EXPERIENCE WITH A NEW THERMOLUMINESCENCE METHOD FOR FINGER AND HAND DOSIMETRY EMPLOYING LITHIUM FLUORIDE-TEFLON DOSIMETERS

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Abstract—A new type of finger and hand dosimeter has been designed which consists of a solid, flexible disc of thermoluminescent LiF incorporated in polytetrafluoroethylene (Teflon) enclosed in black polyethylene covering (7 mg/cm^2 thickness) which is attached to an adhesive tape. The thickness of the polyethylene has been selected to simulate the radiation insensitive layer of the skin. Precision of the dosimeters has been evaluated for gamma and beta irradiation. Ten millirads can be measured with a standard deviation of better than $\pm 20\%$ without individual calibration of the dosimeters. Effects contributing to background such as light sensitivity, mechanical shock and friction have been studied. It is concluded that these dosimeters offer the prospect of reliable routine finger and hand dosimetry with results that can be directly related to the biologically significant dose.

FINGER and hand dose measurements have presented a serious and largely unsolved problem in routine personnel dosimetry. The particular difficulty is that the maximum dose to the finger and hand has to be estimated in an unpredictable radiation field with perhaps very steep dose gradients, and that this estimate must be based on a measurement technique which does not interfere with the monitored persons ability to perform delicate manipulations.

To illustrate the type of dose patterns that can occur, doses at several points on the fingers, palm, and wrist of a person holding a radium needle inside a plastic tube have been measured using LiF-Teflon thermoluminescent dosimeters. As shown in Fig. 1, the maximum dose was 560 mrad on the thumb, while ring and wrist dosimeters showed less than 2% of this. In a similar experiment, illustrated in Fig. 2, a plate of natural uranium was placed on a water-filled glove, simulating a hand. The tips of the fingers in immediate contact with the plate received almost 100% of the dose measured on the surface of the plate, while the ring dosimeters showed less than 0.2%.

It is evident from these experiments that a realistic estimate of the maximum dose to the hand in similar situations can seldom be made unless measurements are actually made where the maximum exposure can be expected, usually on the finger tips.

Consequently the conventional technique for finger and hand dosimetry, i.e. to use photographic film as ring or wrist dosimeters, is of little or no value. As a new approach, Johns[(1)] used loose thermoluminescent LiF phosphor in plastic sachets, which were fixed to the fingertips. Recently, Portal[(2)] assessed existing finger dosimetry techniques and also advocated the use of LiF thermoluminescence for this purpose. Both authors based their judgement mainly upon the properties of LiF, being essentially energy independent for X- and gamma-radiation, the wide range of measurable doses with some tens of mrads as the smallest detectable dose, the ease and speed with which the dosimeters can be read out, and the flexibility of a practical system in routine as well as emergency situations.

Our work has been directed toward maximizing the usefulness and technical capability of the TLD technique in finger and hand dosimetry. The objectives of our work, which is

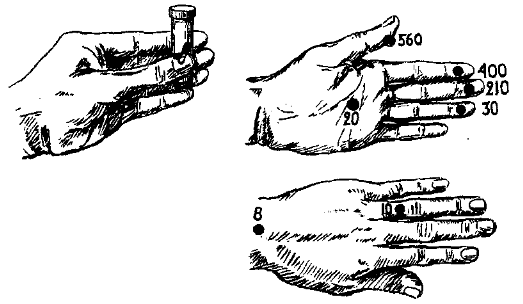

FIG. 1. Doses in mrad at various points after holding a 1 mg radium needle, as shown, for 5 min.

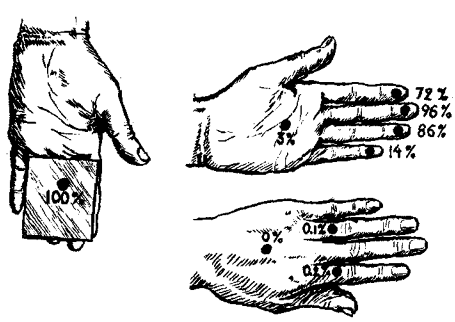

FIG. 2. Doses recorded on the hand after holding a plate of natural uranium as shown. The doses are expressed as a % of the dose at the surface of the uranium plate.

still in progress, have been to design a convenient, technically reliable dosimeter and to evaluate its operational value.

The dosimeters which were developed are illustrated in Fig. 3. The radiation sensing component is a disc, 12.5 mm diameter by 0.4 mm thick, consisting of 28 mg of thermoluminescent LiF uniformly incorporated in polytetrafluoroethylene (Teflon).[3] This disc is contained in a light-proof polyethylene pouch, 7 mg/cm^2 thick. The pouch is, in turn, fastened to a strip of adhesive tape for attachment to the skin. In situations where low energy photon or beta radiation is encountered, a minimum cover over the disc is essential, and the adhesive tape is fastened only to the ends of the pouch, resulting in a covering thickness of 7 mg/cm^2. When a thicker cover can be tolerated, the adhesive tape, 30 mg/cm^2 thick, can be allowed to extend over the pouch.

After exposure the LiF-Teflon discs were measured in a standard Controls for Radiation, Inc. readout instrument, in which the thermoluminescence light is integrated during a 15 sec readout cycle. Nitrogen flush has been employed during readout.[4, 5]

The LiF-Teflon disc responds to the energy deposited by the ionizing radiation within its volume. If the disc is covered with 7 mg/cm^2 and since it is itself 90 mg/cm^2 thick, the response of the disc is a measure of the energy absorbed in a layer at a depth between 7 and 97 mg/cm^2. The biologically important dose is usually taken to be that to the thin basal layer at 7–10 mg/cm^2 depth. As long as there is no significant dose gradient between 7 and 97 mg/cm^2 depth, the measured value in the LiF-Teflon disc will correspond to the dose to the basal layer. This is usually the case for X- and gamma-radiation. Insufficient electron equilibrium may in certain cases complicate interpretation of measured data, but otherwise the close tissue equivalence of the composition of LiF-Teflon ensures a simple relation between the dosimeter response and the dose to the basal layer.

The energy dependence of LiF has been calculated[6, 3] and to some extent also studied with monoenergetic radiation.[7] The two methods agree reasonably well. However,

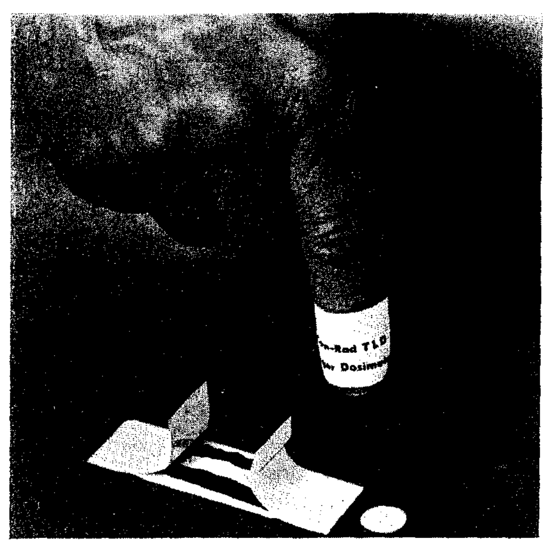

FIG. 3. The Con-Rad Finger Dosimeters.

Naylor[8] has reported an anomalous energy dependence for LiF. He attributes this effect to the relative efficiency of various photon energies in creating traps. We have not observed this effect for exposures below 100 R. Above this dose the effect is significant but small.

For beta and electron radiation, the thickness of the discs is not negligible. 7 mg/cm², the thickness of the radiation insensitive surface layer of the skin as well as of the plastic pouch, corresponds to the maximum range of an electron of about 60 keV energy. Electrons of less energy are therefore hardly of interest. 300 keV electrons have a maximum range corresponding to the thickness of the disc. In the region between these energies, the interpretation of measured values will be difficult and the average dose measured by the discs will be less than the dose to the basal layer. Further calculations are needed to clarify these conditions, as for example, were made by Casnati and Breuer for skin contamination.[9]

For still higher electron energies, the response becomes easier to interpret. In the very important case of natural uranium, the average dose in the discs is about 80% of the dose to the basal layer as estimated from previously published data.[3]

The precision of dose measurements with these dosimeters without individual calibration has been measured by exposing a number of dosimeters to known doses of ^{60}Co radiation. The results presented in Fig. 4 show that measurements down to 10 mR are possible. At this exposure the standard deviation in the set of 20 data was less than $\pm$ 20%. The standard deviation decreases with increasing dose. Our experience from production control is that the standard deviation of the sensitivity in a production batch approaches $\pm$ 3% for exposures above 3 R.

These experiments were conducted in the laboratory under controlled conditions. At 20 mR, the signal due to the irradiation is 40% of the gross value. The background consists of the photomultiplier dark current which is about 40%, and a component which we have called "spurious thermoluminescence" which is the remaining 20%. This latter component is also present in unirradiated dosimeters and is responsible for almost 80% of the *variation* in a set of measurements of 20 mR. The results of an investigation of some possible causes for this effect are described below.

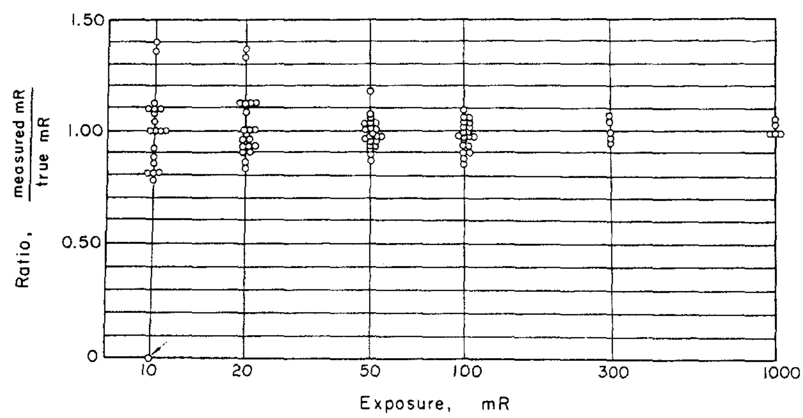

FIG. 4. The precision of dose measurements using LiF-Teflon discs 12.5 mm diameter by 0.4 mm thick.

The sensitivity of the dosimeters to mechanical shock was studied by dropping a hammer onto the LiF-Teflon discs. A signal equivalent to about 10 mR was induced after a dosimeter had been hit 300 times by a hammer dropped through 3 cm. Clearly, the dosimeters are practically insensitive even under these extreme conditions. The possibility that friction could produce tribo-thermoluminescence was investigated by violently agitating dosimeters in a black plastic box on a shaking machine. The results obtained show a slight response to shaking. Here a signal equivalent to about 5 mR was induced after the box had been shaken about 5000 times and 20 mR after shaking 30,000 times. The conclusion must be that mechanical disturbance plays only a small role in the practical use of these dosimeters.

Another possible cause for the spurious thermoluminescence is excitation by light, which has been reported previously for LiF.[3, 10] Dosimeters exposed to normal fluorescent laboratory light exhibit a definite light sensitivity as shown in Fig. 5. Experience with ultraviolet radiation suggests that it is this component of the light that is responsible for the excitation. Light is, however, efficiently excluded by the use of the light-proof pouches into which the LiF-Teflon discs are packed in subdued light. The data in Fig. 5 indicate a slight increase in the signal from dosimeters stored in the dark following the annealing. The reason for this is not known at present.

The conclusion of these experiments is that unirradiated dosimeters should be included in any measurement series for background determination.

In conclusion, these dosimeters fulfill practically all the requirements for finger and hand dosimetry. The most serious drawback is associated with the inherent problems in any measurement of beta and electron dose to a very thin layer. Compared to photographic film dosimeters, the dosimeters have the advantages of being capable of at least the same precision, of having a vastly superior energy dependence for X- and gamma-radiation which leads to better accuracy, and of allowing the monitored person to comfortably and conveniently wear dosimeters where meaningful doses will be recorded, i.e. on the finger tips, without interfering with his work. The ease and speed of readout result in a versatile and adaptable monitoring procedure, a condition that must be fulfilled before finger and hand dosimetry assumes the place in health physics which its importance justifies.

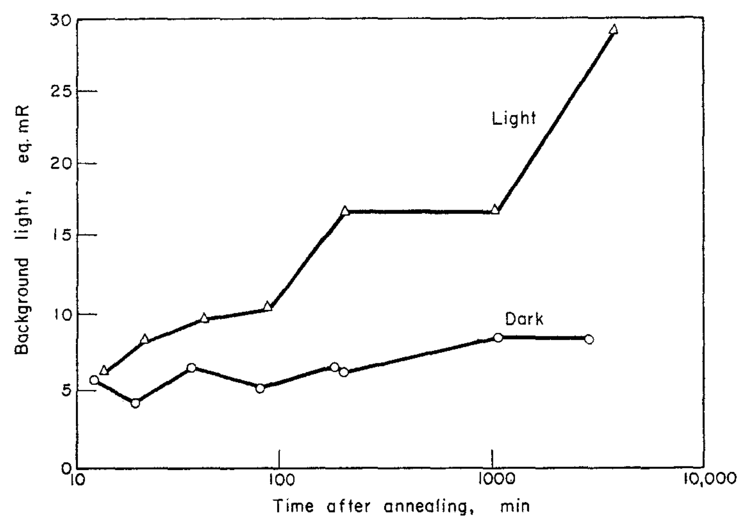

FIG. 5. The appearance of thermoluminescence following annealing in LiF-Teflon discs which have been kept in darkness or exposed to normal laboratory fluorescent light.

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