTAL

The plastic dosimeter compound (90% ground polyethylene and 10% CaF_2:Mn powder 80-200 mesh) were injection molded into sheets 0.1-mm thick. The resulting sheets were sheared into 12.5-mm by 12.5-mm dosimeters. The dosimeters were then laser annealed(2) with 2 joules of 350-nm ultraviolet (UV) light from an Argon ion laser in the multi-line UV configuration. The dosimeters were then exposed to 100 mSv of neutron dose equivalent from a ^{252}Cf source. In one set of dosimeters, 5 cm of lead shield was placed between the dosimeters and the source to reduce the gamma component. In the other set of dosimeters no lead was used. Regular CaF_2:Mn dosimeters were placed next to the plastic dosimeters to establish the gamma component. Control dosimeters were maintained to allow background subtraction. A set of plastic dosimeters was exposed to a range of dose from ^{137}Cs to establish a gamma response of the dosimeters.

After irradiation, the dosimeters were placed in liquid nitrogen and stimulated with 200 to 300 mJ of 350 nm light from an Argon ion laser in the multi-line UV configuration. The dosimeters were then transferred from the liquid nitrogen bath to a photon counting system where the luminescent peaks were recorded.

RESULTS

The luminescent light emitted as the dosimeter warmed from liquid nitrogen to room temperature is reproduced in Figure 1. Overlayed with the 100 mSv peak is the response from the control dosimeter. As can be seen in the figure, there is an exponential tail present in the control and exposed dosimeter. This tail is due to luminescence from the polyethylene matrix itself. A portion of the luminescent peak was selected from Figure 1 and integrated to yield a gross response. This gross response was averaged with four more dosimeters to establish an average gross response to 100 mSv of dose equivalent neutrons. Five control dosimeter response values were also averaged to determine a control response. The areas corresponding to net counts and control counts are plotted for the lead and no lead exposures in Figure 2 and Figure 3, respectively.

In both Figure 2 and Figure 3, a gamma component is also represented. Since the plastic dosimeter does not discriminate between neutrons and gamma, the gamma component had to be established. Plastic dosimeters exposed to ^{137}Cs were read out with the COSL process and the response versus dose curve was fit with a linear regression (Figure 4). The slope of the line, 1,700,000 counts per mSv, is the plastic dosimeter gamma response. The quantity of gamma dose delivered to the plastic dosimeters was determined with regular CaF_2:Mn (TLD 400) chips (which respond very well to gamma but very poorly to the fast ^{252}Cf neutrons) placed next to the plastic dosimeters during the ^{252}Cf irradiation. This measured quantity of gamma dose was multiplied by the plastic dosimeter response factor of 1,700,000 counts per mSv to arrive at the gamma responses plotted in Figure 2 and Figure 3. As can be seen in Figure 3, the gamma component is substantially smaller when 5 cm of lead shield was placed between the ^{252}Cf and dosimeters.

DISCUSSION

On a per-gray basis, the gamma to neutron response of these plastic (polyethylene/CaF_2:Mn) dosimeters is two to one. We hope to improve this ratio and lower the detection limit of neutrons (which is currently 10 mSv) in the future by selectively reading individual grains of CaF_2:Mn powder within the plastic matrix. Grains that have been struck by knock-on protons should produce much larger signals than grains that have been struck with scattered electrons only.

A reader has recently been constructed at the Pacific Northwest Laboratory which allows us to optically stimulate very small spots within the plastic dosimeter. By stimulating smaller areas we hope to observe "bright spots" where proton recoil events have occurred and reduce the interfering luminescence that is observed to emanate from the polyethylene matrix during the COSL read-out process.

If this future work is fruitful we hope to have developed a fast neutron dosimeter with adequate sensitivity for personnel dosimetry that can be interrogated and re-interrogated with minimal effort.

REFERENCES

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2. Miller, S. D.; Stahl, K. A.; Endres, G. W. R.; McDonald, J. C.: Optical Annealing of CaF_2:Mn for Cooled Optically Stimulated Luminescence, Radiat. Prot. Dos. 29(3):195-198 (1989).

FOOTNOTE

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FIGURE CAPTIONS

Fig. 1 The top curve is the luminescent peak recorded from a plastic dosimeter exposed to a dose equivalent of 100 mSv of ^{252}Cf neutrons. The bottom curve is the luminescence of the control dosimeter. The rapidly declining exponential tail is due to luminescence of the plastic matrix.

Fig. 2 A pie graph displaying the net neutron response, gamma response, and control dosimeter response. The Californium exposure was done through 5 cm of lead shield. Each area on the graph represents the average of at least five values. The standard deviation of these five values is also given.

Fig. 3 This pie graph has the same format as Fig. 2, but the Californium exposure was completed without the lead shield. Note that the gamma component, while significantly larger, is still smaller than the neutron response.

Fig. 4 The plastic dosimeter response to ^{137}Cs gamma is plotted as a function of dose to determine the slope (the gamma response per mSv). Error bars represent one standard deviation.

COSL Emisssion Curves

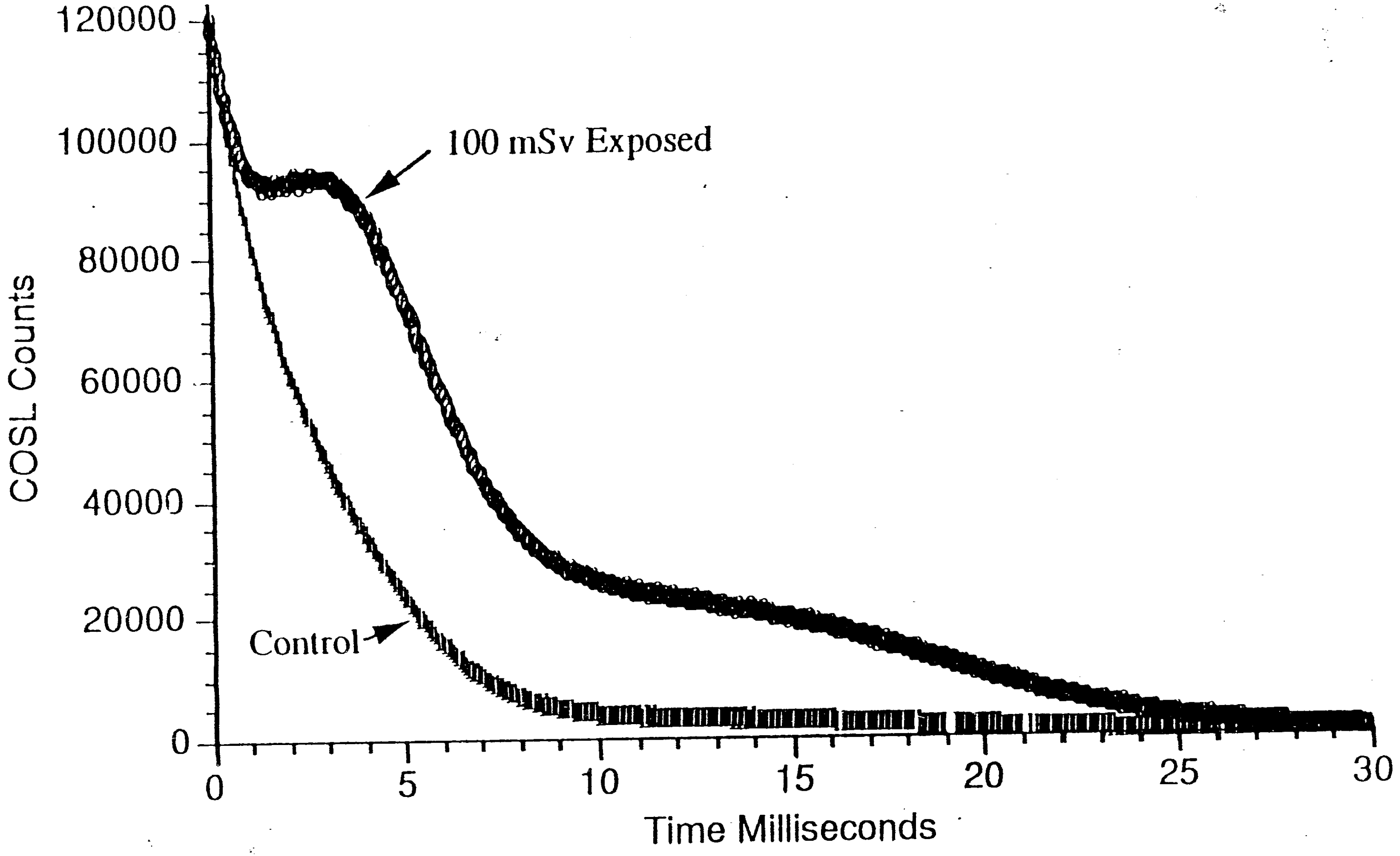
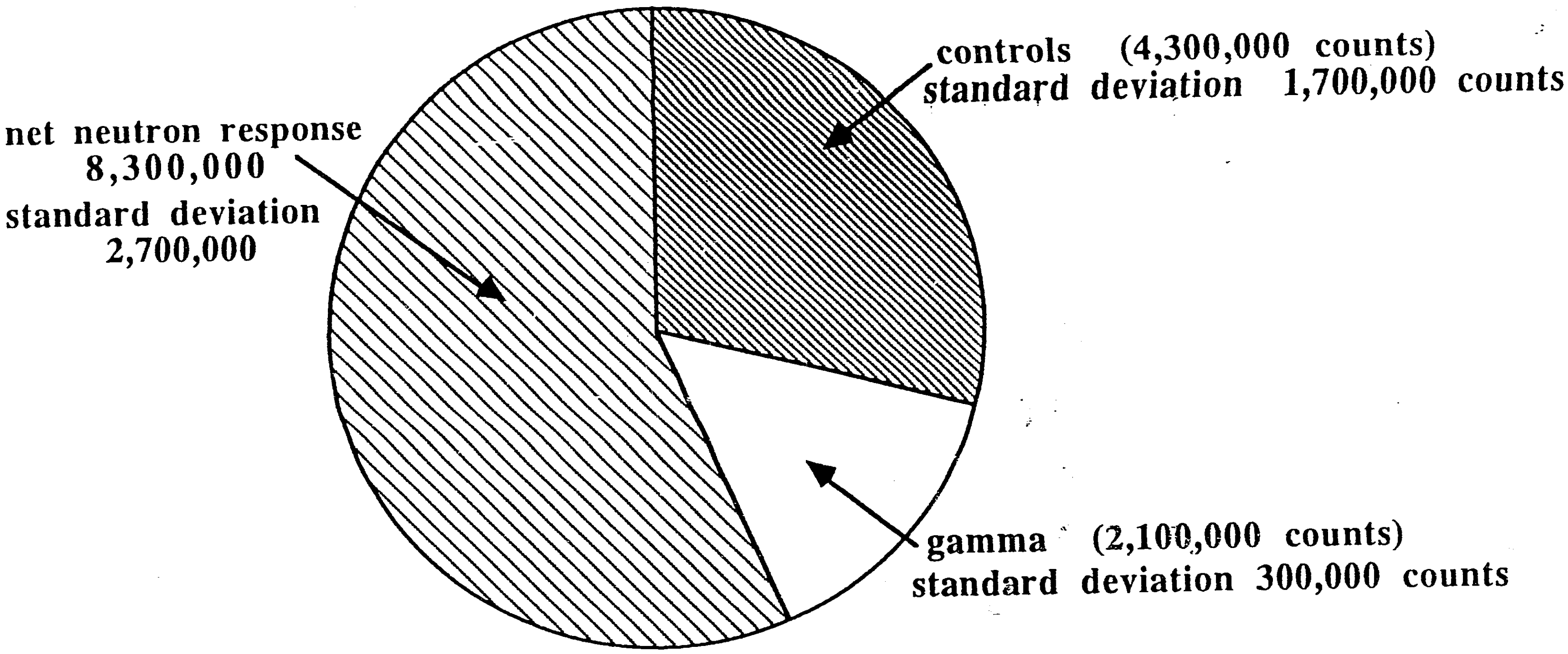


Fig 1

Plastic Dosimeter Neutron Response

(100 mSv Neutron exposure with 5 cm lead shield)

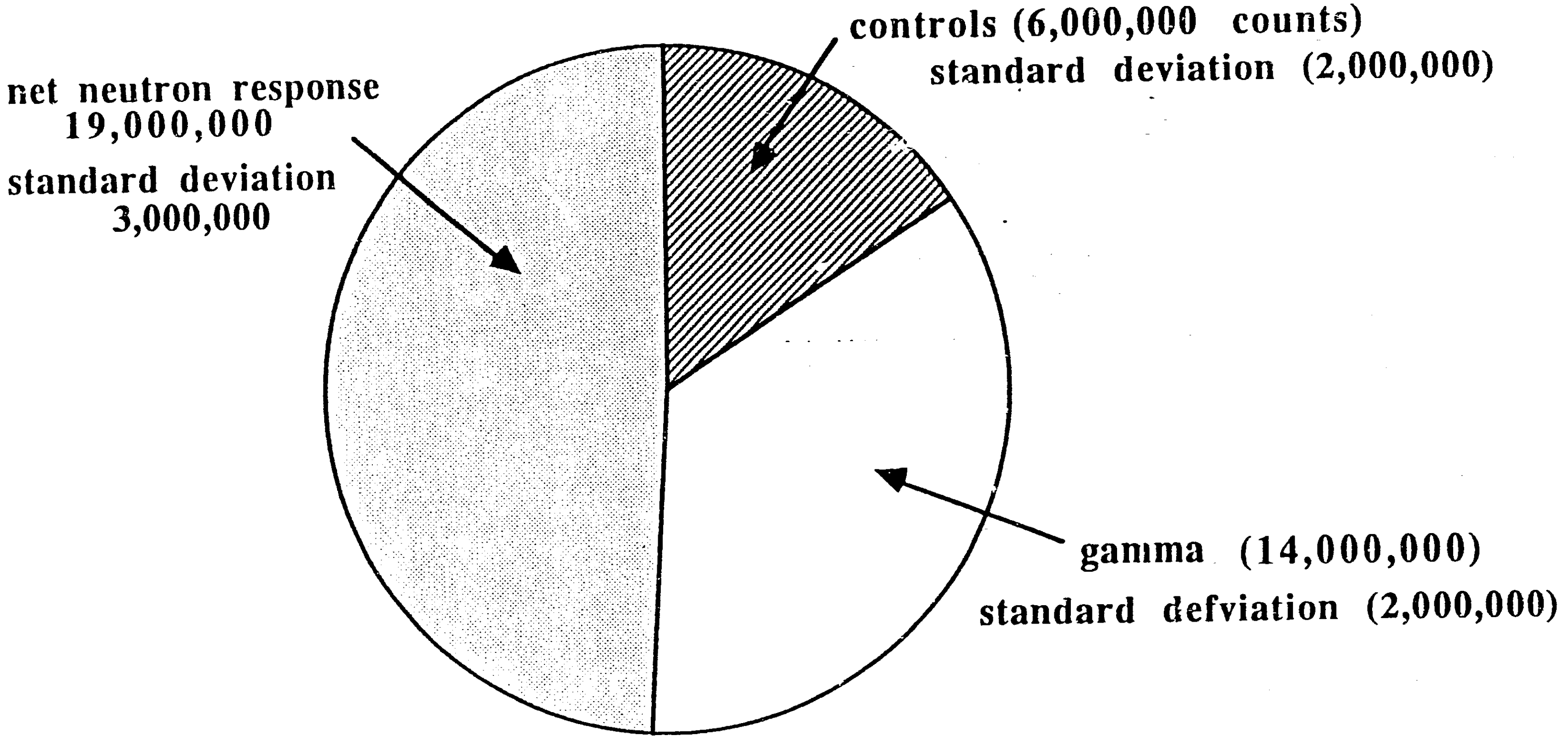


Total Response = 14,700,000 counts
Standard Deviation = 2,000,000 counts

Fig 2

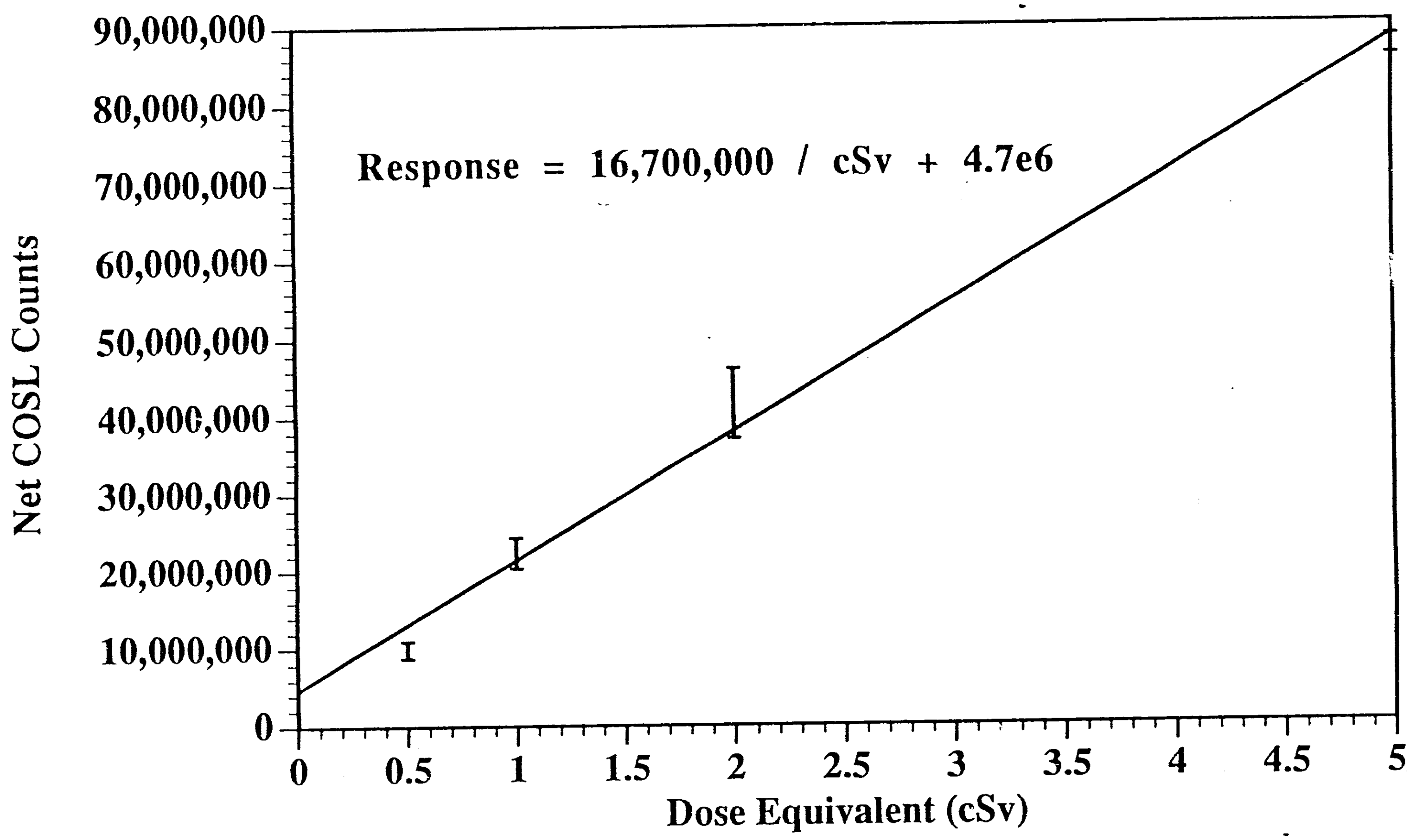
Plastic Dosimeter Response to Bare Californium

(100 mSv exposure , no lead)



Total Response = 39,000,000
Standard Deviation = 1,100,000

Fig 3



Gamma Response of Plastic Dosimeters

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