A COMPARISON OF TLD AND FILM FOR PERSONNEL DOSIMETRY*

JOHN R. CAMERON
and N. SUNTHARALINGAM†
Department of Radiology, University of Wisconsin, Madison, Wisconsin

Abstract—The film badge is today the most widely used personnel monitoring device for want of a more reliable and accurate system. Recent evaluations of the performance of the available commercial film badge services report a wide variation in both the accuracy and consistency of the reported exposures. The best accuracy that one can obtain for X- and gamma-radiation appears to be −50 to +200%. This paper reports the feasibility of using the thermoluminescence of single crystals of LiF (TLD-100)‡ to measure exposure levels of X- and gamma-radiation encountered in the personnel dosimetry range. The use of single crystals greatly reduces the contribution of the non-radiation induced thermoluminescence. The variation in response of individual crystals was taken into account by calibration of the crystal in place at the time of read-out. LiF single crystals in lucite capsules were attached to film badge holders and given known test exposures from X- and gamma-ray sources and mixtures of these radiations. The performance of the TLD system is compared with the measured values reported by the film badge suppliers. No correction was made for the slight energy dependence of LiF at the low keV exposures. The over-all accuracy of the TLD system is about ±30% for X- and gamma-ray energies above 25 keV effective.

INTRODUCTION

The Federal Radiation Protection Code[1] requires that a monitoring device be worn or carried by an occupationally exposed individual for the purpose of measuring the radiation exposure received. The film badge is the measuring device most widely used for this purpose. Even with its numerous limitations[2-5] the film badge has been called upon to provide accurate dosimetry. Documentation of personnel exposure records have become basic in proving compliance or non-compliance with Federal and State regulations and as such the accuracy and reliability of the available commercial film badge services have been questioned.[6] Two separate evaluations[7, 8] of the performance of the film badge suppliers report a wide variation in both the accuracy and consistency of reporting the exposures received by the film. In one of these studies even the companies that did reasonably well demonstrated an accuracy range of only −50 to +200% in reporting gamma and X-radiation exposures with a confidence limit of 90%.[7]

A major advantage of thermoluminescent dosimeters is their wide usable range. The upper limit for LiF (TLD-100) is set by saturation effects that become pronounced at 10^5 R. At the low end of the range, measurements are limited by the presence of a large background part of which is due to the non-radiation induced thermoluminescence from the phosphor. This effect is of the order of 1 R equivalent for a 30 mg sample of TLD-100 when it is used as a loose powder.[9] Single crystals of TLD-100 show a marked decrease (about a factor of 30) in this non-radiation induced thermoluminescence. The feasibility of using the thermoluminescence of single crystals of TLD-100 to measure milliroentgen levels of exposure was investigated

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† National Institute of Health pre-doctoral trainee in Radiological Sciences.

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earlier.[10] This paper reports the results obtained using single crystals of LiF (TLD-100) for monitoring exposures in the personnel dosimetry range in comparison with the film badge evaluation supplied by a commercial company. The advantages of using a TLD system for personnel dosimetry purposes are: (a) relatively good energy independence, (b) linear response with exposure, (c) dose-rate independence, (d) approximate tissue equivalence, (e) negligible decay of stored TL, and (f) unaffected by visible light, moisture, and mechanical vibrations.

METHOD

For the comparative study of personnel dosimetry using LiF single crystals and film badges, the single crystals were placed inside lucite capsules (4 mm wall thickness) and attached to the film badge holders. The single crystals weighing approximately 10–25 mg ($\sim 2 \times 2 \times 3$ mm) were cleaved from a chunk of virgin TLD–100, and annealed for one hour at 400°C before being used in the studies.

Test exposures of known amounts of radium and ^{137}Cs gamma-rays and 140 kVp ($\sim$ 3 mm Al hvl) X-rays were given to the LiF crystals and film badges simultaneously. The calibrations for the test exposures were determined using Victoreen R-meters, but, because of the low exposures used, our values are probably accurate to only $\pm$ 10%. These test film badges were sent back together with the $\sim$ 300 routinely used film badges for evaluation by the company. As normal procedure the company is always informed of the type of radiation each badge might have been exposed to, but no indication was given that some badges were being used in a comparative study. The exposed LiF crystals were "read" using a technique which is described in detail elsewhere.[11] All of the readings were done by one of the authors (N.S.), who did not have any prior knowledge of the test exposure values or the quality of the radiation.

In one study, film badges from a second company were also simultaneously exposed and sent back for evaluation.

In a separate experiment, we subscribed to a special testing service offered by the National Sanitation Foundation Testing Laboratory, Ann Arbor, Michigan, and had sent to them twenty badge holders containing both LiF crystals and film. These were exposed to known amounts of ^{137}Cs gamma-rays, 175 keV effective (270 kVp, 4.1 mm Cu hvl) and 24 keV effective (68 kVp, 1.25 mm Al first hvl) X-rays and a mixture of ^{137}Cs and 24 keV-effective radiations, and sent back to us for evaluation. The true exposures were not known to us until the measured values were reported back to the National Sanitation Foundation Testing Laboratory. The LiF crystals were "read" in our laboratory while the films were sent back to the company for evaluation.

RESULTS

The response of the single crystals in the lucite capsules to known exposures of radium γ-rays, ^{137}Cs γ-rays, and 140 kVp X-rays is seen in Fig. 1. The crystals show about a 40% increase in sensitivity for the low energy X-rays.

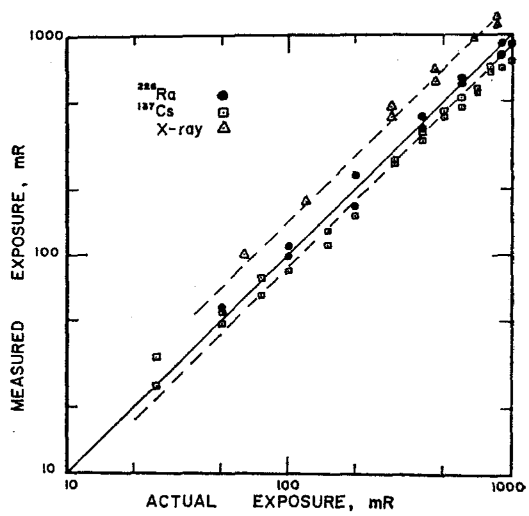

FIG. 1. Response of single crystals to radium and ^{137}Cs gamma-rays and 140 kVp (hvl 3 mm Al) X-rays.

This falls in the range of values previously reported.[9] The ^{137}Cs measurements read about 15% lower than the actual exposures. This was later verified to be an error in the calibration of the source.

Figure 2 shows the results of an experiment conducted with radium test exposures. The broken lines represent an error of $\pm$ 20%. Fourteen of the 15 crystals measured within $\pm$ 25% of the actual exposures.

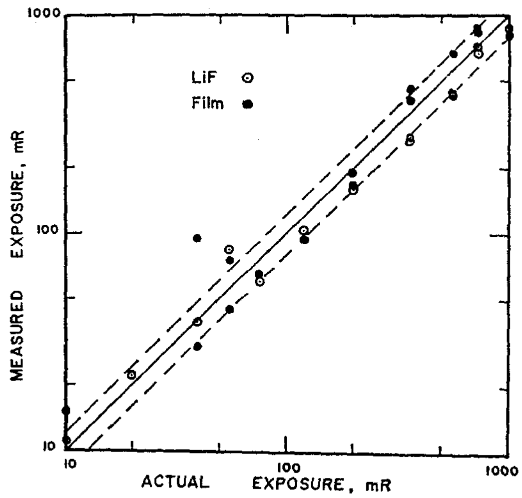

FIG. 2. Exposure readings as measured by LiF single crystals and film. The solid diagonal line represents 100% accuracy. The parallel broken lines indicate an error of $\pm 20\%$ in the measurements.

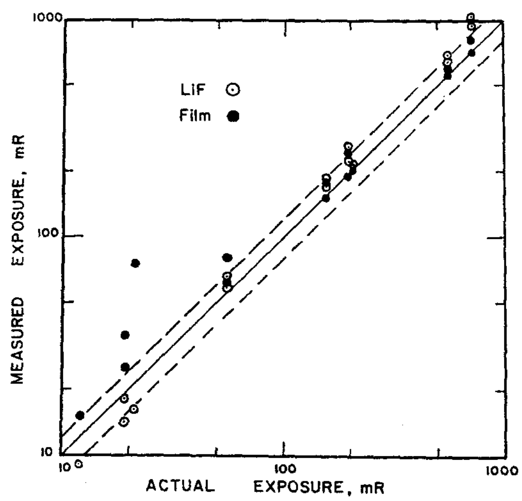

FIG. 3. Exposure readings as measured by LiF single crystals and film. The solid diagonal line represents 100% accuracy. The parallel broken lines indicate an error of $\pm 20\%$ in the measurements.

Figure 3 shows the results obtained with mixed exposures of radium γ-rays and 140 kVp X-rays. Twelve of the 15 crystals measured within $\pm$ 25% of the actual exposures. The measured values using LiF crystals appear to be higher than the actual exposures and this is due to the increase in sensitivity of the LiF to low energy X-rays.

In one experiment film badges from two different companies were exposed simultaneously with the LiF single crystals, to radium γ-rays, ^{137}Cs γ-rays, 140 kVp X-rays and mixtures of these radiations. Figure 4 shows the performance of the LiF single crystals used. Seventeen

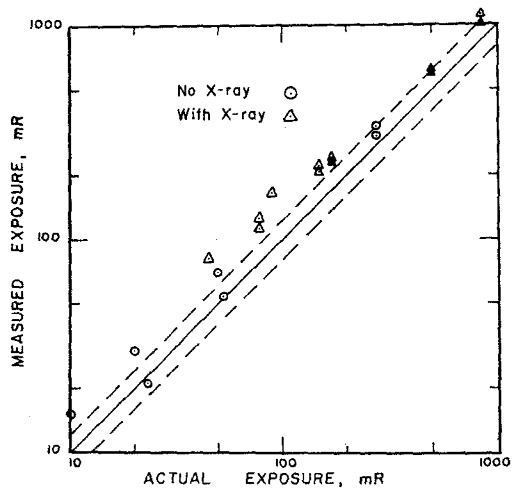

FIG. 4. Exposure readings as measured by LiF single crystals and film. The solid diagonal line represents 100% accuracy. The parallel broken lines indicate an error of $\pm 20\%$ in the measurements.

of the 20 crystals measured within $\pm$ 50% of the actual mixed exposures. Those crystals that had some X-ray exposure are identified separately and these give the higher measured values. No corrections were made for the energy dependence of the LiF. Note, however, the good consistency of measured values on the duplicate sets of crystals given the same exposure.

In Fig. 5 this same performance of the LiF crystals is shown in comparison to the film badge

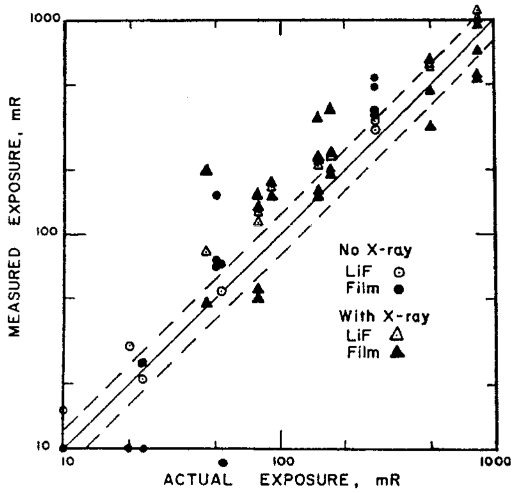

FIG. 5. Exposure readings as measured by LiF single crystals and film. The solid diagonal line represents 100% accuracy. The parallel broken lines indicate an error of ±20% in the measurements.

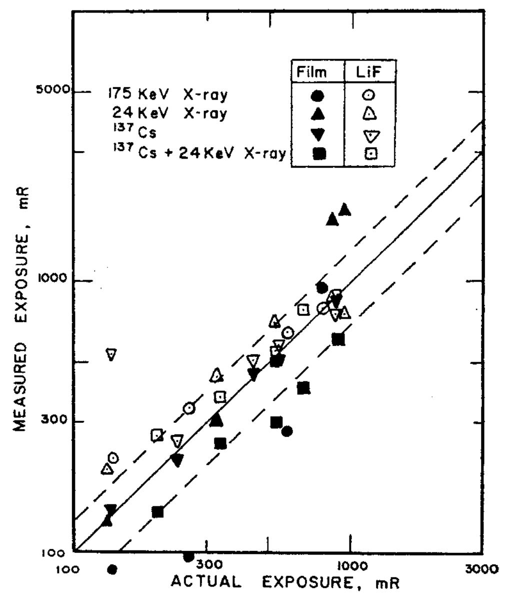

FIG. 6. The results of test exposures given by the National Sanitation Foundation Testing Laboratory, Ann Arbor, Michigan. The parallel broken lines indicate an error of ± 30% in the measurements.

evaluations of the two companies. Note the disagreement between the two companies. One company could not detect anything below 50 mR and reported those badges to have had zero exposure. Also note the poor consistency of some of the duplicate exposures.

The results of the Michigan test exposures are shown in Fig. 6. The measured values using the LiF crystals appear to read high, but within 30%. This is to be expected in the case of the soft X-rays because of the slight energy dependence of the TLD system. No correction has been made for this quality dependence.

CONCLUSION

The film badge continues to be used as the principal personnel monitoring device for want of a better and more accurate and reliable system. This study has clearly demonstrated that the potential exists for the use of LiF single crystals for personnel dosimetry work. The use of single crystals of LiF (TLD-100) in place of the powder is a distinct advantage when measuring milliroentgen levels of exposure. At this lower range the accuracies attainable with the TLD system are somewhat lower than those at higher exposures. The over-all accuracy of ± 30% can be improved upon if one also corrects for the slight quality dependence of the LiF at the lower energies. The TLD system has the advantage that these crystals can be reused over and over again without any loss in sensitivity or accuracy. Also it is possible to monitor each individual with several single crystals, one could be read and replaced at monthly intervals for occupationally exposed personnel and the others used as integrating dosimeters over a longer period of time. Non-occupationally exposed personnel could have their dosimeters read annually or after a suspected exposure. We are undertaking such a program in our institution. The TLD system is inexpensive, rugged and reliable. Suitable single crystals are available in any quantity from the Harshaw Chemical Company. The principal disadvantage at present is the relatively slow read-out (approximately 15 min) because of the need to calibrate each crystal individually. Work is under way to produce single crystals with consistent radiation response to eliminate this calibration step.

We strongly feel that commercial suppliers of film badges should look into the possibility of incorporating a LiF dosimeter in their systems and at least as a beginning monitor the personnel exposures simultaneously with films and the LiF crystals.

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