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MASTER

AN IMPROVED THERMOLUMINESCENCE DOSIMETRY SYSTEM*

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Abstract

By bonding LiF powder to a high temperature plastic with a transparent high temperature binder it has been possible to produce a reusable film badge with the advantages of LiF dosimetry. Because both the plastic and the binder are low Z materials, it is possible to preserve the linear energy response which is one of the advantages of LiF. Since the amount of active material on each dosimeter is fixed, the dosimeter may be accurately calibrated. Obviously this approach simplifies LiF dosimetry because it eliminates the handling and measurement of loose powder.

Because the material is in the form of a piece of film of the same size as a standard film badge, it has been possible to work out improved methods for heating it. The photomultiplier tube now views a constant temperature source,

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thus essentially eliminating variations in background currents. This opens the way to measurement of much lower doses. Because a constant temperature source is used, the heating cycle can be accurately controlled, thus improving reading accuracy. The dosimeters are being developed in a form which will facilitate automatic reading, identification, and printout of results.

Introduction

Most present thermoluminescence dosimetry systems use a small quantity of loose powder or a crystal as the dosimeter. Readout is generally accomplished by heating the powder in a small dish or pan, with the radiation dose being indicated by the amount of light given off.^{1,2} Variations of these systems use permanently packaged thermoluminescent materials, but in doing this compromise the energy independence of lithium fluoride, since high Z materials are used in the package.^{3,4} Other systems have made use of lithium fluoride in plastics, which have a melting point just above the required readout temperature, and quite a bit below that normally used for the regeneration of lithium fluoride.

The system being developed is different from other systems in several ways:

1. In each dosimeter the thermoluminescent material is bound to a piece of low Z high temperature plastic which is in a form specifically designed to make it possible to read out the dosimeter quickly and automatically, and to immediately print out the dose and the dosimeter identification.
2. The heating method used makes it possible to have very close control over the heating cycle, to set the maximum temperature exactly, and to increase the sensitivity of the system.
3. The plastic and binder used can be exposed to much higher temperatures than can be used with other plastics; thus the dosimeters can easily be regenerated and reused.
4. The amount and placement of thermoluminescent material in each dosimeter can be fixed, thus eliminating variation from reading to reading.

The thermoluminescent material used in the dosimeters is TLD-100, which is commercially available from the Harshaw Chemical Company, Cleveland, Ohio.

Description

Figure 1 shows the general composition of the dosimeter. The plastic base is Kapton, a polyimide film which can be raised to 400°C, and which can be exposed to well over 10^9 R of gamma without any significant change in its physical properties. This material is quite tough and inert. The binder becomes a polyimide after curing, so that it has the same properties as the plastic base. Both the Kapton film and the binder, PI-1200, are available commercially from the duPont company. Original difficulties with the binding have been largely overcome, since a number of dosimeters have been irradiated and read out forty or fifty times.

To facilitate automatic readout, the lower half inch of each dosimeter serves as the positioning and identification area. The two locating holes are placed non-symmetrically so that the dosimeter can be mounted in only one way in the reader. There is room for a 4 x 8 array of identification holes, which means that if binary coded decimal notation is used, 100 million dosimeters can be coded uniquely.

Figure 2 is a generalized representation of the dosimeter reader. A flat plastic dosimeter makes it possible to avoid many of the limitations imposed by loose powder; thus in the present design the PM tube is exposed to an essentially constant heat flux, which minimizes fluctuations in the dark current. The brass heater block is approximately 1.75" x 1.75" x 3", and contains heating elements and a temperature controller. A thermocouple is placed in the block, close to the lower surface, so that the temperature may be monitored continuously. The brass block is mounted so that it is self-levelling and sits firmly on the glass; thus the glass tends to rise to the temperature of the heater block. A small fan sucks room air through the lower part of the reader containing the light pipe and PM tube assembly. A small amount of air is permitted to enter the top of the reader and to flow past the block to the exit in the lower part; this acts as a heat sink for the glass and assures that the glass temperature will be a little below that of the lower surface of the heater block.

When a dosimeter is to be read, it is placed in the slide which is then inserted in the reader. As it approaches the heater block two cams press upward on the pivot arms and the

brass block is raised about a quarter of an inch. When the dosimeter is in position over the glass, the carriage on which it rides is stopped by limit pins, and the brass block comes down. The block weighs something over two pounds so it presses quite firmly on the dosimeter, thus assuring good thermal contact and repeatable heat transfer.

The heater block is kept a few degrees above the temperature necessary for readout. Since it has practically infinite mass as compared to the dosimeters and since it has high conductivity, it acts as a constant temperature source, maintained within 1 or 2 degrees of the desired temperature. The upper surface of the glass is usually slightly above the readout temperature, but the conductivity of the glass is quite low. Thus when the dosimeter touches the glass surface, the temperature of the surface drops below readout (since the dosimeter is ordinarily near room temperature initially) and the heat which causes readout comes mainly from the brass block.

The PM tube is an EMI 9502S, which has high gain but very low dark current. Since the photocathode is about a centimeter in diameter, the light coming through the glass block is picked up by a conical light pipe and reduced to a beam less than a centimeter across. The light pipe and the

PM tube are in a container which is chilled by ice water. Between the light pipe and the tube face is a small disc of Kodak #65 infra red filter. Placing the filter where it cannot become warm has the advantage that it filters out infra red without reradiating, as it might if it were placed close to the glass block.

Figure 3 shows a block diagram of the reader. At present one has a choice of either integrating the light output or recording the glow curves. It is planned to make it possible to do both simultaneously, but this feature has not been incorporated in the present system. When a dosimeter is inserted the timer is started, and the interrupt circuit disconnects the signal for 0.3 seconds by means of an electronic timing circuit. This avoids spurious signals which would make it very difficult to get accurate results at low dose levels. The spurious signals occur before the light due to radiation exposure begins to be emitted; thus no needed information is lost by a momentary opening of the signal circuit. Under the conditions normally used, the light output begins about 0.5 seconds after a dosimeter is inserted, and is completed in a little less than seven seconds. The timer is set at seven seconds so that the operator will use

a uniform integrating time for each reading; in an automated version, the timer would command the digital voltmeter readout directly. The integrator is always started on its most sensitive scale, and steps upward when full scale is reached during the course of a reading; thus no readings are lost. In the present model, the dark current is balanced out by manually setting a "bucking current;" thus the integrator output voltage represents only the amount of light emitted by the dosimeter being measured. This bucking current is not used when glow curves are being recorded.

The glow curves in Fig. 4 suggest what sensitivity can be obtained with the present dosimeters and reader. The time scale, as noted, is one second per small horizontal division; the curve returns to its base value within the integration time of seven seconds. The small downward hook just before the beginning of each curve is caused by the interrupter circuit which disconnects the PM tube signal for 0.3 second at the beginning of each measurement in order to get rid of spurious signals. The glow curves indicate that the lower limit of sensitivity of the system as it exists is 10 mR $\pm$ 5 mR.

Figure 5 shows the response of three different dosimeters to various doses of radiation from a Co-60 source. It is obvious from the graphs that there is a difference in sensitivity from dosimeter to dosimeter. The dosimeters are made in small lots, and methods of making them were varied from lot to lot in order to find the best way of obtaining desired characteristics. The dosimeters were individually hand made, with the resulting variation in thickness in active material and binder coating from unit to unit in any lot. The different sensitivities were picked to illustrate that linearity of response with dose is not dependent upon the sensitivity of the dosimeter.

Figure 6 is a tabulation of predicted and actual response of several dosimeters. The calculated response was arrived at by taking the reading at a dose of 6.8 R, dividing this reading by 6.8, and using the result as a calibrating factor to determine the calculated response for the dosimeter at lower values. For the three dosimeters graphed in the previous figure, the results are quite good. No. 114 is included as an example of a dosimeter which is fairly sensitive but which gives erratic readings. If error limits of ± 5 mR $\pm 3\%$ of

reading are used as a method of determining whether dosimeters are acceptable or not, two lots of dosimeters made by somewhat similar methods are generally acceptable. Because of this, it is felt that further study of existing dosimeters, their uniformity or non-uniformity of response, together with records of how they were made, will make it possible to set up machinery for producing dosimeters whose sensitivity is quite uniform.

One of the objectives of this investigation was to produce a thermoluminescent dosimeter which could be handled easily and which would have good response at low energy. Results of irradiation with X-rays of 100 keV and 40 keV effective energy show that the dosimeters have approximately the same relative response at these energies as does TLD-100 powder. Thus binding the powder to the plastic has not destroyed the linear energy response of the TLD-100. It appears that these dosimeters should also be usable in the measurement of beta doses.

For neutron detection in the presence of gammas, Harshaw can supply two LiF powders in which the natural isotopic ratios of Li are changed. TLD-600 is enriched in ^6Li to ~95%, so it is quite sensitive to neutrons but gives a normal response to gammas. TLD-700 is depleted of ^6Li , so that it is ~100% ^7Li ,

and so it is quite insensitive to neutrons but has the normal response to gammas. By exposing samples of both these powders to a mixed neutron and gamma field, it is possible to determine the neutron and gamma contribution. By combining dosimeters made with these powders with dosimeters made with TLD-100, it should be possible to have a package which would measure fields containing betas, gammas, and neutrons.

The coating over the thermoluminescent material excludes the air, thus minimizing the spurious signals which cause difficulty at low levels when the loose powder is used. It was thought that over a period of time oxygen from the air might diffuse through this coating and cause some difficulty. To check this, unirradiated dosimeters were allowed to stand for periods of three and six weeks before being read. The readings indicate accumulated doses of two or three mR/week, which is about what would be expected from background radiation where they were stored. Thus the dosimeters give correct readings when exposed to low dose rates over a period of weeks.

One inherent advantage of the system which has not been specifically discussed is the speed with which the dosimeters can be read. With the present rather elementary experimental

reader, it is possible to read and record manually at least two dosimeters a minute if only the dosimeter number and the dose are to be written down. Because of this, it is felt that an automated version would be able to read and record at least five dosimeters a minute. The reader scales automatically so no difficulty is experienced if dosimeters with high and low exposures are mixed together for reading.

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Figure Captions

Fig. 1 Dosimeter Details

Fig. 2 Dosimeter Reader

Fig. 3 Dosimeter Reader Block Diagram

Fig. 4 Dosimeter Glow Curves

Fig. 5 Dosimeter Response

Fig. 6 Actual vs Calculated Readings

DOSIMETER DETAILS

FIGURE 1

DOSIMETER READER

FIGURE 2

FIGURE 3

DOSIMETER GLOW CURVES

FIGURE 4

FIGURE 5

ACTUAL Vs CALCULATED READINGS

DOSE (mR)		10	25	75	250
#21	READ	9.8	24.5	68.0	227
	CALC	9.2	22.9	68.7	229
#27	READ	9.7	12.6	52.4	175
	CALC	6.7	16.6	49.8	166
#37	READ	11.5	21.2	62.5	201
	CALC	7.6	19.0	57.0	190
#114	READ	7.8	17.0	70.5	223
	CALC	8.3	20.7	62.0	207

FIGURE 6