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The LLNL CR-39 Personnel Neutron Dosimeter*

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INTRODUCTION

We have developed a personnel neutron dosimetry system based on the electrochemical etching of CR-39 plastic at elevated temperatures. The doses obtained using this dosimeter system are more accurate than those obtained using other dosimetry systems, especially when varied neutron spectra are encountered. This CR-39 dosimetry system does not have the severe energy dependence that exists with albedo neutron dosimeters or the fading and reading problems encountered with NTA film.

DESCRIPTION OF THE LLNL BADGE

At Lawrence Livermore National Laboratory (LLNL), we are using the Panasonic TLD Dosimeter. The TLDs are placed in a plastic badge holder (see Fig. 1) that was designed at LLNL. This holder contains the beta and low-energy x-ray shield and has slots into which the components of the nuclear accident dosimeter can be placed. At the time this holder was designed, CR-39 foils were not being used and no provision was made to include them in the holder. To hold the CR-39 foils, we glued a 1/8-in.-thick piece of plastic to the back of the badge holder. An end-mill was used to cut though the back of the badge holder and into the plastic to form a recess. We insert three of

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the CR-39 foils into this recess with the side to be etched next to the wearer. The CR-39 foils are well protected and are not exposed to ambient light. When the foils are placed in the badge, a felt tip pen is used to mark each of the foils with a number that identifies the wearer and the month the badge was issued.

When the badges are returned at the end of the month, one of the foils is etched. If the reading from that foil is greater than 6 mrem above the background, the other two foils are etched on following days. The average reading of the three foils is used to calculate the neutron dose equivalence the person is assigned. If the track density of the first foil is less than 6 mrem, the remaining two foils are not etched. With this procedure, we are able to avoid reading the second and third foils for individuals who did not receive any significant neutron exposure. We can detect most of the neutron exposures above 10 mrem, missing about 5% of the exposures (caused by the statistics of the foils at low doses and of the background).

ETCH CHAMBERS

The etch chambers we are using can handle 8 or 24 foils simultaneously. The cells are made of Lucite and have one liquid electrode and one aluminum-plate electrode. These chambers are easy to handle and have been used daily for about three years with no difficulties. Several of these chambers can be processed at the same time with a single power supply. The chambers were designed to be used in a 60°C oven.

ETCHING PROCEDURE

The etching parameters that we are using are shown in Table 1. We have investigated the effect that changes in the etching parameters have on the results,[1] and the values we show here are optimum. The etch chambers, loaded with the CR-39 foils, are placed overnight (or over a weekend) in an oven maintained at 60°C. The following morning, 60°C KOH is added to the chambers, which starts the first etch step. The power supply is manufactured by Homann-Bell[2] and is programmed using a HP-41CX calculator to provide selected voltages, frequencies, and times. The second step, which we call blow up, is very important because it increases the size of the tracks that exist at the end of the first etch step. This greatly improves the precision that can be attained with the Biotran colony reader because the tracks are large compared to the imperfections, dirt, scratches, etc. often present on the CR-39 foils. The background from the foils is reduced by using a higher track-size threshold on the optical reader, which allows us to discriminate against most of these small imperfections. The precision of the Biotran results are typically within ±1% for repeated readings of the same foil.

The track density on the foil is determined by scanning the foils with an optical bacterial colony counter (Biotran). Six fields of view, 3x3 mm, are counted by starting at the top-center of the etched area on the foil and moving down the center of the foil. If any of the fields have a peculiar appearance such as a scratch, ring of tracks, dirt or other abnormalities, that field of view is avoided and another selected, usually by moving sideways. There are about 13 possible fields in the etched area; we read only 6, which we feel is adequate.

NEUTRON ENERGY RESPONSE

Low-frequency electrochemical etching at elevated temperatures produces a different energy dependence than that obtained depending on with high frequency or chemical etching of CR-39 foils. Figure 2 shows the energy response we obtain. There is a difference in the energy dependence obtained depending on whether the front or the back of the foil is etched. We routinely use the back of the foils to obtain a better directional response (discussed later in this report). Both of the curves in Fig. 2 show that the response to neutrons with energies between about 150 keV and 4.0 MeV is relatively energy independent.

The energy dependence is affected by changes in the etching high voltage but is not affected by changes in the etching time. CR-39 does not respond to thermal neutrons or to neutrons with energies between 0.01 and about 0.05 MeV, and it has a lower than desired response to neutrons with energies in the 13-16 MeV region (see Fig. 2).

The CR-39 dosimeter will under-respond to the neutron spectrum present inside the containment of a power reactor. In addition to the thermal neutron component, which is around 4% to 8%, about half of the remaining neutron dose equivalent is delivered by neutrons having energies of less than 100 keV (based on multisphere neutron instrument measurements). The CR-39 responds to only half the actual neutron dose equivalent.

If the CR-39 dosimeters are calibrated using a ^{252}Cf source and the person is exposed to a ^{239}Be source, the results will be low by about 40% because many of these neutrons have energies above 4 MeV, where the response of the CR-39 falls off.

The personnel dosimeter system is calibrated with CR-39 foils located in the badge because the badge decreases the response of the foils to neutrons (by about 15% for neutrons from ^{252}Cf sources). The dosimeters are also placed on a phantom since the backscatter increases the response of the CR-39 foils by about 8%. The foils must be properly loaded in the holder with the side to be etched in the same position as it is in the personnel dosimeters. Our routine calibration is to ^{252}Cf at a dose equivalence of 400 mrem.

PERFORMANCE OF THE DOSIMETER SYSTEM

Linearity

The linearity of the dosimetry system is shown in Fig. 3. This curve was obtained when our sensitivity was about 8 tracks/mrem and is linear only to about 450 mrem or about 4000 tracks/cm^2. Linearity is a function of the number of tracks on the foil and not the neutron dose equivalent. Our reader is linear to about 4000 tracks/cm^2. The dose equivalent corresponding to 4000 tracks/cm^2 depends on the efficiency of the system at the time the etch is performed. The linearity can be extended to higher dose equivalence by reducing the etch time or changing some of the other etching parameters, which will produce fewer tracks/mrem. The foil results can also be corrected for nonlinearity by using the curve shown in Fig. 3 if the track density is less than about 15,000 tracks/cm^2.

Sensitivity

Our present CR-39 dosimeter and etching procedure result in a sensitivity of about 4.5 tracks/mrem. The background on new foils varies but is around 36 tracks/cm^2 which is equivalent to about 8 mrem. This gives us a limit of sensitivity of approximately 10 mrem for a single CR-39 foil. The standard deviation of the track count for foils exposed to 400 mrem (bare ^{252}Cf source) varies with the individual sheets but is between 3 and 5%. For background foils, it is around 30%.

Directional Dependence

We have measured the directional dependence of CR-39 foils both in air and on a phantom and found them to be similar. The directional dependence obtained with CR-39 foils in a personnel badge and placed on a phantom is shown in Fig. 4 (the side of the foil next to the wearer was etched). The directional response for most neutron energies is shown by the solid line. High- and low-energy neutrons have a different directional dependence at the larger angles of incidence.

The response shown in Fig. 4 is the best directional dependence attainable at present. This directional dependence is not very good. We apply a correction factor to partially compensate for the error that one would have in the dosimetry results caused by the directional dependence. We selected as our calibration point a value 20% lower than the results obtained from a face-on (0°) exposure. This means that if a person were exposed face-on to the source, his actual dose equivalent could be overestimated by 20%. But for exposures at the higher angles of incidence, the error in underestimating his dose equivalent would be reduced. The disadvantage of etching the back of the foil is that the sensitivity on the back side of the foils is about 30% less than the value on the front. This reduces the sensitivity of the dosimetry system from about 8 to 4.5 tracks/mrem.

CR-39 FOILS

Foil Stability and Fading

All of the CR-39 foils that we have used have been manufactured by American Acrylics (25 Charles St, Stratford Conn 06497). They are "dosimetry grade" CR-39 made of high-purity monomer purchased from Pittsburg Plate Glass

(PPG). The CR-39 sheets are 63.5 µm (0.025 inch) thick and usually vary little in thickness over the sheet (±5 µm--0.002 inch). The sheets are covered on both sides by American Acrylics with a nominal 13 µm (0.005 inch) thickness of polyethylene, which is required to protect the foil from radon alpha particles and to protect the foils from abrasion.

Our sheets are laser cut (and sometimes laser numbered) by Applied Fusion Inc. of San Leandro, Ca. The foil size we use was selected to allow the foil to be placed inside the Hankins type albedo neutron dosimeter. We have discontinued the use of these albedo dosimeters but the foil size has not been changed because it is convenient to handle and we get over 500 foils from each CR-39 sheet.

The CR-39 foils have a reasonably low background on the side of the sheet that was on the top of the mold during casting. The background track density on the back of the sheet is about 10 to 15 times higher than on the front. This requires that the side of the sheet that was on the top of the mold be marked to assure the proper orientation of the foils when they are laser cut. We do this by drawing lines with a felt tip pen at an angle on the polyethylene covering the sheets. In some cases, the side of the sheet that was on the top of the mold during casting has been mislabeled, and the foils must be checked before they are used.

A recently completed 1-year study of storage conditions indicates that when the foils are protected from light, little if any fading or change in sensitivity occurs, and the background increases at a rate consistent with the ~8 mrem/y environmental neutron background. Foils used in this study that were not protected from ambient light faded, lost sensitivity, and suffered background increase to the point where the foils were useless. We conclude from the above studies that fading, changes in sensitivity, or increases in the foil background are not a problem if the foils are protected from light. The CR-39 foils could be issued for a 6-month exchange period if the results are corrected for the environmental neutron background. To keep the background of the CR-39 foils as small as possible, only fresh foils are issued.

ADDITIONAL STUDIES.

We have recently found that the track-size distribution has a relationship to the incident neutron energy. To determine the usefulness of track-size distributions for personnel neutron dosimetry applications, we are studying the effect of etching parameters on the track size-distributions. This work is described in another paper being presented at this meeting.(3)

REFERENCES

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3. Hankins, Dale E., Homann S., and Westermark, J., "Neutron Spectrum-Dependent Track-Size Distribution of Electrochemically Etched CR-39 Foils," presented at the Sixth Symposium on Neutron Dosimetry, Neuherberg, Germany, October 12-16, 1987.

FIGURE CAPTIONS

Figure 1. The LLNL personnel badge, showing the Panasonic TLD, the three CR-39 foils, and the beta shield. The CR-39 foils are placed in the recess at the back of the badge holder.

Figure 2. The energy dependence of electrochemically etched CR-39 foils, showing the difference between foils etched on the front or the back. The energy dependence is relatively flat from about 150 keV to 4.0 MeV.

Figure 3. The response of the CR-39 foils is linear up to about 4000 tracks/cm^2.

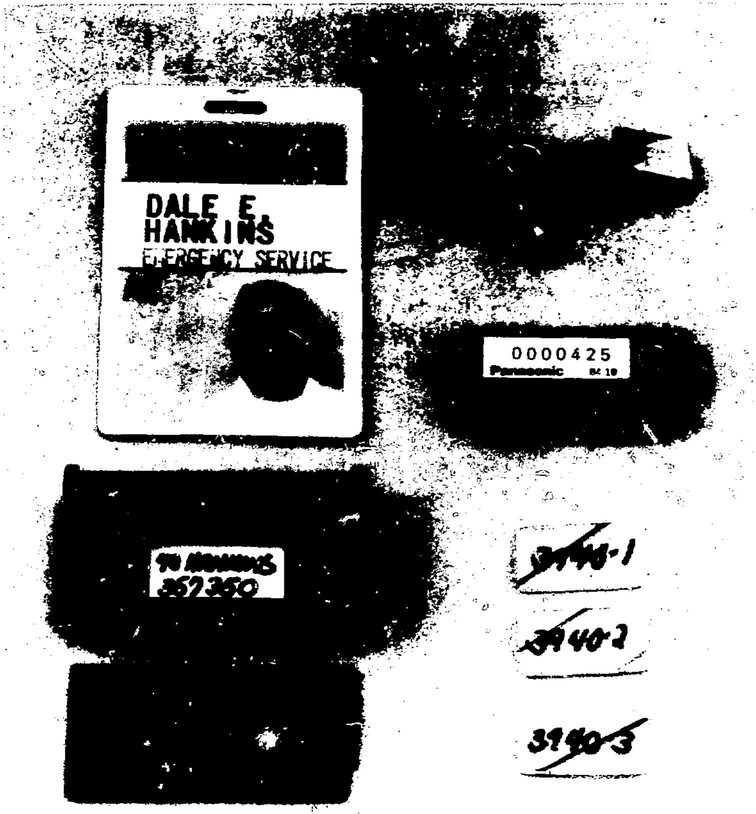
Figure 4. The directional response of CR-39 foils decreases as the angle of incident becomes larger. It is the same for most neutron energies but decreases less at 15 MeV and more at low neutron energies.

Table 1. CR-39 processing parameters.

	Etching	Blowup	Post Etch
High voltage	3000 V	3000 V	0
Frequency	60 Hz	2.0 KHz	0
Temperature	60°C[a]	60°C	60°C
Time	5 hours	23 min[b]	about 15 min
KOH normality	6.5 N	6.5 N	6.5 N

[a] The etch chambers and KOH must be left in the oven overnight (or over a weekend).

[b] No adjustment for foil thickness is required if the foils are between 0.022 and 0.029 inch.



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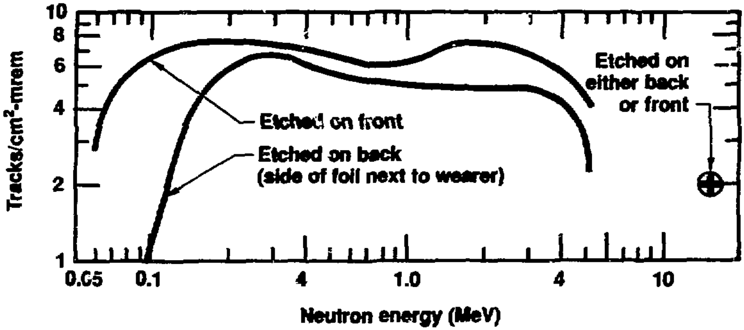

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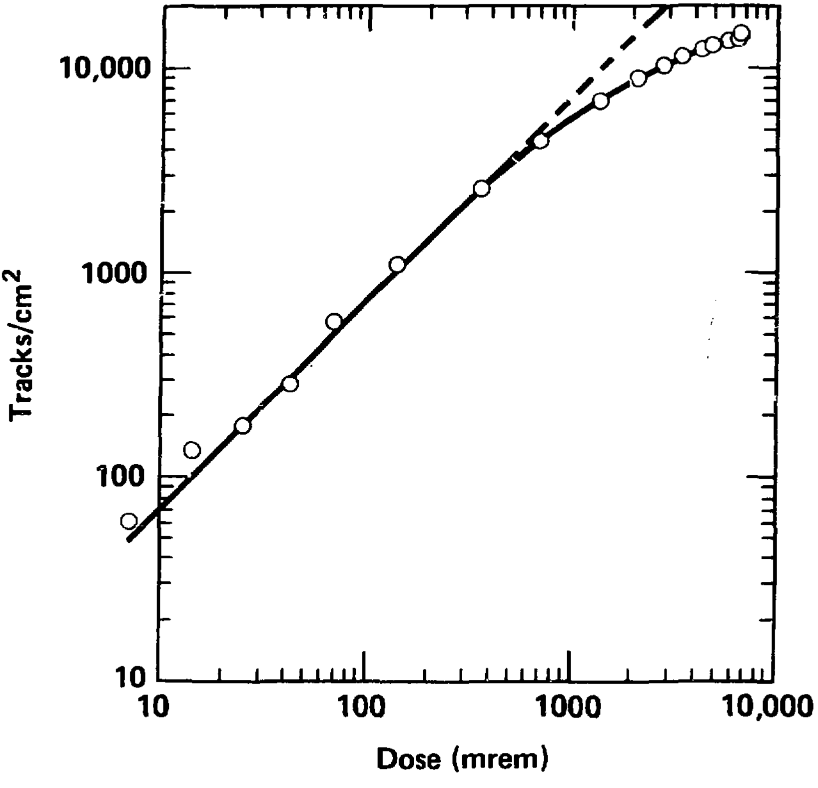

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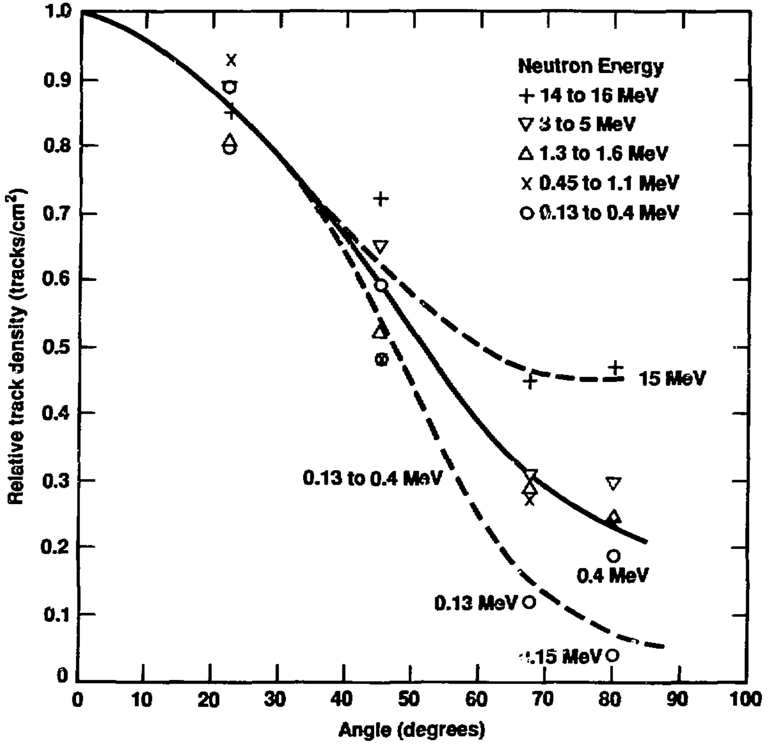

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