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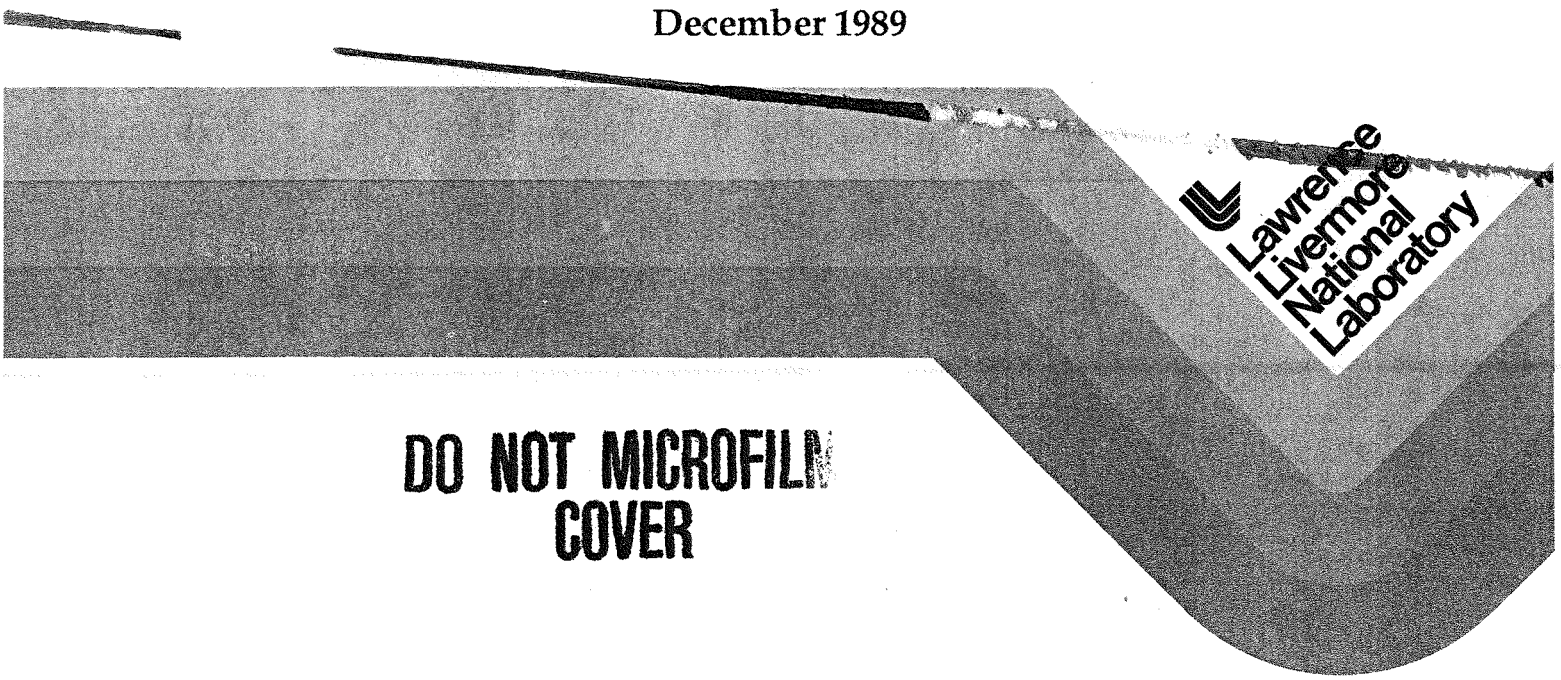

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Preface

This report was originally prepared for distribution at the "Technology Transfer Meeting on CR-39 Neutron Track Detectors and the Neutron + Gamma Total Dose Meter," Denver, CO, Sept. 24–25, 1986, and published as report UCRL-95350. Since that meeting, we have continued to study the use of CR-39 as a personnel neutron dosimeter. This document was first compiled in November 1987, but this comprehensive revision updates the earlier reports and also includes results from our recent studies.

Personnel Neutron Dosimetry Using Electrochemically Etched CR-39 Foils: Revision 1

Dale E. Hankins, Steven G. Homann, and Brooke Buddemeier

Abstract

This comprehensive report describes our personnel neutron dosimetry system that is based on the electrochemical etching of CR-39 plastic at elevated temperatures. The CR-39 dosimetry system has several advantages: the doses obtained using this system are more accurate than those from other dosimetry systems, especially when varied neutron spectra are encountered; CR-39 does not have the severe energy dependence that exists with albedo neutron dosimeters, nor does it have the fading and reading problems encountered with NTA film. The energy response of CR-39 to neutrons is fairly flat from about 150 keV to 5.0 MeV, but drops by about 60% in the 13–16 MeV range. The sensitivity of the dosimetry system is about 4.5 tracks/cm^2-mrem, with a background equivalent to about 3 mrem for new CR-39 foils. The limit of sensitivity (a = b = 0.05) is approximately 6 mrem.

We describe our four-stage electrochemical etch procedure that can be used to process quickly large numbers of CR-39 dosimeters. The stages in the etching procedure improve the track quality and the precision of the track counting, and also reduce the background counts caused by imperfections, scratches, adhesive, or dirt on the foils. We have developed an image analyzer that is used to measure the track-size distribution and the track density on the foils. The track-size distribution is used to identify and eliminate foils with high defect-caused backgrounds and to reduce the effective background on the foils by discriminating against defect-caused tracks. The track-size distribution can be used to obtain information on the incident neutron energy or spectrum.

Introduction

We have developed a personnel neutron dosimetry system based on the electrochemical etching of CR-39 plastic at elevated temperatures. This system is superior to any neutron dosimeter used previously. The doses obtained from electrochemically etched CR-39 are more accurate than those from other dosimetry systems, especially when varied neutron spectra are encountered. The CR-39 dosimetry system does not have the severe energy dependence that exists with albedo neutron dosimeters, nor does it have the fading and reading problems encountered with NTA film.

The CR-39 system employs an electrochemical etch procedure that can be used to process large numbers of CR-39 dosimeters. The etch procedure is suitable for operations where the number of personnel requires that many dosimeters be processed in a prompt and efficient manner. Our experience shows that one full-time technician can etch and evaluate 2000 CR-39 foils per month.

To improve the energy dependence, we adopted the hot (60°C) low-frequency (60 Hz) etch procedure recommended by Tommasino.[1] The energy response to neutrons is fairly flat from about 150 keV to 5.0 MeV, but drops by about 60% in the 13–16 MeV range. The sensitivity of the dosimetry system is about 4.5 tracks/cm^2-mrem, with a background equivalent to about 3 mrem for new CR-39 foils. The limit of sensitivity (a = b = 0.05) is approximately 6 mrem.

We etch the foils using a four-stage etching procedure, which improves the track quality and the precision of the track counting. The multi-stage etch procedure also reduces the background counts caused by imperfections, scratches, adhesive, or dirt on the foils. We have been using CR-39 dosimeters for personnel neutron dosimetry at the Lawrence Livermore National Laboratory for more than five years.

Etch Chambers

Our Homann-type etch chambers can handle 8 or 24 foils simultaneously. The chambers can be made in any high-quality machine shop. Originally we made the chambers in our own machine shop, but have recently purchased chambers made by EG&G at the Nevada test site. These chambers were made using a programmable-end mill and are of excellent quality and precision. Drawings of both the 8- and the 24-cell chambers are included in Appendix A of this report. We have found the 24-cell etch chamber to be the most useful, and we use the 8-cell chambers only if small or odd numbers of foils are to be etched. One or two of the 8-cell chambers should be adequate for most dosimetry facilities.

The cells are made of lucite and have one liquid electrode and one aluminum-plate electrode. These chambers are easy to handle, and some have been used daily for five years. Several of these chambers can be used at the same time with a single power supply. These chambers were designed to be used in a 60°C oven. Other etch chambers have been designed, but because of the excellent results we have had with these particular chambers, we strongly recommend that they be used during an initial trial period. The only maintenance required of the etch chambers is replacing the O-rings when they become permanently flattened (after one month of daily use) and replacing the rubber silastic seal around the stainless-steel electrode when a leak develops (every 2–4 weeks).

We recently made a device to rapidly and precisely position the foils on the etch chambers. Previously the foils were placed on the O-rings by hand and individually positioned using a scalpel or knife. The positioner consists of 24 holes cut into a 1/4-in.-thick lucite plate. The top half of each hole is bevelled at 45°, which allows the foils to be dropped easily into position over the O-rings. The hole sizes are only a few mils larger than the foils, which accurately positions the foils on the O-rings. A pusher plate made of 1-in.-thick lucite was cut with 24 projections slightly smaller than the foils and is used to push the foils onto the O-rings until a seal is obtained.

Etching Procedure

Our etching parameters are shown in Table 1. We have investigated the effect of the etching high voltage on the energy dependence of the CR-39 foils, and the effect that changes in the other etching parameters have on the results. We now feel these parameters are optimal and do not expect to change them.

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.

We added a pre-etch step to the cycle when we found that this greatly reduced the defect-caused background on the foils. Previously, entire sheets of CR-39 had to be discarded because the defect caused-background was unacceptably high. The pre-etch step also reduces the background on the foils from about 8 mrem to about 5 mrem (or to 3 mrem, if track-size analysis is used). We believe that the reduction in the defect-caused background tracks is caused by the dissolving of the adhesive left behind when the polyethylene protective covering is removed from the CR-39 foil.

Following the pre-etch, the high voltage is applied to start the second etch step. The power supply is manufactured by Homann-Bell (1985) and is programmed using a HP-41CX calculator to provide selected voltages, frequencies, and times.

The third step, which we call the "blow-up" step, is very important because it increases the size of the tracks that exist at the end of the second etch step. This greatly improves the precision that can be attained with the image analyzer (used for track counting and analysis of the track-size distributions), because the tracks are large compared to the imperfections, dirt, and scratches often present on the CR-39 foils. The defect-caused background from the foils is also reduced by track-size analysis, which allows us to discriminate against many of these small imperfections and from the very large tracks that are on most foils. The precision of the image analyzer results are typically within ±1% for repeated readings of the same foil.

When the etch chambers and foils are left in the oven over a weekend, the number of tracks/mrem on the foils is reduced to about 7% less than the number of tracks usually obtained with an overnight etch. For long weekends, the decrease is larger, being about 3–4% for each additional day.

The track density (number of tracks/cm^2) and the track-size distribution on the foil is determined by reading the foils with the image analyzer. Three fields of view, 4.5×4.5 mm, are counted by starting at the top-center of the etched area on the foil and moving down the center of the foil. Although the image analyzer can discriminate against images that are not shaped like

Table 1. Recommended etching parameters. The etch chambers and KOH must be left in the oven overnight (or over the weekend). No adjustment for foil thickness is required if the foils are 25 mils ± 3 mils.

	Pre-Etch	Etching	Blow up	Post etch
Time (min)	105	108	30	~15
Voltage (kV)	0	3	3	0
Frequency (Hz)	0	60	2000	0
Temperature (°C)	60	60	60	60
KOH normality	6.5	6.5	6.5	6.5

tracks, if visual observation indicates the foil is dirty, it is usually removed and cleaned. The area counted is about 0.6 cm^2, and the track density is converted by the image analyzer to tracks/cm^2. Only a small part of the total etched area is not read. A description of the track-size distributions and their application is given in the section "Track-Size Distribution" near the end of this report.

A copy of the "Operating Procedures for Electrochemical Etching of CR-39" is given in Appendix B of this report. It describes the steps we use in etching and reading the foils.

Neutron Energy Response

Using low-frequency electrochemical etching at elevated temperatures produces a different energy dependence than that obtained with high-frequency or chemical etching of CR-39 foils. Figure 1 shows the energy response as a function of the etching voltage. These results were obtained using monoenergetic neutrons (with energies below 1.0 MeV) from the Tandem Van de Graaff accelerator at the Los Alamos

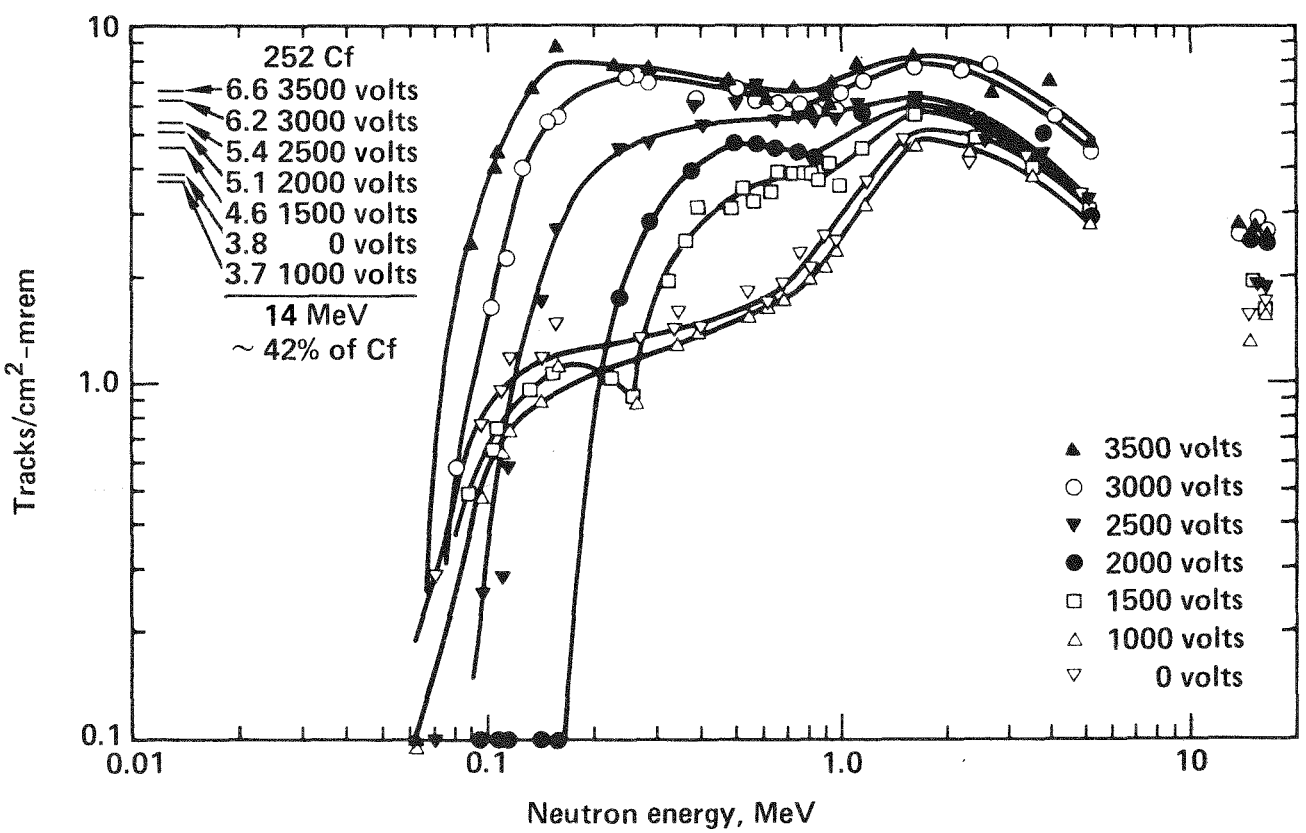


Figure 1. Energy dependence of electrochemically etched CR-39 foils as a function of the etching high voltages, using a five-hour etching procedure.

National Laboratory, and an accelerator at the Battelle Northwest Laboratory (for neutron energies above 1.0 MeV).

The curves shown in Fig. 1 were obtained using voltages from 0–3500 V for the etching cycle. The blow-up step was varied to give the same track sizes on the foils. The effect of increasing the high voltage is most dramatic in the keV region, where the response to the lower-energy neutrons is progressively increasing. At 3000 V the energy response is relatively flat from about 150 keV to about 5.0 MeV.

The lowest threshold energy occurs when 3500 V etching voltage is used. The background tracks increase to an unacceptable level at this voltage, however, eliminating it as a useful etching potential.

The response of CR-39 to neutron energies around 14 MeV is about 42% of its response to a ^{252}Cf source. We had hoped that changes in the etching voltage could be used to increase the sensitivity of the CR-39 to these high neutron energies, but we have found that this cannot be done.

We obtained the results shown in Fig. 1 with CR-39 foils that were exposed with the side to be etched oriented *toward* the incident neutrons. When the side *away* from the source (next to the phantom) is etched, a different energy dependence is obtained. Figure 2 shows the difference in the energy response, depending on which side of the foil is etched. We routinely etch the side of the foil that is toward the incident neutrons (away from the wearer). Although exposing the foils with the side to be etched next to the wearer results in an improved directional response, the sensitivity of the foils to neutrons decreases, and to retain a high sensitivity, it is not used (see "Directional Dependence," below).

The difference between the two curves in Fig. 2 is caused by the polyethylene protective layer that is on the foils to prevent damage by abrasion and alpha particles. Polyethylene has a higher hydrogen content than CR-39 and therefore generates more recoil protons. Some of the protons originating in the polyethylene from neutrons with energies above 1.0 MeV reach the CR-39 and cause damage that becomes a track when etched. Below 1.0 MeV, the protons originating in polyethylene either do not reach the CR-39 or have too little energy to damage the foil.

CR-39 does not respond to thermal neutrons or 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. 1). Our studies have shown that the relative response to high-energy neutrons and to other neutron energies is not affected by changes in any of our etching parameters. However, a correction for the underresponse between 13–16 MeV can be made by using the track-size distribution, as discussed later in this report.

When the pre-etch step was added to the etching cycle, we were concerned that the energy dependence may have changed. We repeated the study of the energy dependence and obtained the results shown in Fig. 3. No significant change in the energy dependence was found. At the lower neutron energies between 100 and 200 keV, a small increase in sensitivity is indicated, but we do not know if this is real or merely experimental error.

The energy dependence of our CR-39 foils is far superior to that obtainable with albedo neutron dosimeters or from chemical etching of CR-39. In Table 2, we show the results obtained using a ^{252}Cf source moderated in the polyethylene, water, D_2O, and aluminum spheres that are used for studies in our calibration facility. These results indicate that the energy dependence of CR-39 using our etching parameters is sufficiently flat to give CR-39 readings within a few percent

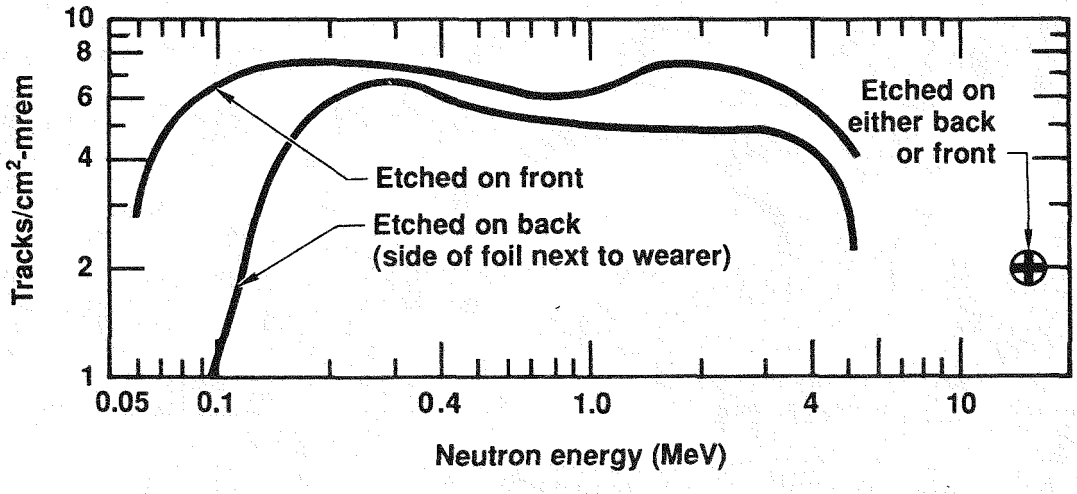


Figure 2. Energy dependence of electrochemically etched CR-39 foils as a function of etching high voltages, using a five-hour etching procedure. The energy dependence of foils etched on the front side (incident) is different from the energy dependence of those etched on the back side (against the phantom).

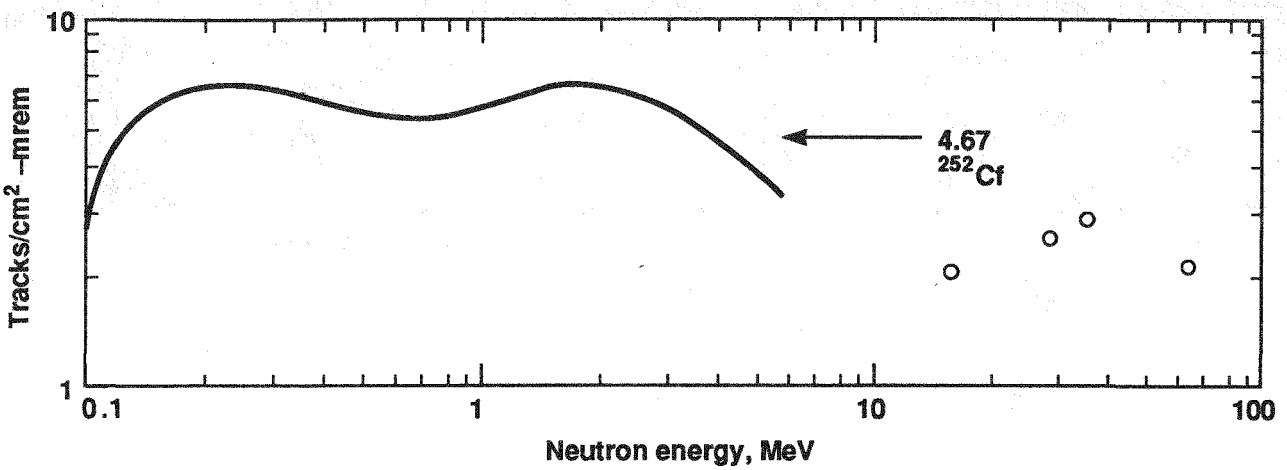


Figure 3. The most recent determination of the energy dependence of CR-39 after adding the pre-etch step to the etch cycle.

Table 2. Spectrum dependency of CR-39 for moderated ^{252}Cf neutrons.

^{252}Cf moderator	For neutron energies > 0.1	For all neutron energies
None	0.0	0.0
2-cm poly	+9.5	+8.4
5-cm poly	+5.0	+1.5
10-cm poly	–5.7	–5.1
25-cm H_2O	–4.7	–6.7
5-cm D_2O	+4.1	+7.8
10-cm D_2O	+0.5	–5.3
15-cm D_2O	–0.1	–14.1
25-cm D_2O	–2.6	–31.9
20-cm Al	–3.6	+2.1

of the actual dose equivalents, except for low readings from the large D_20 moderators. These low readings are caused by the undetected thermal neutron contribution to the dose equivalent, which is significant for the larger D_20 spheres and is not detected by CR-39. For comparison, the calibration factors for albedo neutron dosimeters used with these moderators range over one decade.

The important finding of this study is that the CR-39 results are not affected by large water and polyethylene moderators, which are similar to the materials used in neutron shielding and storage containers. Therefore, the response of the CR-39 should be correct for leakage neutrons through shielding or from a storage container and will still be correct for the bare source itself when it is removed from the shield or container.

If the CR-39 dosimeters are calibrated using a ^{252}Cf source, and the person is exposed to a PuBe source, the results will be low by about 30% because many of the PuBe neutrons have energies above 5 MeV, where the response of the CR-39 falls off.

The personnel dosimeter system should be calibrated with CR-39 foils located in the badge. The dosimeters must also be on a phantom, which increases the reading of the CR-39 foils by about 7%. 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. The calibration should be slightly below the point where the foils become nonlinear (about 3000 tracks/cm^2 for our foils and reading procedures).

Shown at the right in Fig. 3 are the data points we obtained using high-energy neutrons. The energy

response of CR-39 to high-energy neutrons can not be accurately determined because monoenergetic neutron beams above 14 MeV are difficult to produce and the dosimetry of high-energy neutron beams is not precise. Within these limitations, we believe the data points we show are reasonably accurate. The data points show that the response of CR-39 to high-energy neutrons is reasonably flat. To evaluate the dose from high-energy neutrons, we have been applying a dose-correction factor based on the response of CR-39 to 14-MeV energy neutrons. The data points in Fig. 3 indicate that this was a reasonable assumption.

Because its energy response is relatively flat, CR-39 should be seriously considered for use as personnel dosimeters at high-energy accelerators. The energy response of CR-39 is superior to that of NTA film in the energy range shown. A practical problem is that most personnel exposure at high-energy accelerators includes some neutrons with energies between 150 keV and 5 MeV where the response of CR-39 is higher. When the calibration is based on high-energy neutrons, the evaluation of the person's dose could be overestimated.

Effect of Various Changes in Etching Parameters

Since this report was last revised, we have changed the etching parameters that are being used. Previously the track density on the foils was determined using a Biotran colony reader. This reader has been replaced by an image analyzer that also gives us the track-size distribution on the foils. To obtain as much information as possible from the track-size distributions, the etching times were changed and a pre-etch step was added to the etch cycle. Details of these changes are given below and in "Track-Size Distributions."

We recently found that the addition of a pre-etch step to the etching cycle removes most of the defect-caused background tracks on the CR-39 foils. This allowed us to salvage previously unacceptable sheets of CR-39 and has reduced the defect-caused background on acceptable sheets by about a factor of two. The pre-etch also reduced the standard deviation of the background track densities by eliminating the occasional high background readings from some foils.

When the pre-etch is added to the etch cycle, the number of defect-caused tracks decrease rapidly at first and then continue to decrease exponentially as the pre-etch time is increased. To avoid increasing the etching time unreasonably, we selected a pre-etch time of 1 h 45 min. By adding this pre-etch step, we now have a four-stage etching cycle (see Table 1).

We have investigated the effect of changes in our etching parameters on the response of CR-39 foils. Figures 4 and 5 show the track density as a function of high voltage. For foils exposed to neutrons from a ^{252}Cf source, Fig. 4 shows that the track density is not a strong function of the high voltage. Part of the decrease in track density at lower voltages is caused by changes in the energy dependence at different etching voltages, shown previously in Fig. 1. However, the effect of high voltage on the background tracks, shown in Fig. 5, is significant. The background track density increases exponentially as the etching high voltage is increased.

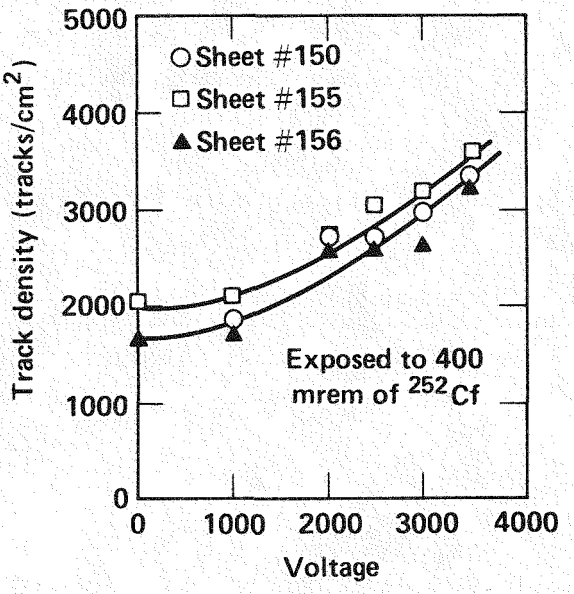


Figure 4. Track density as a function of etching high voltage.

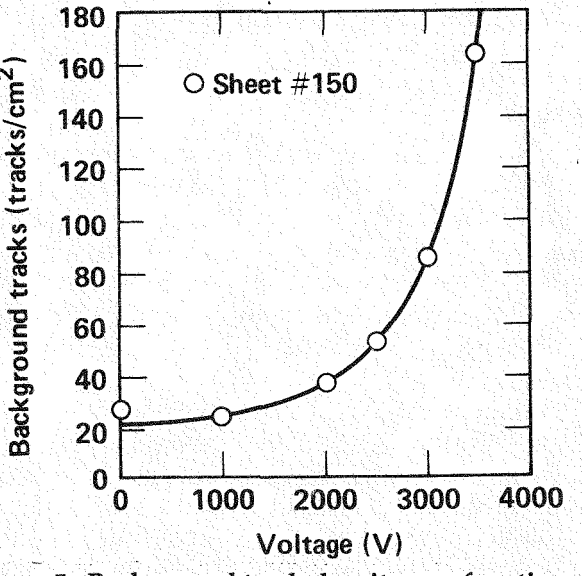


Figure 5. Background track density as a function of etching high voltage.

We have investigated extensively the effect that a decrease from 3000 V to 2750 V has on the background track density and energy dependence. Since both the energy dependence and background track density changed only slightly, we did not make the change to the lower voltage.

When the high voltage used in the second etching step is changed, though, it is necessary also to change the third-stage (blow-up) etching time to keep the proper track size, as shown in Fig. 6.

Oven temperature is very important in the etching procedure. Before we recognized this, we placed the etch chambers in the oven and immediately started the etching process using room temperature KOH. Later, we measured the temperature of the KOH inside the cells and found that the 24-cell etch chamber never attained the temperature of the oven, even after six hours (see Fig. 7). The 8-cell chamber reached equilibrium temperature after three hours. The 8-cell chamber therefore gave us more and larger tracks than the 24-cell chamber. The room temperature also varied, which caused the initial temperature of the etch cycle to vary. To solve these problems, we now place the loaded etch chambers in the oven the night before the etch is to be performed. The KOH is also placed in the oven in a plastic squeeze bottle. The following morning, we add the KOH to the etch chamber to start the first etch step.

Figure 8 shows how changes in the oven temperature affect the track density. Small changes in oven temperature are important and must be avoided. At an oven temperature around 60°C, a 1°C change in temperature causes about a 3.5% change in the track density. An oven with a digital temperature controller (±0.1°C) is required. If several etch chambers are to be used simultaneously, an oven with forced-air circulation is required to keep the temperature uniform throughout the oven. The oven's temperature sensor should be located near the etch chambers.

If oven temperatures other than 60°C are to be used, the blow-up time must be adjusted; Figure 9 shows the blow-up time required as a function of the oven temperature. The CR-39 foils are damaged by oven temperatures above 65°C—the foils will bend or be distorted, and at temperatures above 70°C, the etched surface of the foil will become cloudy. If either of these effects are observed, the oven temperature is too high and should be reduced.

Recently we found that in an emergency, we could perform an accurate etch without having to leave the chambers in the oven overnight. We add hot (60°C) KOH to a room-temperature etch chamber. By measuring the KOH, we found that the temperature dropped sharply when the KOH was added to the cold etch chamber and gradually increased until it was almost 60°C by the end of the etch cycle. We found that by adding one hour to the pre-etch time (extending it to 2.75 hours), the track density is very close to that obtained with a normal etch. Therefore, if required, an etch could be performed in one day without having a significant change in the track densities. This procedure would be especially useful in the event of an

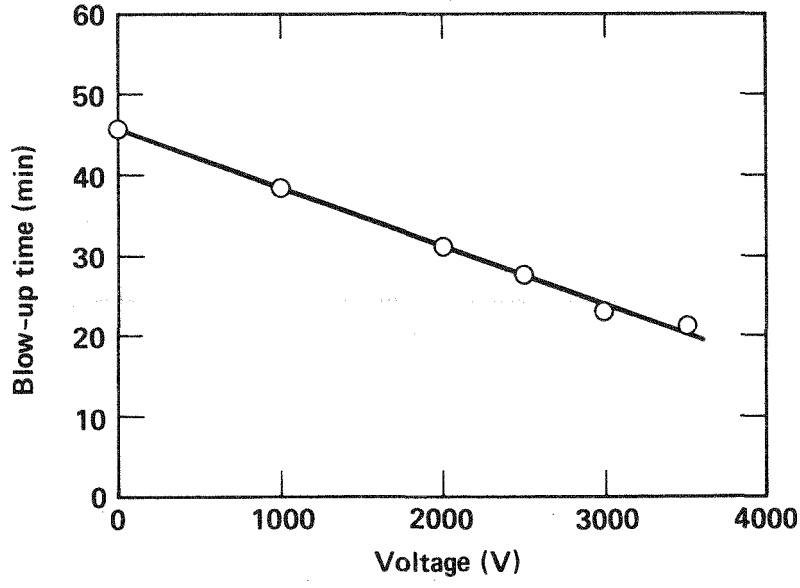


Figure 6. Blow-up time as a function of etching voltage.

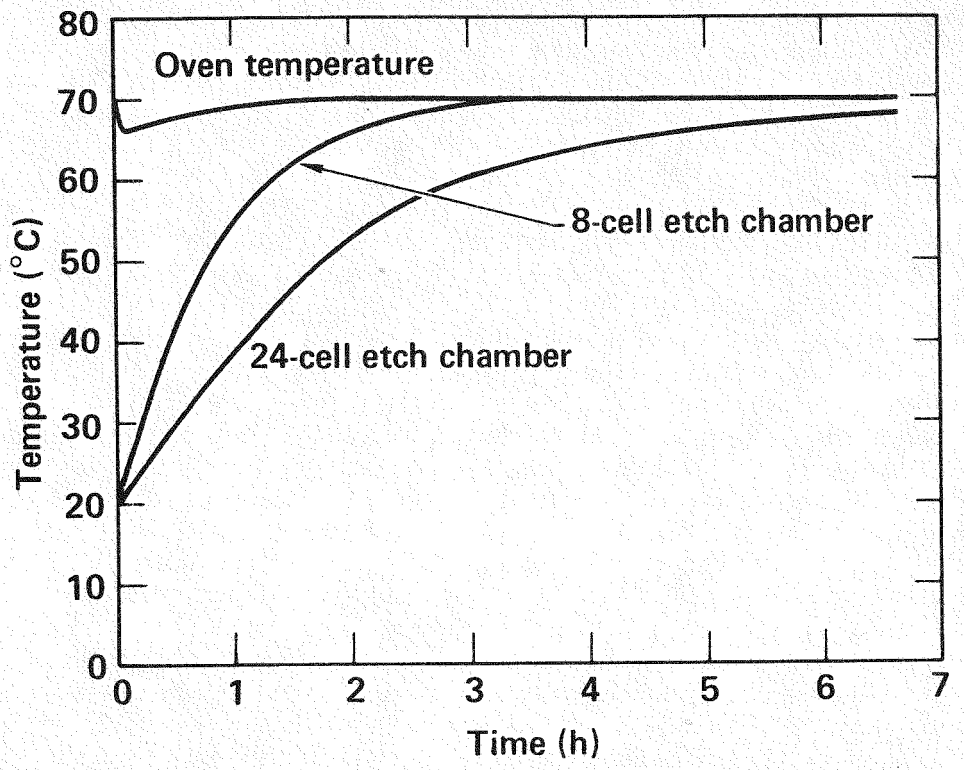


Figure 7. Temperature inside the 8- and 24-cell etch chambers as a function of time.

accidental exposure where a rapid evaluation of the dose is required.

Our recent studies have shown that changes in the etching time have no effect on the energy dependence of the CR-39. The track density is approximately a linear function of the high-voltage etching time, i.e., the sum of the second- and third-stage etching time. The time required for the blow-up stage as a function of the second-stage etching time is shown in Fig. 10. As the second-stage etching time is reduced, the blow-up time must be increased to keep the track size correct.

If the CR-39 foils are exposed to high neutron dose equivalents, the number of tracks obtained can be reduced by using shorter second-stage etching times. This may keep the track density within the linear region of the linearity curve (see "Linearity," below) or will allow a correction for nonlinearity to be made. We have used second-stage etching times as short as one hour, but the track quality is poor. The track quality is adequate down to two hours, though; if the track density is still too large, a lower etching temperature may also be used. Another method, and the preferred procedure, for evaluating foils with high exposures is to increase the magnification of the microscope.

The track density is affected by variations in the thickness of the foils. Thicker foils increase the effective electrode separation, which results in fewer and smaller tracks. The opposite effect occurs for thin foils, resulting in more and larger tracks. The track density varies by about 1% per mil of foil thickness and is normally ignored because the thickness variation is small in the sheets of CR-39 recently being received from American Acrylics (±2 mils). If the average thickness of the CR-39 sheets varies more than 3 mils from the specified 25 mils, though, the blow-up time will need to be adjusted or the size of the tracks will be too large for thin sheets and too small for thick sheets. If the neutron doses are large and high magnification reading is performed (see below) a correction for foil thickness should be made.

Variation in foil thickness will cause the standard deviation of the track density to increase, giving the false impression that the quality of the CR-39 is poor. If this occurs, the foils must be sorted for thickness or corrections will need to be applied to the results.

Track density is also affected by the KOH normality. We use a hydrometer to determine the normality (at a specific gravity of 1.276). We have found no significant difference in the track density for KOH normalities between 6 and 7; therefore, we recommend the KOH normality be 6.5 ±0.25. Repeated use of the same KOH causes a reduction in track density by about 1% for each use. This change is not detectable with the hydrometer and must therefore be caused by changes

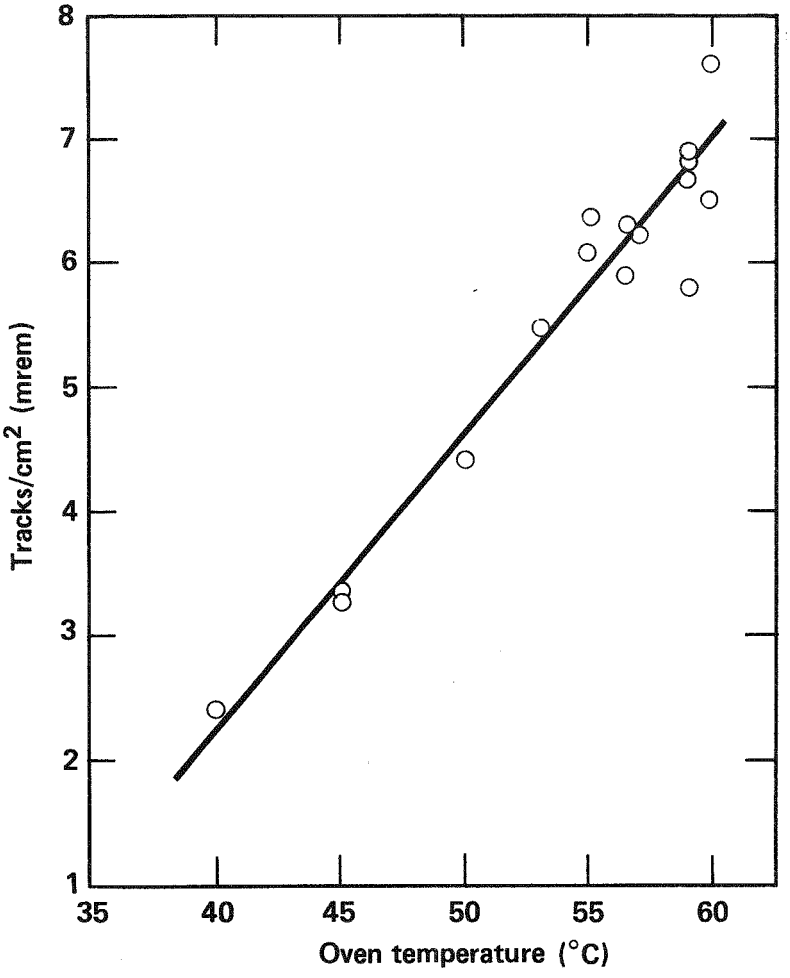


Figure 8. Track density as a function of oven temperature (five-hour etching cycles using 6.5 N KOH).

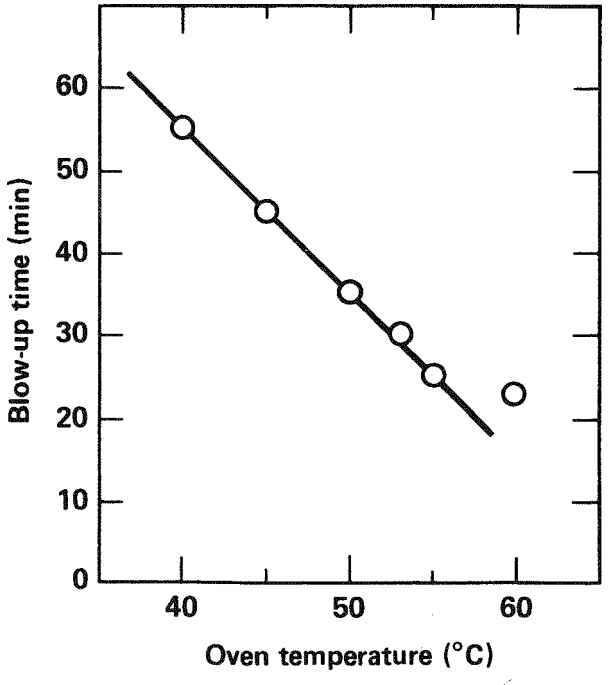


Figure 9. Blow-up time as a function of oven temperature (five-hour etch cycles using 6.5 N KOH).

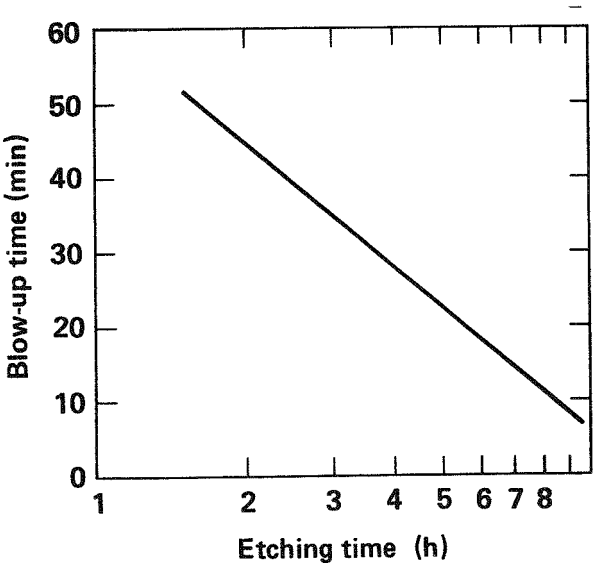


Figure 10 Blow-up time as a function of etching time (6.5 N KOH).

in the KOH that do not affect its density. We recommend that each batch of KOH be used a maximum of five times.

We use a 15-min post etch, which makes the tracks rounder and less ragged, but has little or no effect on the evaluation of track density. Using a 30-min post-etch, however, the track quality begins to change. Therefore, the foils should be removed from the etch chamber within 25 min after the completion of the etch cycle. An important feature of the post etch is that the cells do not need to be removed from the oven precisely at the end of the third etch cycle. This gives the technician flexibility in removing the cells, and if several cells are being used, they can be removed at various times within the 25-min period.

We include standard foils, exposed to 400 mrem of ^{252}Cf, in each etch chamber to ensure that the foils are properly etched. If only one etch chamber is being used, we include four standard foils in the chamber. If more than one chamber is being used, we reduce the number to three and use the average of all standard foils etched that day for the calibration.

Performance of the Dosimeter System

Linearity

The linearity of the dosimetry system is shown in Figs. 11 and 12. In Fig. 11, the neutron sensitivity of our etching procedures was only about 4 tracks/mrem. The curve is linear out to about 1.5 rem (4000 tracks/cm^2). In Fig. 12, our sensitivity was about 8 tracks/cm^2-mrem, and is linear only to about 450 mrem (also, 4000 tracks/cm^2). These curves show that linearity is a function of the number of tracks on the foil and not the neutron dose equivalent. 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 equivalents by reducing the etch time or by 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 curves shown in Figs. 11 and 12 if the track density is less than about 15,000 tracks/cm^2.

The results in Figs. 11 and 12 were obtained using the Biotran reader, which was linear to about 4000 tracks/cm^2. The new image analyzer is only linear to about 2000 tracks/cm^2, but the shape of the linearity curve is similar to those shown in Figs. 11 and 12. For track densities above 2000 tracks/cm^2 we are using a polynomial regression technique that allows automated high dosage analysis on a computer. This method of evaluating high exposures is more precise than reading correction values from the curves in Figs. 11 or 12.

If the neutron exposure received by the badge is greater than about 1.0 rem, an alternate method of reading the foils is used. The magnification of the microscope is increased by a factor of two. The image analyzer determines the track density using the same light intensity as that used for reading foils at low doses. (A new illumination correction field for the image analyzer must be obtained each time the magnification is changed.) Three fields of view are read, although six fields of view could be used to obtain higher precision. Because of the higher magnification,

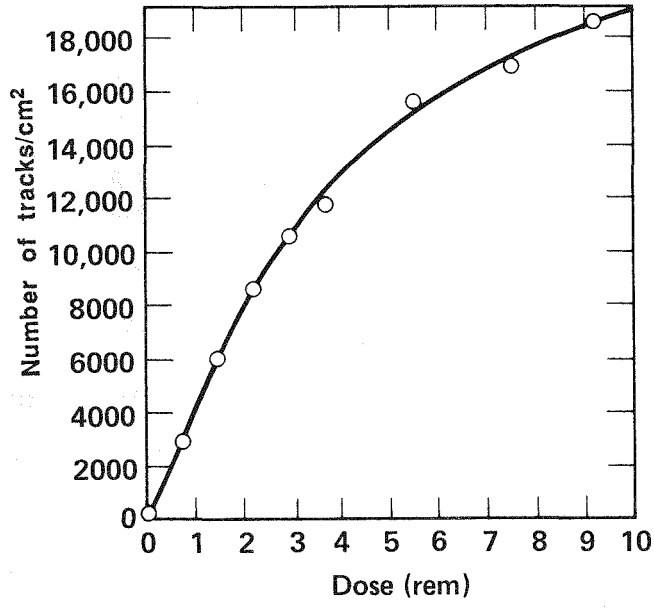


Figure 11. Linearity of the CR-39 foils produced in June 1984.

each foil may require manual focusing, and if the foil thickness varies by more than 1 mil from the average foil thickness, a correction for foil thickness is required (–1.2% per mil of foil thickness for thin foils and +1.2% for thick foils). A correction taken from a linearity curve or a polynomial-regression technique on the computer can be used to evaluate the dose. The readings at high magnification are affected by small changes in the light intensity and the evaluation procedure should be confirmed each time it is used by comparing with control foils exposed to high doses. If pre-etched foils at high doses are not available, then foils must be exposed and etched. If possible, the control foils should be etched at the same time as the foils being evaluated.

Doses as high as 5 rem can be determined with reasonable accuracy by increasing the magnification of

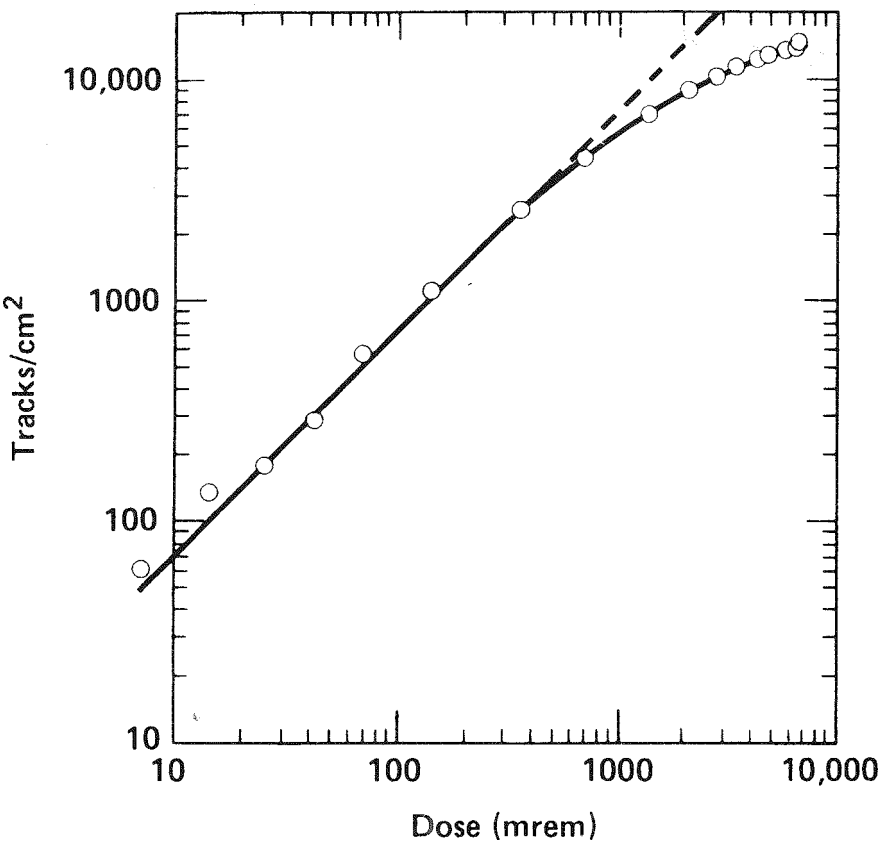


Figure 12. Linearity of the CR-39 foils produced in October 1986.

the microscope and using the technique described above. At this time we have not exposed foils to doses higher than 5.5 rem and do not know how far this method can be extended to higher doses. Neutron doses as high as 5 rem must be evaluated to pass the DOELAP certification program. The high-magnification technique described above is much easier than attempting to get lower track densities by reducing the oven temperatures, etching times, or KOH normality.

Sensitivity

Our current CR-39 dosimeter and etching procedure result in a sensitivity of about 4.5 tracks/mrem when the incident side of the foils (away from the wearer) is etched. The background on new foils varies, but when track size analysis is used it is around 10 to 15 tracks/cm^2, which is equivalent to about 2–3 mrem. This gives a limit of sensitivity (a = b = 0.05) of approximately 6 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 4–5%. For background foils. the standard deviation is around 40%.

In a one-year study of storage techniques, we inadvertently placed some of the foils in an area that had a previously undetected neutron field of about 6 mrem/y above background. This was easily detected, but required that a number of foils be evaluated, and the results averaged. One can determine neutron fields smaller than the environmental neutron background (about 6–8 mrem/y at LLNL) if a number of foils are used. We have started a one-year study to evaluate the use of CR-39 as environmental monitors.

Directional Dependence

The directional dependence of CR-39 is a strong function of the angle of incidence of the neutrons, as shown in Fig. 13. As the angle approaches 90°, the response of the CR-39 foil drops rapidly. This is caused by the recoil protons entering almost parallel to the surface of the foil. When the foil is etched, no track develops. Figure 13 is different from the curve obtained by Cross and Ing with collimated protons.[2] The neutrons used for this curve were from a small uncollimated ^{252}Cf source. Many of the neutrons have been scattered, and the protons produced are emitted

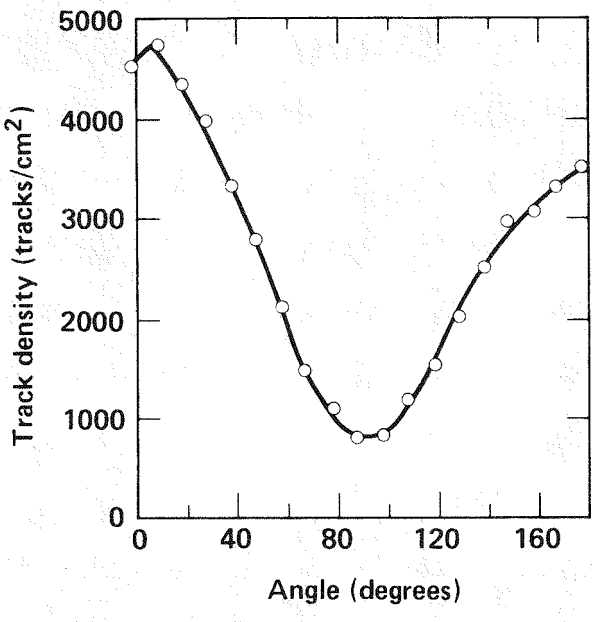


Figure 13. Directional response of CR-39 foils in air.

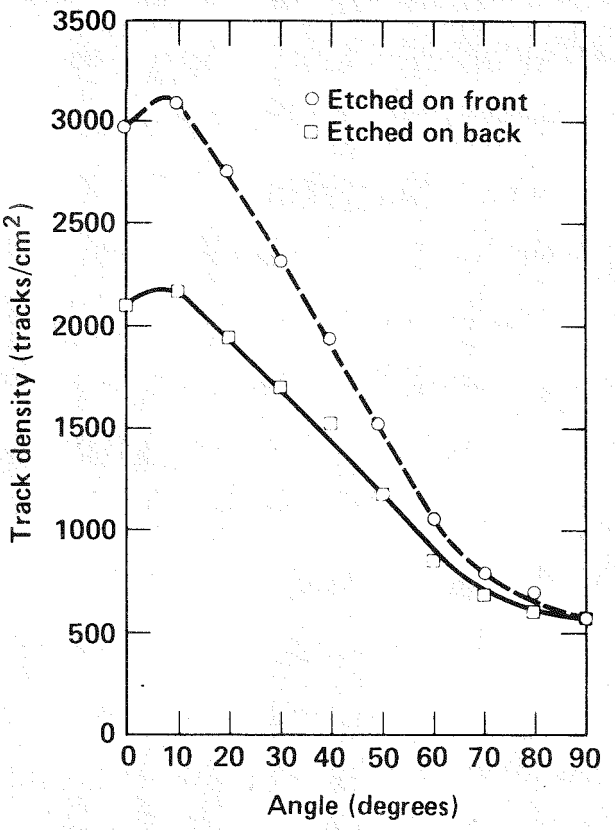


Figure 14. Directional response of CR-39 in a personnel badge on a phantom.

at various angles. The effect is a rounding of the angular-response curve from that obtained by Cross and Ing using protons.

Figure 13 also shows that the track density is less for neutrons entering the foils through the back (180°) than for those entering through the front (0°). The CR-39 sheets have a 5-mil-thick polyethylene protective covering. As mentioned earlier, polyethylene has a greater hydrogen density than CR-39, and therefore the proton production (n,p) with hydrogen is greater. Consequently, the side of the foil facing the source has a higher track density than the backside by about 25%. By etching the side of the foil next to the wearer, we can use this effect to improve the directional dependence.

Figure 14 shows the directional response obtained from CR-39 foils in a personnel badge located on a phantom and exposed to a ^{252}Cf source. The lower solid curve, obtained by etching the side of the foil next to the wearer, is the best directional dependence attainable at present. This directional dependence decreases to about 20% at 90×, but this is in reasonable agreement with the ~30% decrease in the l-cm-depth dose delivered to tissue exposed at 90× (see NCRP Report #38).[3]

A study was made of the directional response of CR-39 as a function of the neutron energy. In this study, we included foils exposed in air and on a phantom to determine the effect of the phantom on the directional response (see Figs. 15 and 16). The shapes of the response curves are similar, indicating that the phantom does not affect the directional response.

Figures 15 and 16 show that for neutron energies between 300 keV and 5.0 MeV, the directional response is essentially the same, and we show a single solid response curve for all these energies. The solid response curve is in good agreement with the directional response shown in Fig. 13 obtained with the ^{252}Cf source. However, at 15 MeV the directional response drops less at large incident angles, which results in a more favorable directional response. At neutron energies below about 300 keV, the response at larger angles decreases and becomes less favorable.

To partially compensate for the error caused by directional dependence, we apply a correction factor to our dosimetry results. We selected a calibration 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 or her actual dose equivalent could be overestimated by 20%. But for exposures at the higher angles of incidence, the error in underestimating a person's 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 on the front. This would reduce the sensitivity of our dosimetry system from about 4.5 to 3 tracks/cm²-mrem. The background track density on the CR-39 foil is not changed, so the effective dose equivalence of the background is increased. To retain the highest possible sensitivity of the dosimeter system and to keep the background as low as possible, we routinely load the CR-39 foils in the badges so that the side to be etched is exposed to the incident neutrons.

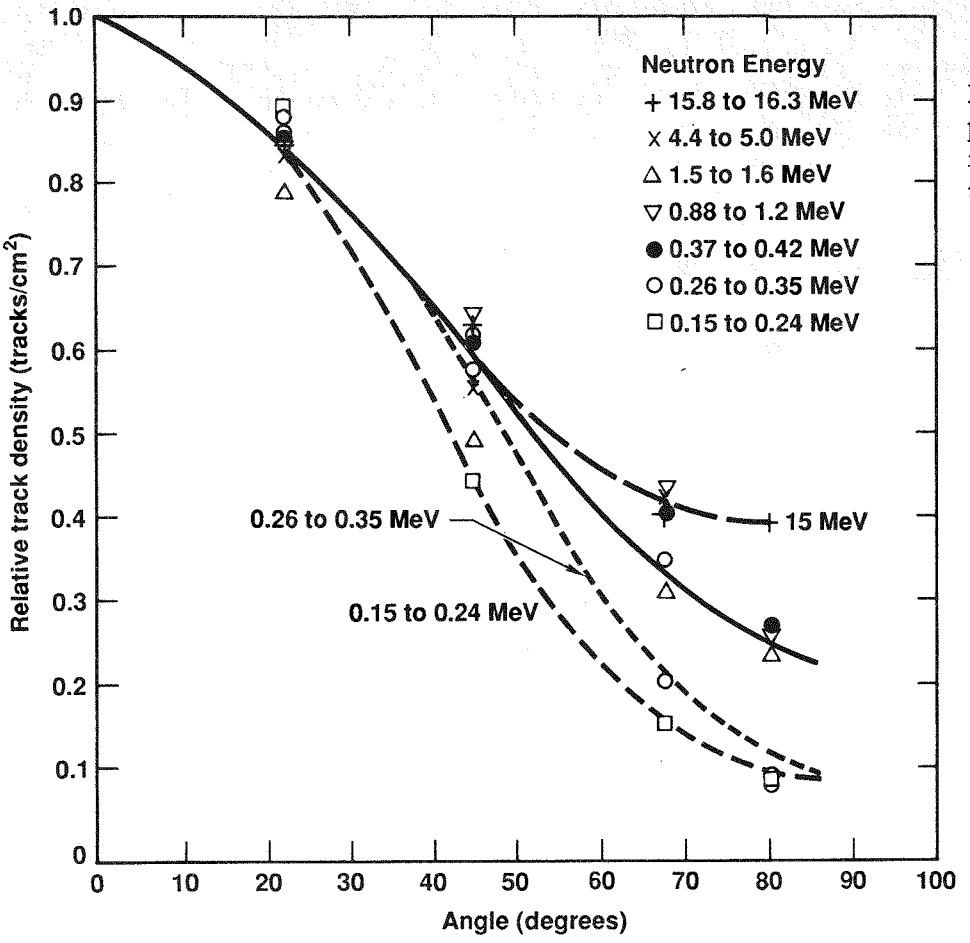


Figure 15. Directional dependence in air of CR-39 foils as a function of the neutron energy

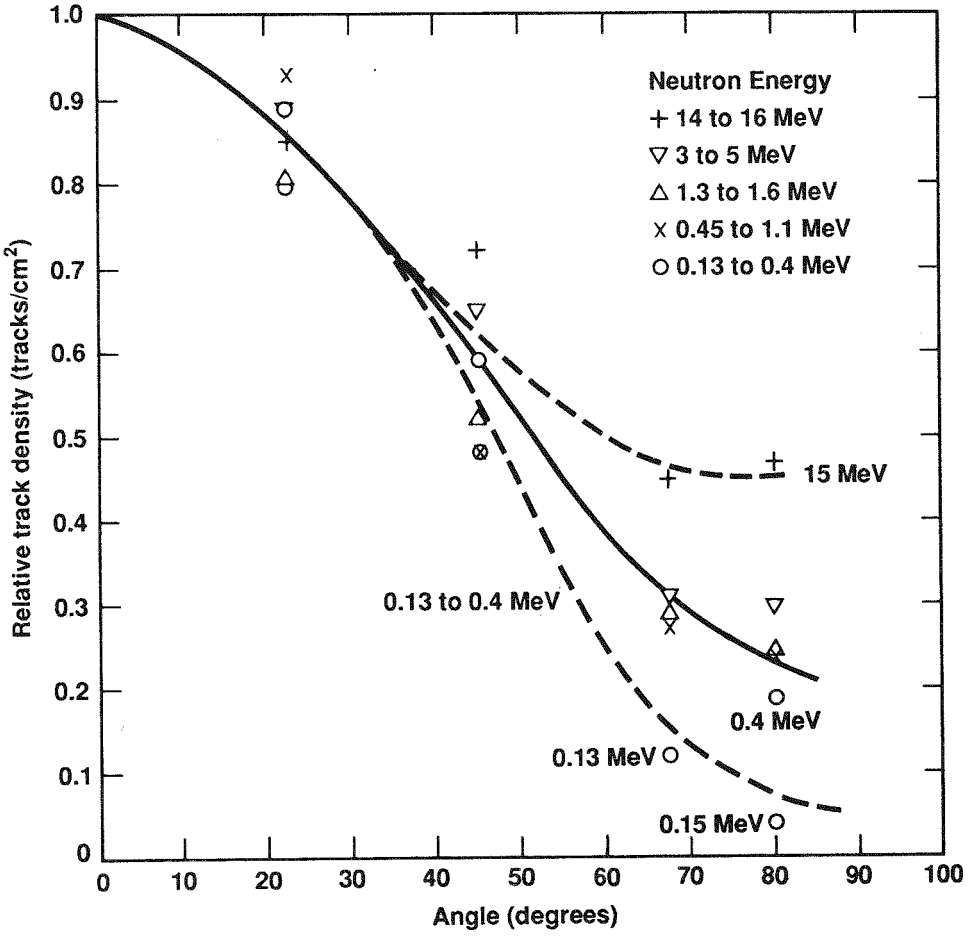


Figure 16. Directional dependence on a phantom of CR-39 foils as a function of the neutron energy.

Efforts to improve the directional response of CR-39 have been only marginally successful. We attempted to improve the directional dependence by bending or arching the foils. The results indicated a slightly improved directional response that was too small to justify the time and effort involved in bending the foils.

Description and Evaluation of the Current LLNL Badge

At LLNL, we are currently using the Panasonic TLD dosimeter. The TLDs are placed in a plastic badge holder that was designed at Livermore. This holder contains the beta and low-energy x-ray shield and has slots into which the components of a nuclear accident dosimeter can be placed. At the time this holder was designed, we were not using CR-39 foils 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 CR-39 foils into this recess with the side to be etched (low-background side) away from the wearer. The CR-39 foils are well protected and are not exposed to ambient light (which is essential). 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 8 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 assigned to the person. If the track density of the first foil is less than 8 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 received no significant neutron exposure. We can determine most of the neutron exposures above 10 mrem, missing only an occasional low exposure (caused by the background and the statistics of the foils at low doses).

The thermal-neutron-sensing TLD in the Panasonic 810 dosimeter can be used as a flag to determine if the CR-39 foils need to be etched. The TLD has a high sensitivity to the thermal neutron component of the dose: for personnel exposures this provides a good signal to indicate that a neutron exposure has occurred. By identifying and removing unexposed foils, the cost and time required to maintain the CR-39 dosimetry system is reduced. In a study we made using results from badges worn at LLNL, we found that only a small percent of the smaller neutron doses would be missed if the Panasonic badge were used as a flag, and that there would be a significant savings in time and effort by not having to etch and read unexposed foils. The details of this study are given in Ref 7.

CR-39 Foils

Foil Stability and Fading

All of our CR-39 foils have been manufactured by American Acrylics. They are "dosimetry grade" CR-39, made of high-purity monomer (about 94% pure) purchased from Pittsburg Plate Glass. Standard grades of CR-39 sheets cannot be used in personnel neutron dosimetry. The CR-39 sheets are 25 mils thick and vary little in thickness over the sheet (±2 mil). The sheets are covered on both sides by American Acrylics with a nominal 5-mil thickness of polyethylene, which is required to protect the foil from radon alpha particles and to protect the foils from abrasion. Earlier, an antioxidant was added to the monomer, but our studies indicate this had no effect on the short- or long-term quality of the CR-39. At present, nothing is added to the monomer.

Our sheets are laser cut by Applied Fusion Inc. of San Leandro, CA. We originally selected the foil size to allow the foils to be placed inside the Hankins-type albedo neutron dosimeter. Recently, however, we increased the length of our CR-39 foils by 1/16 in. to enable us to laser number each foil for positive identification. The power of the cutting laser is reduced to etch the numbers on the foils. Various size letters or numbers can be selected. We use two rows of numbers with the upper number identifying the sheet from which the foils were cut and the second row consisting of consecutive numbers from 1 to 504. The size and location of the two sets of numbers on the foils was selected to allow them to be viewed in one field of view by our microscope. A small reference dot is also inscribed on the foil between the numbers and is used by the image analyzer to locate and read the numbers.

Larger foils had been considered by others to permit the use of a bar code for identification but this technique has been abandoned because it was too labor intensive. Laser numbering has the advantage that it clearly indicates the side of the foil that must be etched, and assigns a permanent, unique number to it.

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. Although we do not know the reason for the difference, the background track density on the back of the sheet is about 10–15 times higher than on the front. This requires that the "top" side of the sheet be marked to assure the proper orientation of the foils after they have been laser cut. When the foils have been laser numbered, the orientation can be determined by looking at the laser numbers or by using a small circle inscribed in one corner of the foil. The circle also provides a quick method to visually check that the foils are loaded properly on the etch chamber. Another method to rapidly assure proper orientation consists of drawing lines with a felt tip pen at about a 45° angle on the polyethylene covering the sheets. The foils are properly oriented when the lines on the foils are all facing the same direction. In the past, the top side of the sheet was mislabeled by the manufacturer, and a test run with the foils should be performed before they are used. Another marking method we have used is to cut off one corner of each foil at a 45° angle.

We performed a seven-month fading study which indicated that little fading of latent tracks had occurred.[4] A six-month environmental study indicated that about 18% fading does occur if the foils are kept at higher temperatures (40°C).[5] A one-year study of storage conditions indicates that when the foils are protected from light, little if any fading or change in sensitivity occurs; the background increases at a rate consistent with the environmental neutron background. In this study, foils that were not protected from ambient light faded, lost sensitivity, and suffered an increase in background to the point where the foils were useless. In a recent study, we etched some of the foils that had been left over from the one-year study. They had been exposed 3.5 years earlier and kept in the dark in a box in the laboratory. We found that they had not faded (lost latent tracks) when compared to other foils from the same box that were exposed just prior to etching. We also found that there was no detectable change in the sensitivity of the foils.

We conclude from these studies that fading, changes in sensitivity, or increases in the foil background are not a problem if the foils are protected from light and exceptionally high temperatures. It has been reported, however, that CR-39 sheets made by an English supplier lose sensitivity at a reported rate of 8% per month, but show no fading of the latent tracks.[6]

The mechanism for damage by UV light or prolonged exposure to high temperatures is not known, but may be associated with the adhesive that is on the foils' protective polyethylene cover. When the foils are exposed to UV or ambient room light for several months, the surfaces of the etched foils have many small dots or spots of material on them. These dots apparently cause tracks to appear on the foil. As these dots become larger from additional exposure to light or heat, the number of background tracks increases. The background tracks are more dense in areas on the foils where these small dots are more dense. We believe that these dots are the adhesive on the polyethylene, which has deteriorated and remains on the foils when the polyethylene is removed.

If care is taken to protect the foils from light or excessive heat, the foils are useful for at least one year. The CR-39 foils could be issued for a six-month exchange period. It should be remembered, however, that the background track density on the foils will be increased by the environmental neutron background. To keep the background of the CR-39 foils as low as possible, only fresh foils should be issued.

CR-39 Material Made by Suppliers Other Than American Acrylics

We recently evaluated CR-39 (or equivalent) foils made in Japan, Italy, and England. We found, to our surprise, that the CR-39 materials are not the same. There were large differences in the defect-caused backgrounds, the sensitivity, and the track-size distributions. At this time we do not know what is responsible for the large differences we observed. A study needs to be made of these materials to see if one of these other CR-39 materials would be superior to the CR-39 we are presently using. In the interim, we caution that if CR-39 material is used that is not the "dosimetry grade" CR-39 made by American Acrylics, the results may not be similar to those described in this report.

Storage of New Foils

The CR-39 foils must be stored in the dark. Earlier we stored the material in a refrigerator or freezer, but the results from our one-year study of storage techniques indicate that such reduced temperatures are not necessary. Storage in a refrigerator, however, does provide a convenient guarantee of a dark environment.

Foil Reading and Track-Size Distributions

An image-analyzer system has been developed at LLNL that enables us to determine the track density and track-size distribution on a CR-39 foil in the same time previously required to determine the track density using the Biotran colony reader. The image analyzer consists of a Hewlett Packard Vectra computer (equivalent to the IBM AT computer) with 4 Mb of extended memory, a Data Translation frame-grabber board (512 × 512 pixel × 8 bit gray level), and a Dage model 650 camera connected to a standard microscope. At present, approximately 1.5 minutes is required to process each CR-39 foil. We anticipate that the processing time will be reduced to less than 20 seconds by upgrading from the 80286 to a 80386 CPU.

A computer-controlled automated stage moves the foil through four steps. The first step identifies the laser-inscribed identification number on the foil, and the remaining three steps are used to read the tracks. If an automated stage is not available, manual adjustments for the microscope stage are used to position the foils for reading. The foil identification number is determined by using a pattern-recognition program in the image analyzer. The image analyzer displays the track-size distribution, the number of tracks, and percent of tracks in each of 20 bins. These data are transferred to a floppy disk, which is used for computer analysis of the neutron dose and for track-size distribution plotting and evaluation using a standard spreadsheet program. A printer records the number and percentage of tracks in each of the 20 bins and the total track density in tracks/cm^2.

Previously, six microscope fields of view (each about 0.09 mm^2) were used to determine the track density on a CR-39 foil. This was changed to three larger fields of about 0.6 cm^2 each by using a lower magnification on the microscope. The lower magnification eliminated the need to focus the microscope because of the increased depth of field (about 30 mils before changes in track density or track-size distributions become apparent). Since our nominal CR-39 foil thickness is about 25 mils, once we focus, no further focusing is required.

At the lower microscope magnification, the light intensity across the microscope's field of view is not uniform. This causes the reported size of a track to be dependent on where in the field of view the track is located. To solve this problem, the image analyzer software was modified to include a background light-intensity correction.

The image analyzer and supporting video equipment is calibrated by using a CR-39 foil that has a strong peak in the track-size distribution at one of the larger bins or track sizes. Calibration foils are made by etching foils exposed to about 400 mrem from a ^{252}Cf neutron source. The foils are etched with no high voltage being applied during the second etching step. The etch time for the third stage (blow-up) is increased to 60 minutes.

The calibration is performed by placing the calibration foil on the microscope stage with the same area of the foil being used each day. This is done by either using a reference mark scratched on the foil or by some other easily identifiable reference point on the foil. If an automated stage is used, the foil will be automatically positioned. The microscope light intensity is adjusted until the peak occurs in a specified bin (usually bin 8). (A new light-intensity background for the image analyzer must be obtained each time the light intensity is adjusted.) The track density (tracks/cm^2) should be essentially the same each time the unit is calibrated.

The size of a CR-39 track depends on the incident neutron energy. When a CR-39 foil is exposed to neutrons, some of the neutrons interact with hydrogen to produce recoil protons. These protons break the chemical bonds along their paths in the CR-39. The etching rate along the path of a recoil proton is a function of the density of the broken chemical bonds that were broken. The highest density of broken bonds results from recoil protons with the highest linear energy transfer (LET), which are produced by neutrons having energies from about 500–900 keV. These protons produce the largest tracks. The recoil protons from neutrons with either lower or higher-energy neutrons (up to 5.0 MeV) break fewer bonds and thus yield a reduced etching rate. At higher neutron energies, recoil carbon and oxygen atoms or alpha particles are created. These recoil atoms and alpha particles have higher LET than protons and create a high density of broken chemical bonds; the etched tracks are then larger than those produced by protons.

The best resolution of the track-size distributions occurs when the foils are etched for three hours instead of the five hours we had been using for several years. Track-size distributions obtained using a three-hour etch with a 30 minute blow-up cycle (without a pre-etch) are shown in Fig. 17 for ^{252}Cf and monoenergetic neutron energies between 152 keV to 16.2 MeV. We cannot precisely determine a specific neutron energy from these track-size distributions, but we can infer information on the approximate neutron energy, particularly in selected energy regions. The interesting feature of these distributions is that there are two distinct peaks, one occurring at neutron energies between 300–800 keV and the second starting at 800 keV up to 5.2 MeV. At 820 keV both of these peaks can be seen. Track-size distributions can be used to approxi-

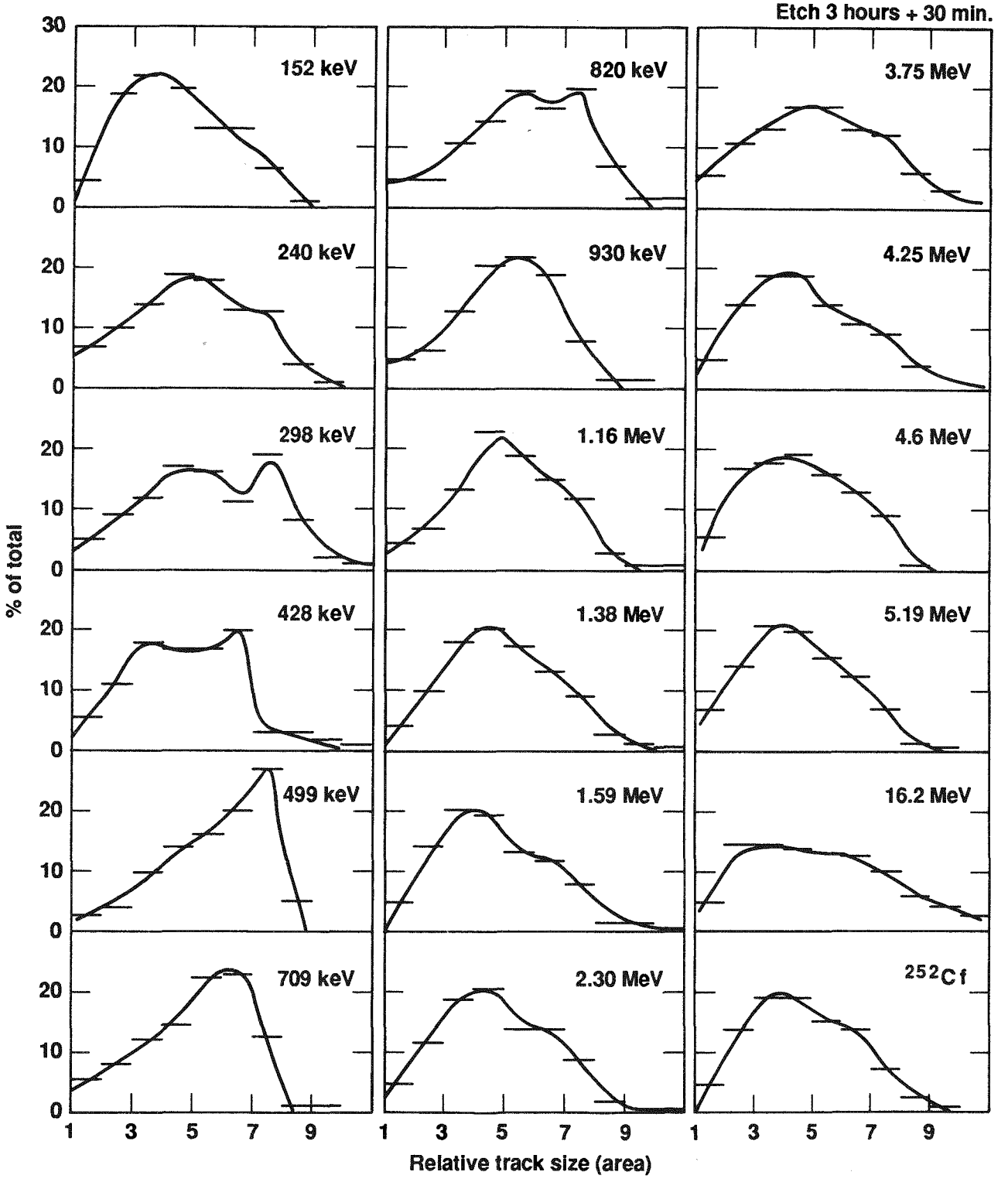


Figure 17. The track-size distributions on electrochemically etched CR-39 foils, obtained with monoenergetic neutrons. The etching conditions were three hours at 60 Hz with a 30-minute blow-up stage at 2000 Hz, 3000 V, 6.5 N KOH, and an oven temperature of 60°C.

mately determine the energy of monoenergetic neutrons that are between about 300 keV and 1.0 MeV. Above 1.0 MeV the track-size distributions are essentially the same out to 5.2 MeV.

The effects on the track-size distributions caused by changing the etching time are shown in Fig. 18. Longer etching times increase the number of small tracks. This is particularly noticeable at 499 keV, where a large increase in small tracks is very apparent. These small tracks can also be seen in the track-size distribution for the ^{252}Cf neutron source. Since one of our primary interests in using track-size distributions is to determine if low-energy neutrons are present, three-hour etching cycles are preferred. The second stage (blow-up) time is 30 minutes. The number of large tracks in the track-size distribution at 14–16 MeV neutrons remain unchanged by changing the etching time.

The addition of the pre-etch step (1.75 hr) to the etch cycle caused significant changes in the track-size distributions, as shown in Fig. 19. The second peak in the track-size distribution is observed to occur at higher neutron energies, with the peaking that was present at 499 keV being moved to about 820 keV. The ^{252}Cf track-size distribution is flatter and has a second hump at bin 7. When the pre-etch step is used, the track-size distributions are not as sharp or as well defined as those obtained without the pre-etch step.

When the pre-etch step is added to the etch cycle, we see a significant reduction in the defect-caused background track density. We find that the reduced background outweighs the loss of resolution in the track-size distributions. We therefore recommend using the pre-etch step for all etchings.

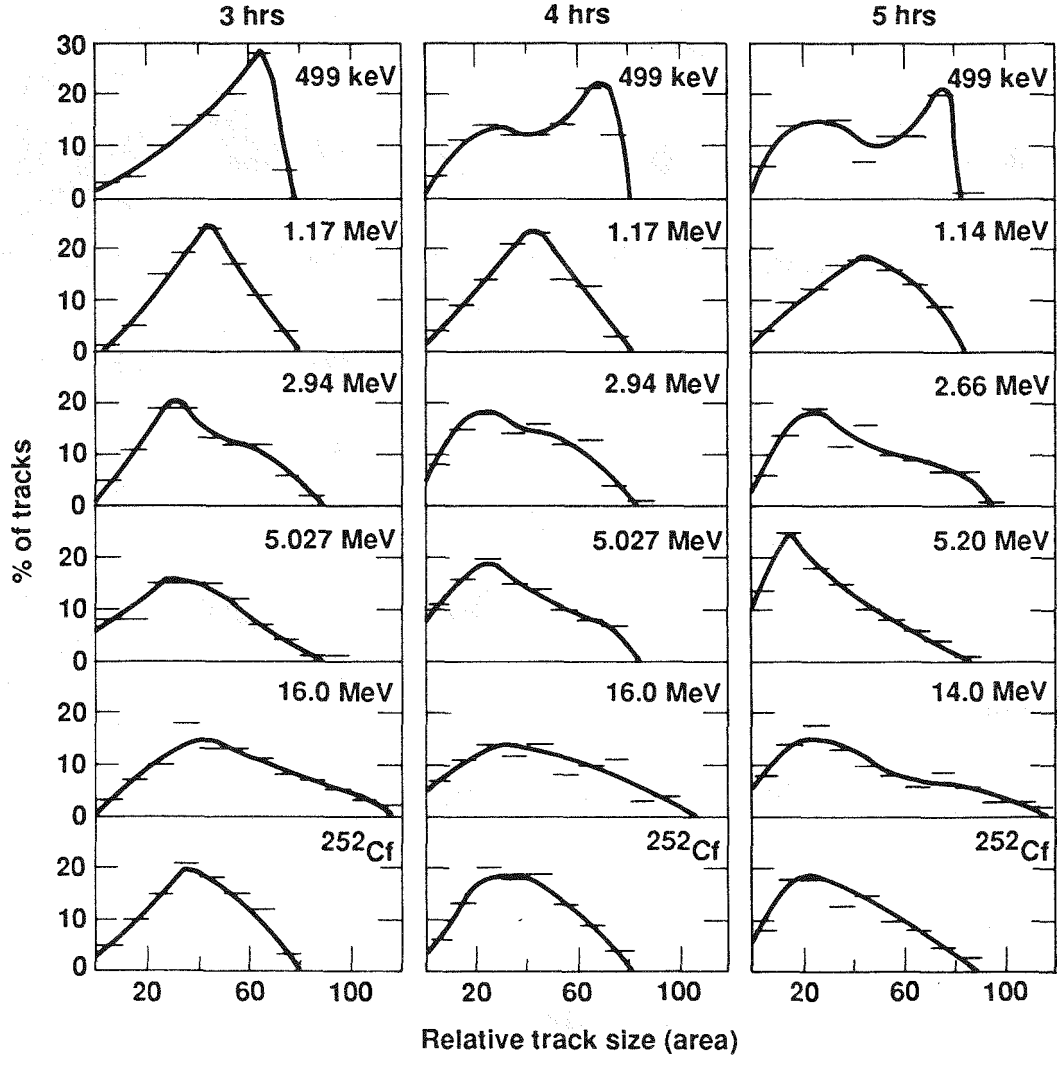


Figure 18. The effect of changes in the etching time on the track-size distributions obtained with monoenergetic neutrons and ^{252}Cf sources.

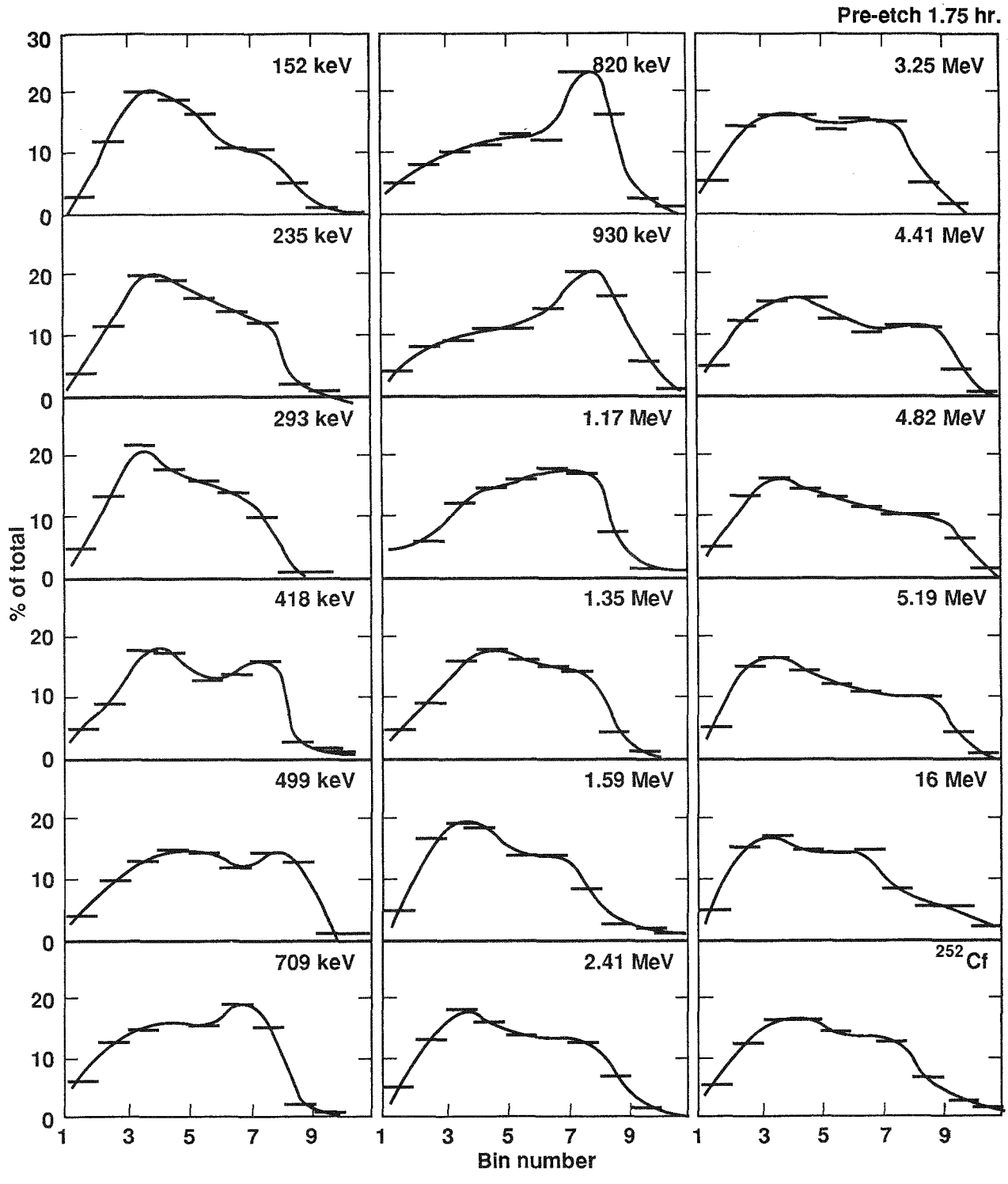


Figure 19. The track-size distribution on electrochmically etched CR-39 foils, obtained with monoenergetic neutrons. The etching conditions were the same as those in Figure 17, ecxept that a 1.75 h pre-etch step was added to the cycle.

Before we added the pre-etch step to the etch cycle, the main use of track-size distributions was to identify and eliminate the reading of foils with a high defect-caused background. Occasionally, some of the CR-39 foils had defects that would appear as lines or groups of tracks. The tracks were frequently large and most of them were nearly the same size. This apparently was caused by some type of surface defect or damage, and the tracks would begin to develop early in the etching process. Foils with these defects have a prominent peak appearing in the track-size distribution. These distributions are significantly different from those caused by actual neutron exposures and therefore indicate that the reading of the foil is not valid. After the pre-etch step was added, these defects either do not exist or are too small to be observed.

Following the addition of the pre-etch step to the etch cycle, the most important aspect of the track-size distributions is to reduce the effective background. This is done by using only a portion of the defect-caused background tracks. Usually the smaller and larger tracks are excluded in the analysis. This procedure can be illustrated by using the results obtained in a study we made of the lower limit of sensitivity. Figure 20 shows the track-size distributions obtained from unexposed foils and foils exposed to selected

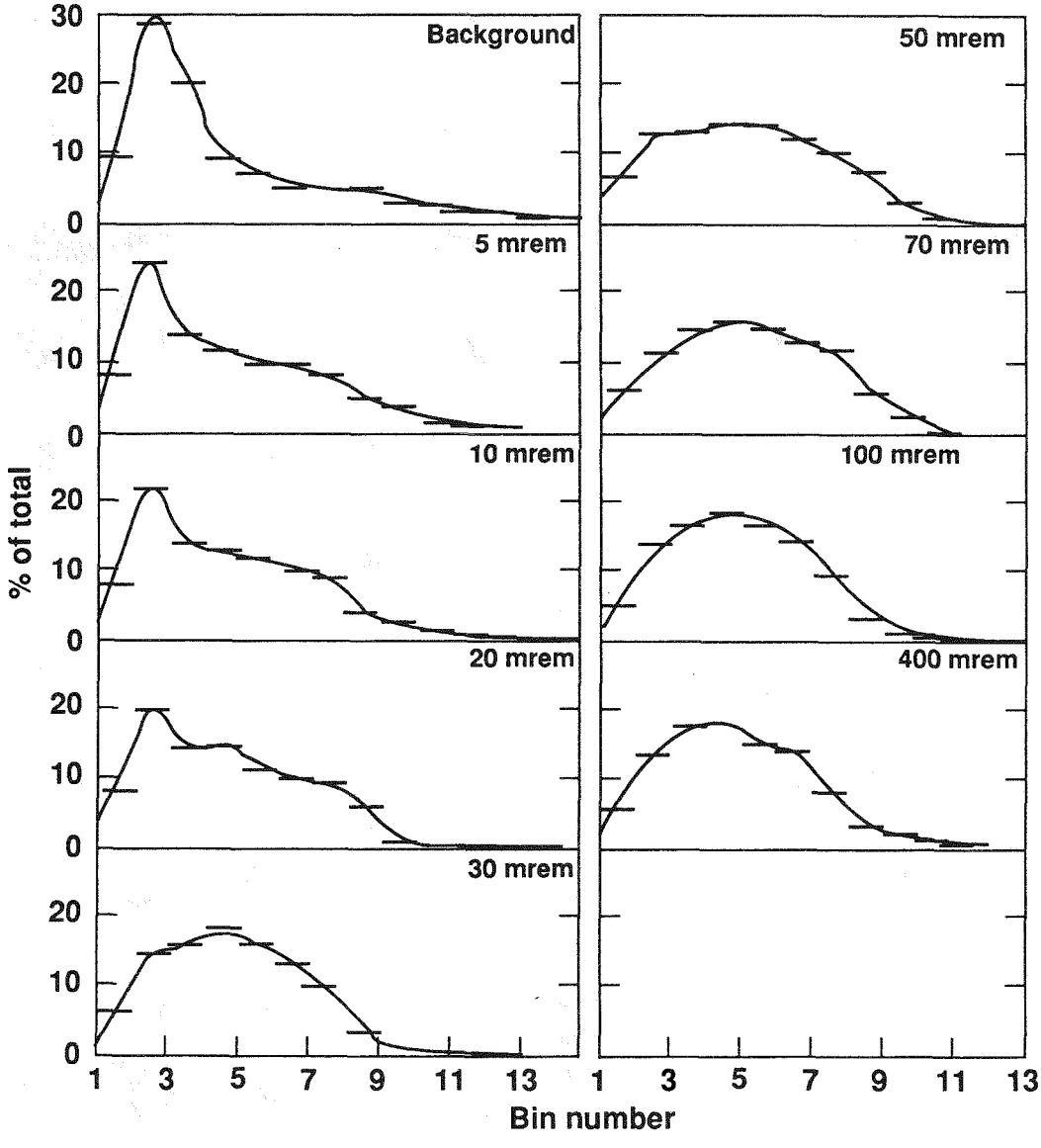


Figure 20. Track-size distributions of unexposed foils and foils exposed at varying doses.

doses up to 400 mrem from a ^{252}Cf source. The defect-caused background track-size distribution on these foils have a large number of tracks in the smaller bins. Exposing the foils to 5 mrem did not change the total track density greatly, and the exposure is therefore difficult to detect. However, if only the tracks in bins 3 through 8 are used, a larger difference in the track relative densities is found, and 5 mrem is easier to detect. This can be seen by visual comparison (Fig. 20) of the number of tracks in bins 3–8.

The results shown in Fig. 20 show a progressive change in the track-size distributions as the neutron dose is increased. The peak in bin 2 becomes smaller as the neutron dose is increased and at 70 mrem is no longer discernible. The background tracks in bin 2 are still present, but are overwhelmed by the neutron tracks.

With the addition of the pre-etch step, the background track-size distribution is usually different from the one shown in Fig. 20. Examples of the background from four different sheets of CR-39 are shown in Fig. 21. These were taken from the results obtained in our evaluation procedure for new sheets of CR-39. They are much flatter, have more of the larger tracks, and the background tracks extend out to about bin 15.

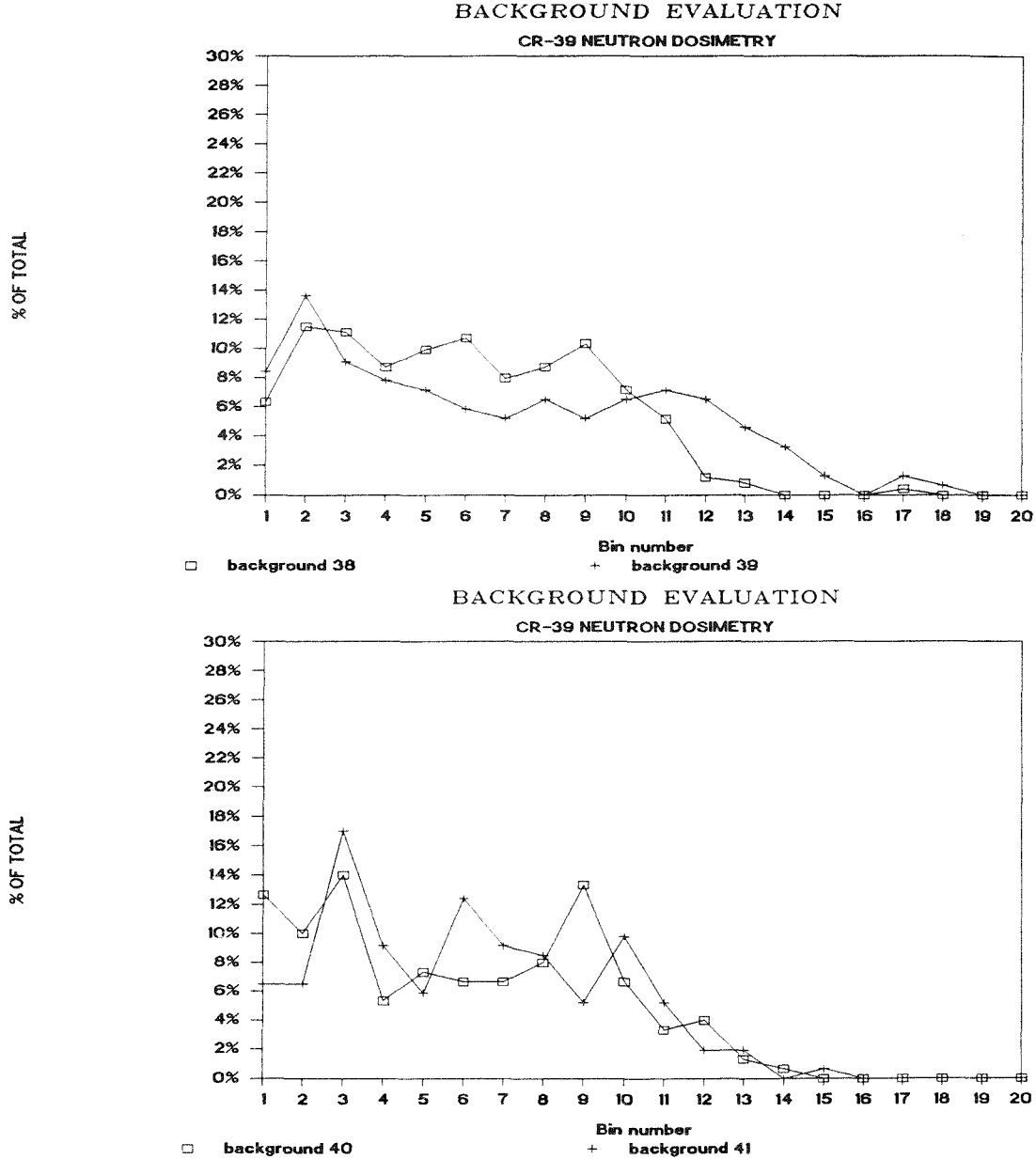
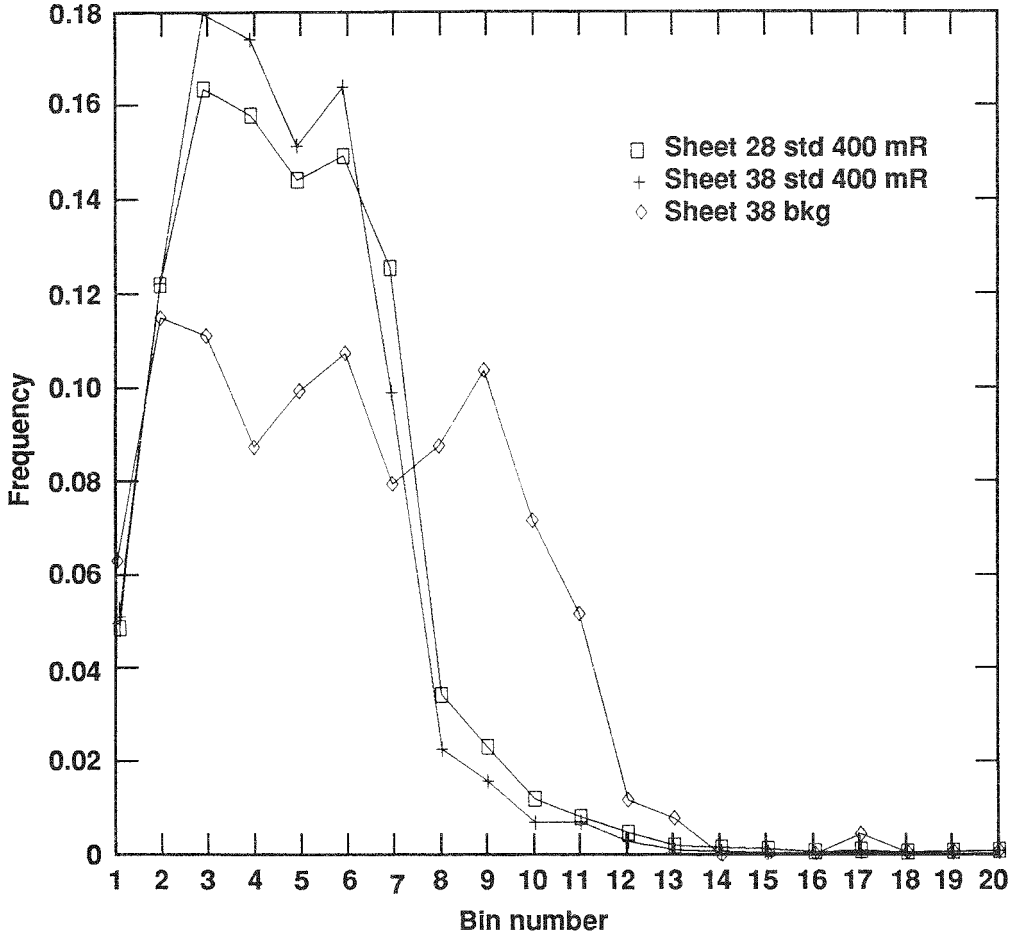


Figure 21. The track-size distributions of the defect-caused background distributions on foils from four new sheets of CR-39.

We routinely use the tracks in bins 3–8 in the analysis of our personnel dosimeter results (except for exposures to high-energy neutrons). The background tracks in these bins are normally around 50% of the total background tracks. This compares to 75–80% of the total tracks in bins 3–8 for ^{252}Cf sources. By using only the tracks in these bins, we are able to reduce the effective background dose to 2–4 mrem without seriously reducing the neutron sensitivity of the foils.

Figures 22 and 23 are examples of the results that we obtain with our new computer evaluation procedures for sheets of CR-39. This presentation method requires less time, the track-size distributions are better defined, and the results can be presented in several formats. The computer evaluation includes information on the relative sensitivity to neutrons, the background dose equivalent, the percentage of tracks is bins 3–8, and information on the foil thickness. This evaluation procedure is used to accept or reject new sheets of CR-39.

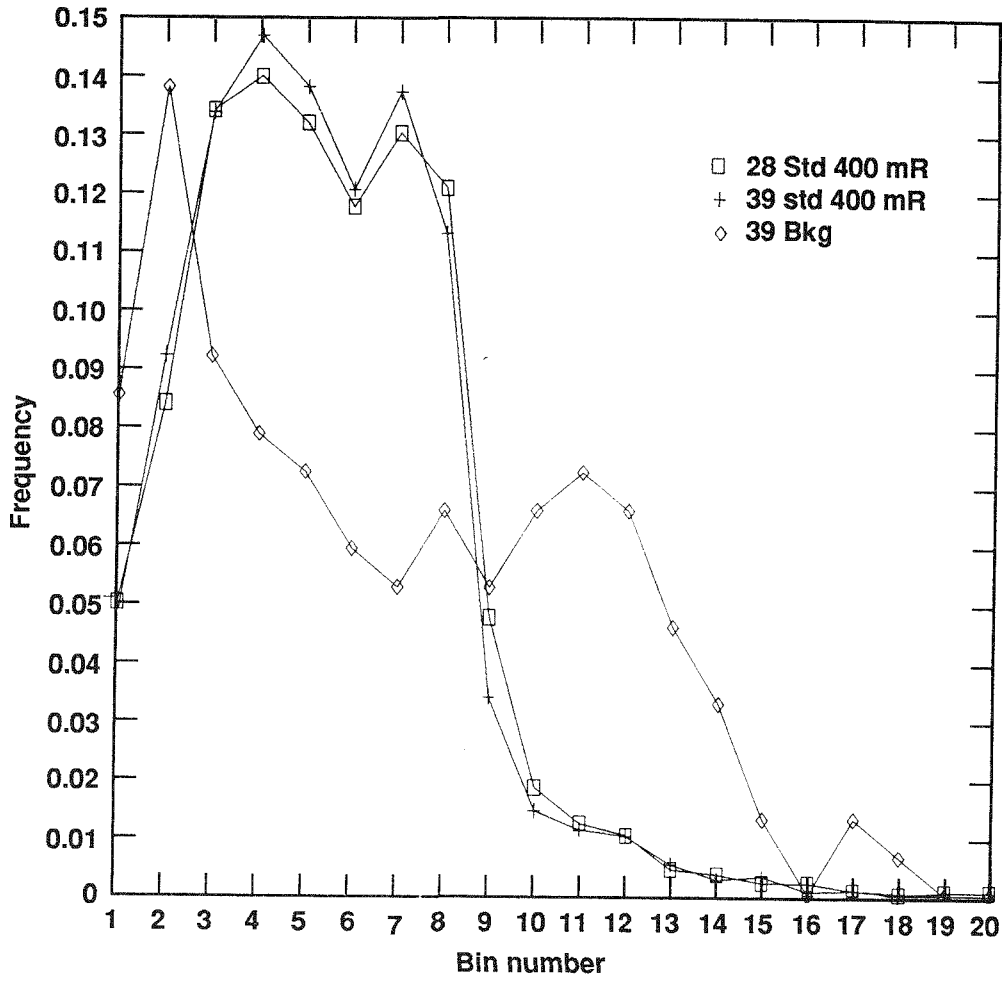
Although Figs. 19 and 20 do show large differences in the track-size distributions from the various



SH #	Type	Dose (mR)	Bins 3–8 tracks/mR-cm²	Tracks/cm² bins 3–8	% tracks bins 3–8	Natural bkg (mR)
28	std	400	4.28	1713	0.77	NA
38	std	400	4.12	1646	0.79	NA
38	bkg	NA	NA	15.6	0.57	4.47

Avg. thickness = 24.4 mils
high/low = 22/26

Figure 22. The track-size distributions and the results obtained from the evaluation test made on a new sheet of CR-39 material (sheet #38).



SH #	Type	Dose (mR)	Bins 3–8 tracks/mR-cm²	Tracks/cm² bins 3–8	% tracks bins 3–8	Natural bkg (mR)
28	std	400	3.75	1498	0.77	NA
39	std	400	3.75	1504	0.78	NA
39	bkg	NA	NA	6.9	0.42	2.07

Avg. thickness = 23.1 mils
high/low = 21/26

Figure 23. The track-size distributions and the results obtained from the evaluation test made on a new sheet of CR-39 material (sheet 39).

monoenergetic neutrons, in practical applications track-size distributions have only limited value in providing information about the neutron spectra. For example, dosimeters worn by personnel working around fission sources at LLNL have track-size distributions that are only slightly different (having more large tracks) than the track-size distribution obtained using a ^{252}Cf source. However, if the neutron exposure is from a PuBe source, the track-size distributions are appreciably different and can be used to confirm that the exposure was indeed to a PuBe source (see Fig. 24). The track-size distribution shown in this figure was obtained from foils exposed at the ORNL intercomparison of personnel neutron dosimeters. The track-size distribution was used to identify the source, and the dosimetry results were corrected for an underresponse of CR-39 to PuBe neutrons.

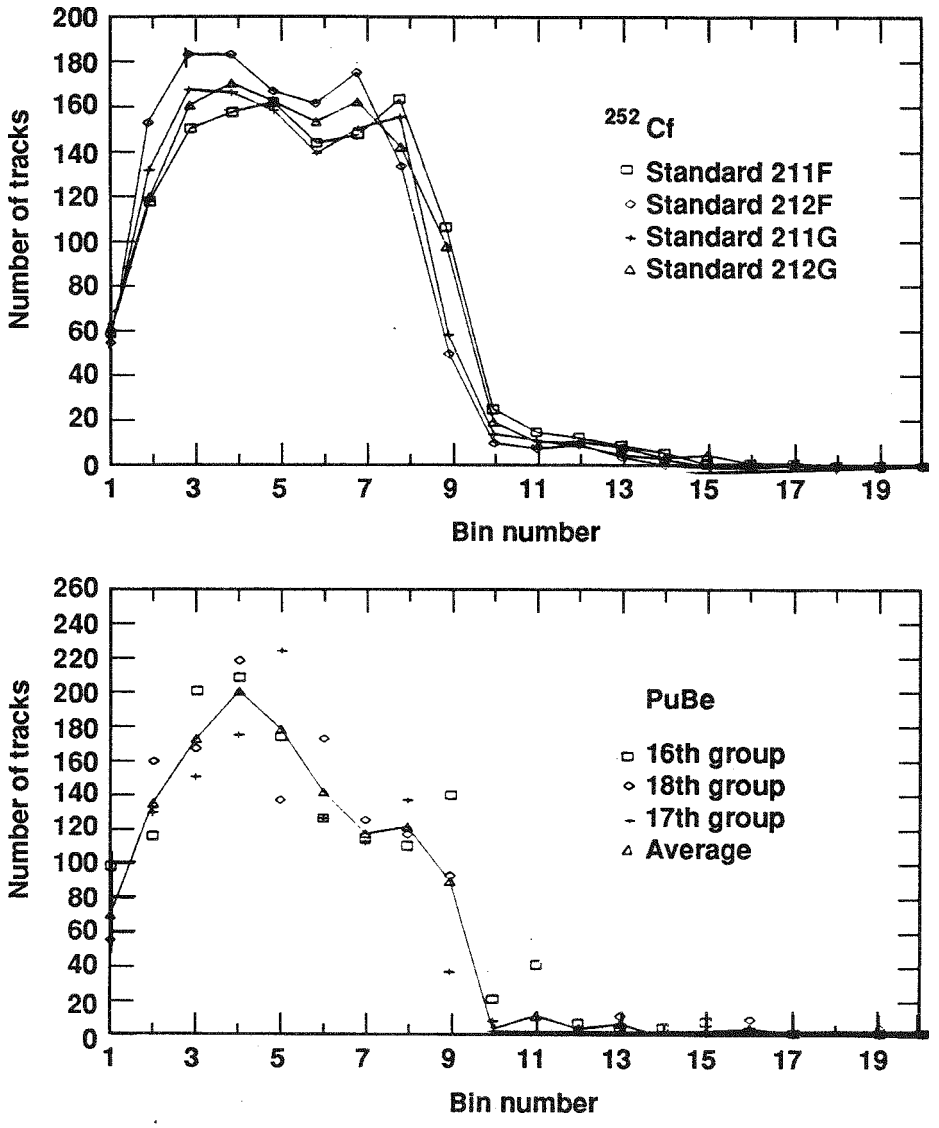


Figure 24. The track-size distributions obtained from ^{252}Cf and PuBe neutron sources exposed in the ORNL intercomparison of personnel neutron dosimeters.

Neutrons with energies between 13 and 16 MeV create recoil carbon and oxygen atoms that produce tracks larger than those produced by protons. Large tracks in the distribution can thus be used to identify exposures from high-energy neutrons; a correction for the underresponse of CR-39 at these neutron energies can then be applied to the dosimetry results. Figure 25 shows the track-size distribution obtained from a badge exposed to the leakage neutrons in the control room of the Lawrence Berkeley Laboratory Bevalac Biomedical Facility. Even though the neutron exposure was small, the difference between this track-size distribution and that of a ^{252}Cf source is apparent and was used to indicate that a correction for the underresponse of CR-39 to high-energy neutrons needed to be applied in the evaluation of the dose.

The thickness of the foil has an effect on the track density and the track-size distribution. When thin foils are used, the voltage gradient across the foil is higher and the etching rate is increased. This increases the number of tracks that are etched, and they are larger than those normally obtained. The thinner foils have a track-size distribution that is shifted to the larger track sizes, but the shape remains the same. Conversely, the thick foils have a lower voltage gradient, a slower etching rate; also, fewer tracks are etched, and the track-size distribution is shifted to the smaller track sizes. When we purchase CR-39 sheets from American Acrylics, we specify that the foil thickness should be a nominal 25 mil, and the variation in foil thickness can not exceed ±2 mil. If the sheet meets these requirements, the variation in track density and the change in

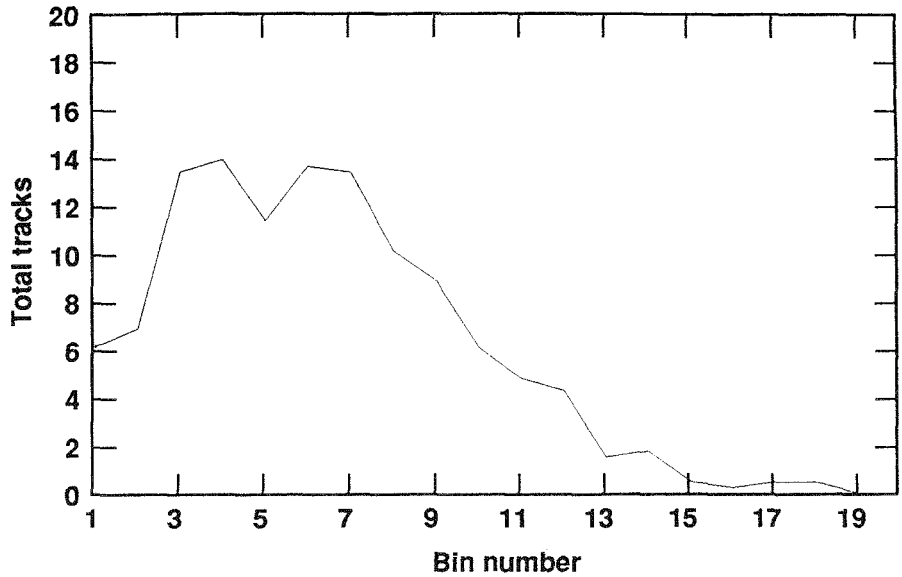


Figure 25. The track-size distribution obtained from foils exposed in the control room of the LBL Bevalac Biomedical Facility to high-energy neutrons.

the track-size distributions is minimal. We recommend that all sheets of CR-39 being used for personnel dosimetry meet the above specifications.

It is likely that if different etching techniques or CR-39 foils from other manufactures were used, additional information on the incident neutron spectrum could be obtained from analysis of track-size distributions. Of particular interest would be information that could be used to determine the appropriate dosimetry quality factor (Q) or the LET distribution. We hope to investigate these possibilities in future studies.

We recommend that all dosimetry organizations use image analysis when reading CR-39 foils. This provides a method of reducing the effective defect-caused background on the foils, eliminates false readings from defective foils, and provides a method to identify and correct for the underresponse of CR-39 foils exposed to PuBe and high energy neutrons.

Use of CR-39 at Power Reactors

At this time, CR-39 cannot be used as a personnel dosimeter for the neutron leakage spectra inside the containment of a power reactor. We recently etched CR-39 foils that had been exposed inside the containment of a power reactor at locations where the multisphere neutron instrument had been used to characterize the neutrons' spectra and dose rate. The component of the neutron dose delivered by neutrons with energies above the threshold energy of CR-39, ~150 keV, varied from 23 to 65%. The reading of CR-39 dosimeters exposed in the reactor would therefore only respond to between 23 to 65% of the total neutron dose. Without knowing where the exposed person worked, the dosimeter readings could not be corrected to total neutron dose because the correction factor required at various locations in the reactor would vary by a factor of three.

Another complicating factor is the directional response of the CR-39. If the exposure was isotropic, the response of the dosimeter would be only about 42% of the response obtained from a face-on exposure (obtained by integration of the curve shown in Fig. 13. Inside the containment of a reactor the direction of incident neutrons can be nearly isotropic at some locations, and have varying degrees of directionality at others.

The total neutron dose can also not be obtained from the thermal neutron response of a TLD dosimeter (^{6}Li or ^{10}B) or CR-39 with a boron loading or radiator. The thermal neutron component of the total neutron dose can vary greatly (from 4–45% at the reactor we studied), and applying an accurate factor to total dose would not be possible.

Automated Foil Reading

If large numbers of etched CR-39 foils are to be etched and evaluated, automated methods must be used to position the foils on the microscope and to remove them when the reading is complete. We have developed a loading and unloading device that will perform this task. The device is operated by using the action provided by a computer-controlled microscope stage. The microscope stage must have three degrees of motion (x, y, and z axis) and is controlled by the image analyzer computer.

A drawing of the loader/unloader and the viewing platform that holds the foil during the reading procedure is shown in Fig. 26. The loading device is made of lucite and aluminum and consists of two slots that hold the foils for loading or unloading. The device is attached to the microscope as close as possible to the lens to limit the distance the stage must move during the loading and unloading cycles. It is held onto the side of the microscope by using bolts and clamps as shown in Fig. 27.

The viewing platform is made of lucite. The recess that holds the foil during reading has edges that are beveled at an angle of 45°. The beveled edges guide the foil into position on the viewing platform as it is dispensed from the loader. The sides of the recess can be adjusted and are set to be just a few mils larger than the foil. Several voids are cut into the platform to allow the loading and unloading of the foil without the loader contacting the viewing platform. A small piece of lucite is glued to the upper surface of the viewing platform to dispense the foils from the loading device. Various movements of the stage provide the action necessary to dispense and remove the foils from the viewing platform.

The foils to be read are wiped clean, properly oriented, and stacked into the loading slot of the loader/unloader. A pivoted plastic weight is placed on the stacked foils. The weight is pivoted because when the foils are laser etched, the surface around the numbers is melted and becomes slightly thicker than the rest of the foils. When large numbers of foils are stacked, the stack begins to tilt. A pivoting weight must be used to distribute the weight evenly on the bottom foils, otherwise each foil will not be properly dispensed.

The dispensing cycle of a foil begins by positioning the viewing platform under the dispensing slot of the loader. The top of the lucite projection on the viewing platform must be about 15 to 20 mils above the bottom of the foil to be dispensed. The dispenser slot has an exit gap that allows only one foil to be dispensed. If the projection on the viewing platform is too high, two foils may be caught, and the projection may be broken off, or a snapping noise is heard as the second foil is bent and then jumps over the projection.

The motion of the y-axis is used to push the foil out of the loader. It drops onto the viewing platform and is positioned by the beveled edges of the platform recess.

After the foil has been dispensed, the z-axis is activated, moving the loader up until it is clear of the viewing platform. The stage is moved to position the foil under the microscope lens, and the laser-inscribed numbers on the foil are read by the image analyzer. The foil is then moved sequentially to read three fields of view on the foil.

After the foil has been read, the loading platform moves the foil into position under the unloading slot. The loader moves down and the foil causes the springs on the unloader to be forced outward. As the loader continues to move down, the springs snap under the foil. Each spring has been slit and bent so that about one third of the spring is used to properly guide the foils as they are moved progressively upward in the unloading slot by additional foils. The remainder of the spring supports the foils. A lucite weight is placed in the unloading slot, which prevents the foils from turning sideways in the slot. In the final steps of the loading cycle, the loader is moved up until the loader is clear of the viewing platform, and the device is moved into position to dispense the next foil.

We tested the loader/unloader extensively, using over 600 cycles. It will dispense and pick up the foils without failure as long as the microscope stage moves properly through the loading and unloading cycle. Occasionally the stage controller failed to receive the proper message from the image analyzer computer, and the stage would move to the wrong location. We also had a problem with the z-axis drifting slowly down. These problems can be or have been solved.

We were concerned that the springs in the unloader section would eventually break or fail to pick up the foils. To date this had not occurred. The dispensing device is a simple design and should be free of failures as long as the stage is operating properly.

The time required by the stage to make the eleven steps necessary to load, read and unload a foil is about 1 minute and 40 seconds. However, the image analyzer with the faster computer can read and process the results from a foil in about 20 seconds. The speed the stage moves cannot be significantly increased, and therefore the loading and unloading time limits the number of foils that can be read in a given time. If the number of foils that are to be read is high and the time required to load and unload a foils must be shortened, a different method of unloading the foils must be used.

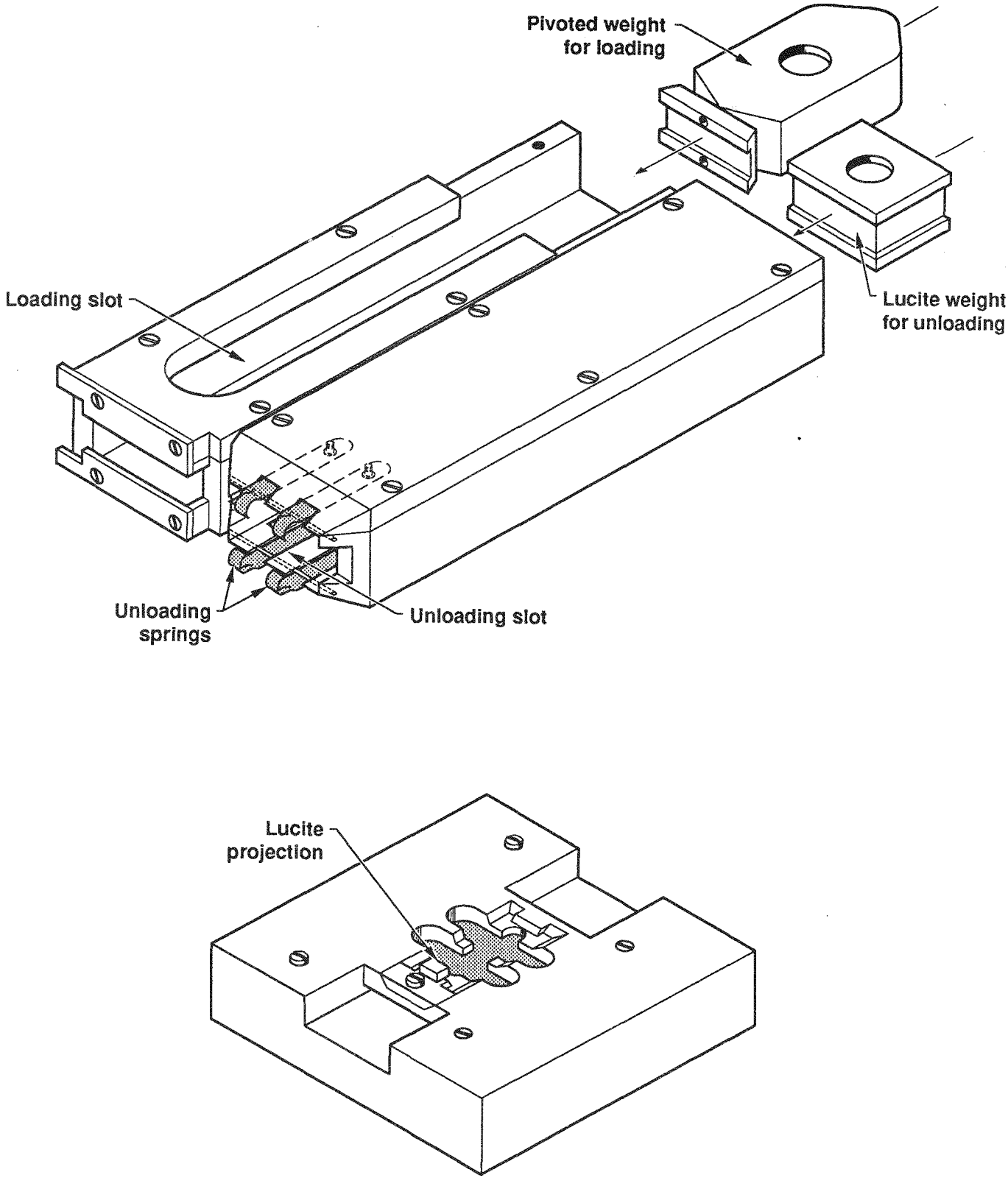


Figure 26. Drawing of the loader/unloader mechanism for CR-39 foils. The mechanism consists of two slots for the loading and unloading of the foils. The foils are unloaded and held in the slot by the springs. Also shown is the viewing platform that holds the foils during reading.

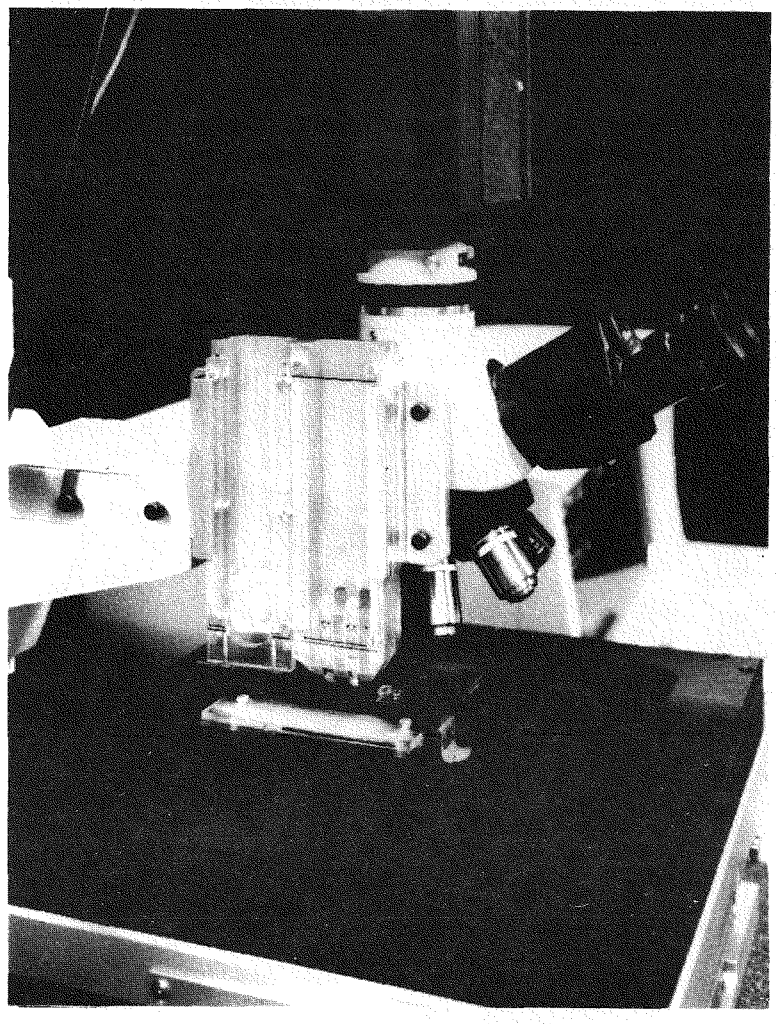


Figure 27. Photograph of the loader/unloader mechanism clamped onto the microscope. The mechanism is located close to the microscope lens and stage to limit the distance the stage must move in loading and unloading a foil.

Improved Unloading Device

We designed a second and simpler unloading device that does not require motion along the z-axis. A sketch of the device is shown in Fig. 28. The unit was made entirely of lucite (though aluminum could be used). The device consists of an arm with two fingers that move under the foil, lift it from the viewing platform, and dispense it to the side of the stage. A viewing platform was made with two slots that guide the fingers under the foil (see Fig. 28).

The foil is unloaded from the viewing platform when the stage moves along the x-axis, as shown in Fig. 29. The fingers on the arm move under the foil until the lucite between the fingers contacts the curved surface of the viewing platform, which then lifts the foil from the viewing platform. As the stage continues to move, it contacts the lucite plate on the bottom of the arm forcing the arm upward. The foil slides down the arm and can either be temporarily stored on the arm or allowed to drop off the end of the arm.

One of the previously described loader/unloader units was cut in half and the dispensing part was attached to the microscope. The height of the dispenser above the viewing platform is critical. The lucite projection for loading foils must be able to move freely under the lens of the microscope without touching the lens. For the microscope lens we are presently using, this is 1/8 in. or less. The dispenser must be adjusted so that this lucite projection will be about 13 mil above the bottom of the foil being dispensed. If the dispenser is too high, the projection may slip under the foil and it will not be dispensed. If the dispenser is too low, the projection may catch two foils and since only one can be

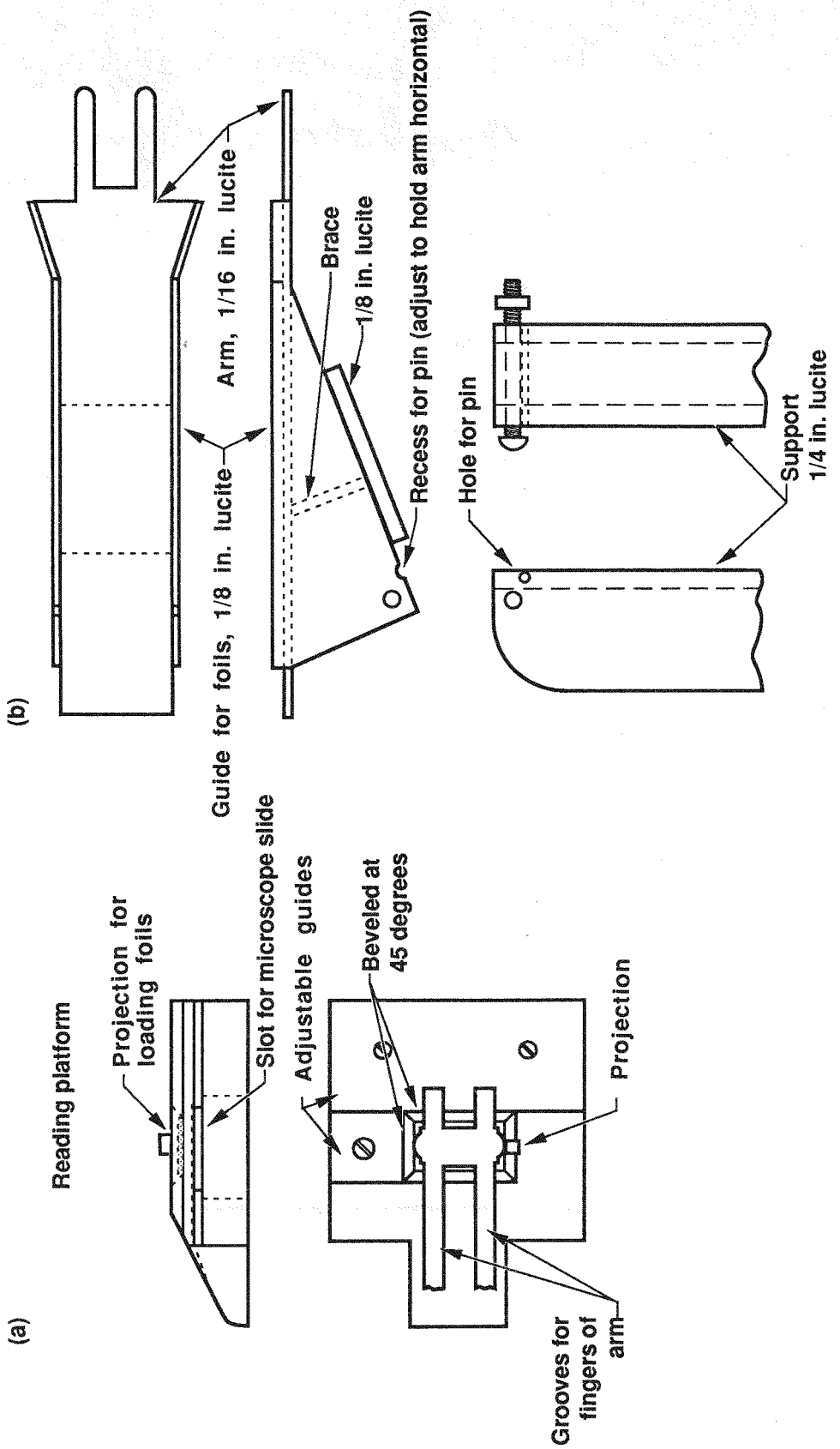


Figure 28. Drawing of the new unloading device, support arm, and the modified viewing platform.

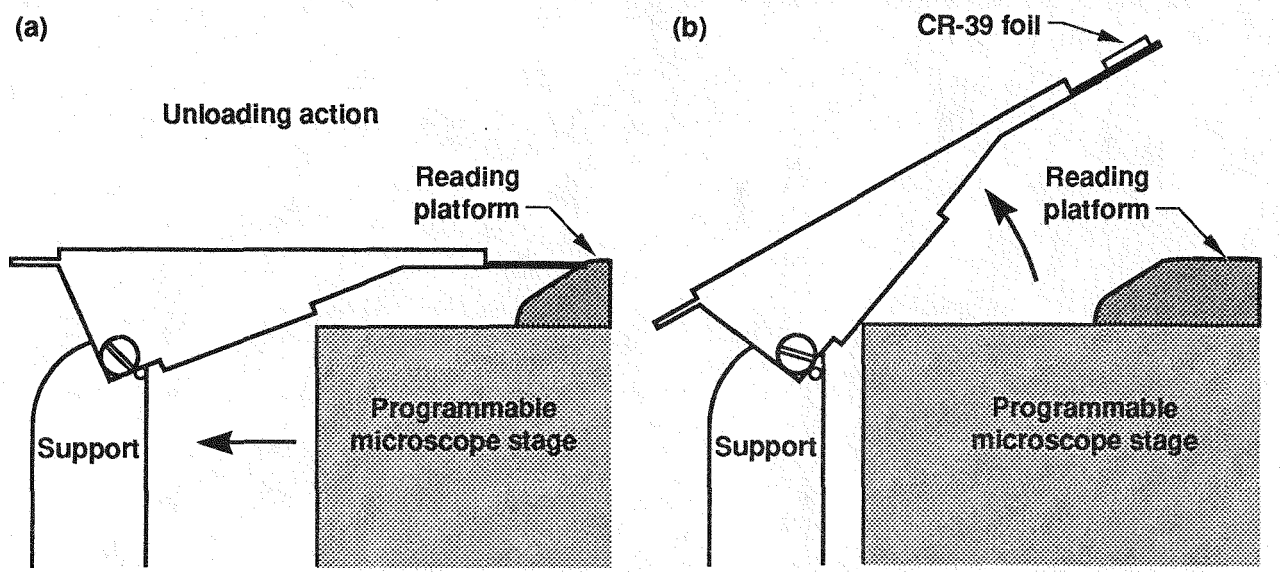


Figure 29. The motion of the programmable stage and the unloading device.

dispensed at a time, a snapping noise occurs as the second foil is bent and jumps over the projection. A dowel pin, with small clearance, is used to assure accurate repositioning of the dispenser.

The location of the dispenser, microscope lens, and the unloader, were selected to minimize the distance the stage must travel. The time required to complete a loading, reading, and unloading cycle is 50 seconds. This is 30 seconds less than the time required with the original loader/unloader unit described above—a significant savings in time if large numbers of foils must be read. The new unloader has the disadvantage that the foils are not kept in order after being read.

Since no motion of the z-axis is required, the cost of an automated microscope stage is reduced. In addition, an error in the movement of the automatic stage will not damage this unloader or dispenser. It could, however, break off the lucite projection on the reading platform, but this can easily be repaired or replaced.

Another possibility would be to remove the foils using a vacuum arm similar to the one we use to handle TLDs. If the foils could be unloaded using a vacuum arm, the z-axis motion could be eliminated or greatly reduced, and the motion in either the x- or y-axis could be eliminated. This would reduce the time required to load and unload a foil and bring it closer into line with the time required by the image analyzer to evaluate a foil. The procedure we are using to load the foils is fast, simple, and essentially error proof, and we will probably continue to use a similar dispenser.

Cost and Equipment

Appendix C lists the items required to establish a CR-39 dosimetry system, along with an estimate of the cost for the major items.

References

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2. W.G. Cross and H. Ing, "Overview of Neutron Dosimetry in Canada," *Proceedings of the Tenth DOE Workshop on Personnel Neutron Dosimetry*, U.S. Department of Energy, Washington, DC, Conf.-8308140-PNL-SA-12352, pp. 13–28 (1984).

3. National Council on Radiation Protection and Measurements, *Protection Against Neutron Radiation*, National Council on Radiation Protection and Measurements, Washington, DC, NCRP-38 (1971).

4. D.E. Hankins, Steven G. Homann. and Joane M. Davis, "Personnel Neutron Dosimetry Using Hot, Low-Frequency Electrochemical Etching," in *Proceedings of the 13th International Conference on Solid-State Nuclear Track Detectors*, Rome, Italy [in press] (1985).

5. D.E. Hankins, Steven G. Homann, and Joane M. Westermark. "Use of CR-39 Foils for Personnel Neutron Dosimetry: Improved Electrochemical Etching Chambers and Procedures" in *Hazards Control Department Annual Technology Review 1985*, Richard V. Griffith and Kevin J. Anderson, eds., Lawrence Livermore National Laboratory, Livermore. CA UCRL-50007-85 (1986).

6. K.G. Harrison, Harwell Laboratory, Oxfordshire, UK, private communication.

7. D.E. Hankins, "Use of Neutron-Sensitive Personnel TLDs As Flags for CR-39 Processing," in *Hazard Control Department Annual Technology Review 1987*, Richard V. Griffith and Kevin J. Anderson, eds., Lawrence Livermore National Laboratory, Livermore, CA UCRL-50007-87 (1988).

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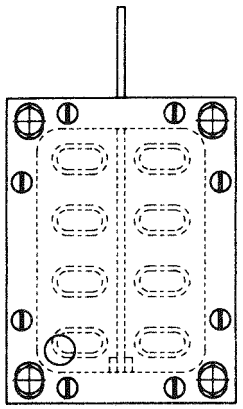
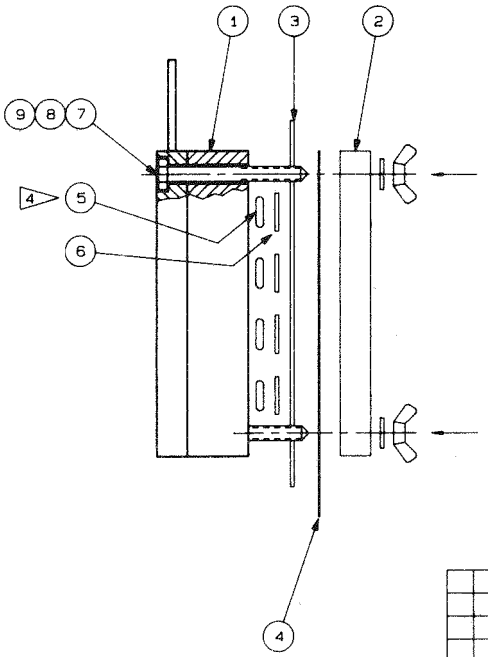
Appendix A

This Appendix contains engineering drawings for the 8- and 24-cell Homann-type electrochemical etch chambers. Full-scale drawings are available from the authors.

NOTES
UNLESS OTHERWISE SPECIFIED:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
2. SURFACE TEXTURE PER ANSI B46.1-1978.
3. ALL DIMENSIONS ARE IN INCHES.
4. O-RINGS ARE TO BE PLACED IN OBLONG SLOTS ON SHOULDER IN ITEM 1.





NO REQD	PART/LLNL STK NO	DESCRIPTION/MATERIAL	SPEC NO	ITEM
4		SCR.HEX HD, STL .250-20UNC X 2.250 LG		9
4		WASHER, FLT RD, STL .750 X .312 X .062		8
4		NUT, WING, PLN .250-20UNC / BRASS		7
8		CR-39 FOILS (SUPPLIED BY LLNL)		6
8	PARKER NO. 2-113	O-RING BUNA-N .562 I.D. X .094 W		5
1	85-109460 / TAB 02	COVER SHEET / TAB-02 (AL)		4
1	85-109460 / TAB 01	COVER SHEET / TAB-01 (POLYETHYLENE)		3
1	85-109440	PRESSURE PLATE		2
1	85-109439	O-RING PLATE ASSEMBLY		1

LTR	DWN	CHK	DATE	ZONE	CHANGE

DWN D. MAULDIN 8/85
CHK 9/85
APVD 9/85
CLASSIFIED BY:
TITLE DATE

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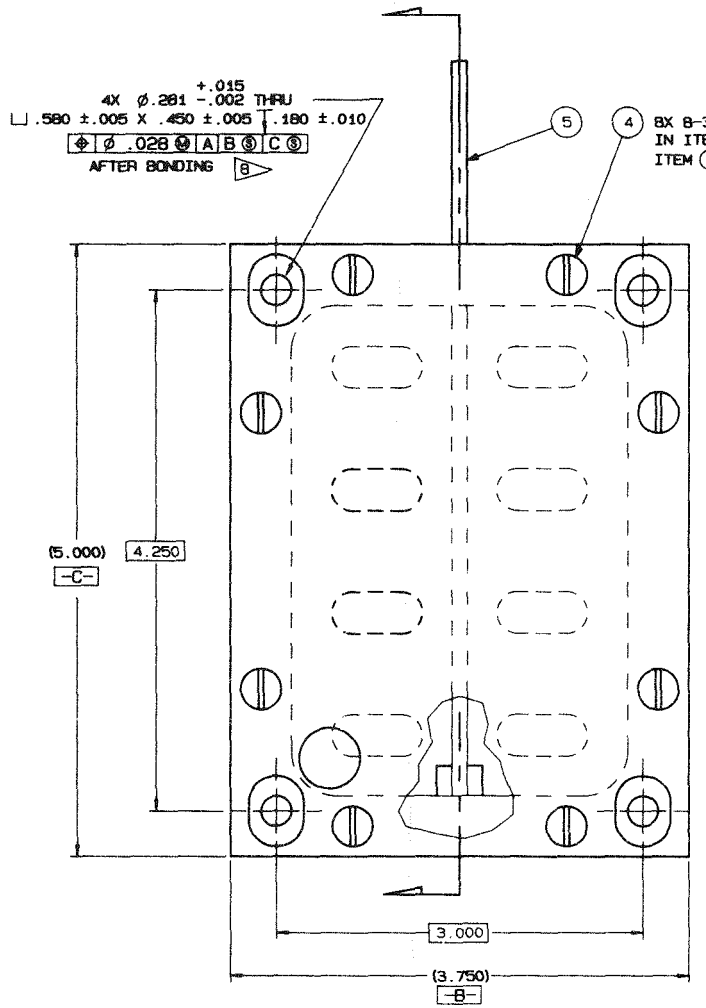
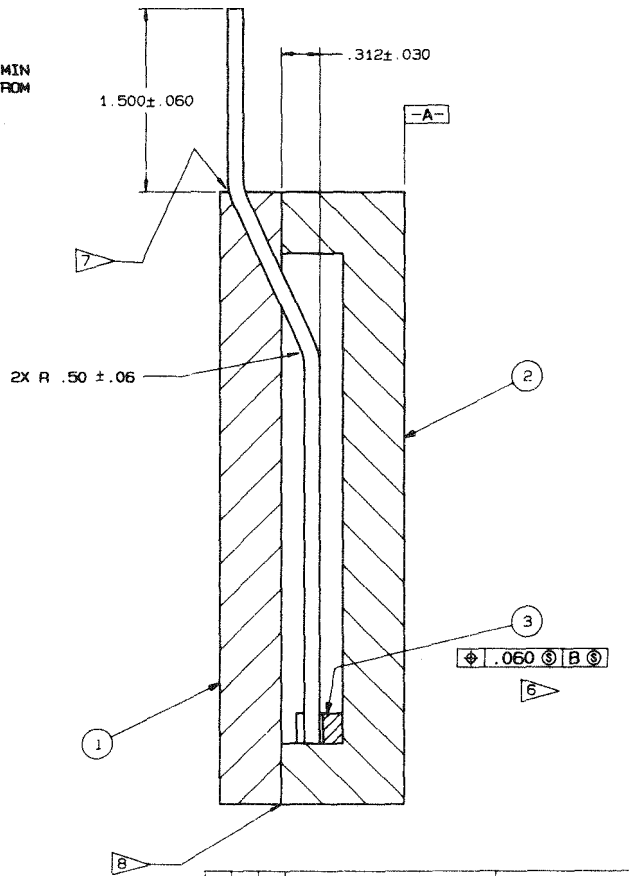
CLASSIFICATION

MAJOR UNIT: HOMANN TYPE ELECTROCHEMICAL ETCH CELL
SUBASSY:
DETAIL: ASSEMBLY
SHOWN ON AAA: N/A
ACT 0774-83
DRAWING NO: AAA 85-109457-00
COPY
SCALE HO — 2.00 — IN
SHEET 1 OF 1





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UNLESS OTHERWISE SPECIFIED:

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2. SURFACE TEXTURE PER ANSI B46.1-1978.
3. ALL DIMENSIONS ARE IN INCHES.
4. 125 ▽ OR STOCK.
5. BREAK EDGES .030 MAX.

6. BOND ITEM 3 TO ITEM 2 AS SHOWN WITH ETHYLENE DICLORIDE.
7. BOND ITEM 5 TO ITEM 1 WITH EPOXY BEFORE NOTE 8.
8. BOND ITEM 1 TO ITEM 2 WITH ETHYLENE DICLORIDE. USE ITEM 4 (8PLS) TO CLAMP PARTS TOGETHER.

NO REQD	PART/LLNL STK NO	DESCRIPTION/MATERIAL	SPEC NO	ITEM
AR		ROD, .125 DIA / 316 CRES		5
8		SCR.FLH, SLTD, 8-32UNC X .75 LG / BRASS		4
1	85-109456	ELECTRODE CLIP		3
1	85-109441	O-RING PLATE		2
1	85-109442	BOTTOM PLATE		1

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MAJOR UNIT: HOMANN TYPE ELECTROCHEMICAL ETCH CELL
SUBASSY: O-RING PLATE ASSEMBLY
DETAIL
SHOWN ON AAA 85-104457
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DRAWING NO AAA 85-109439-00
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SHEET 1 OF 1

35

NOTES
UNLESS OTHERWISE SPECIFIED:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
2. SURFACE TEXTURE PER ANSI B46.1-1978.
3. ALL DIMENSIONS ARE IN INCHES
4. 63 & STOCK
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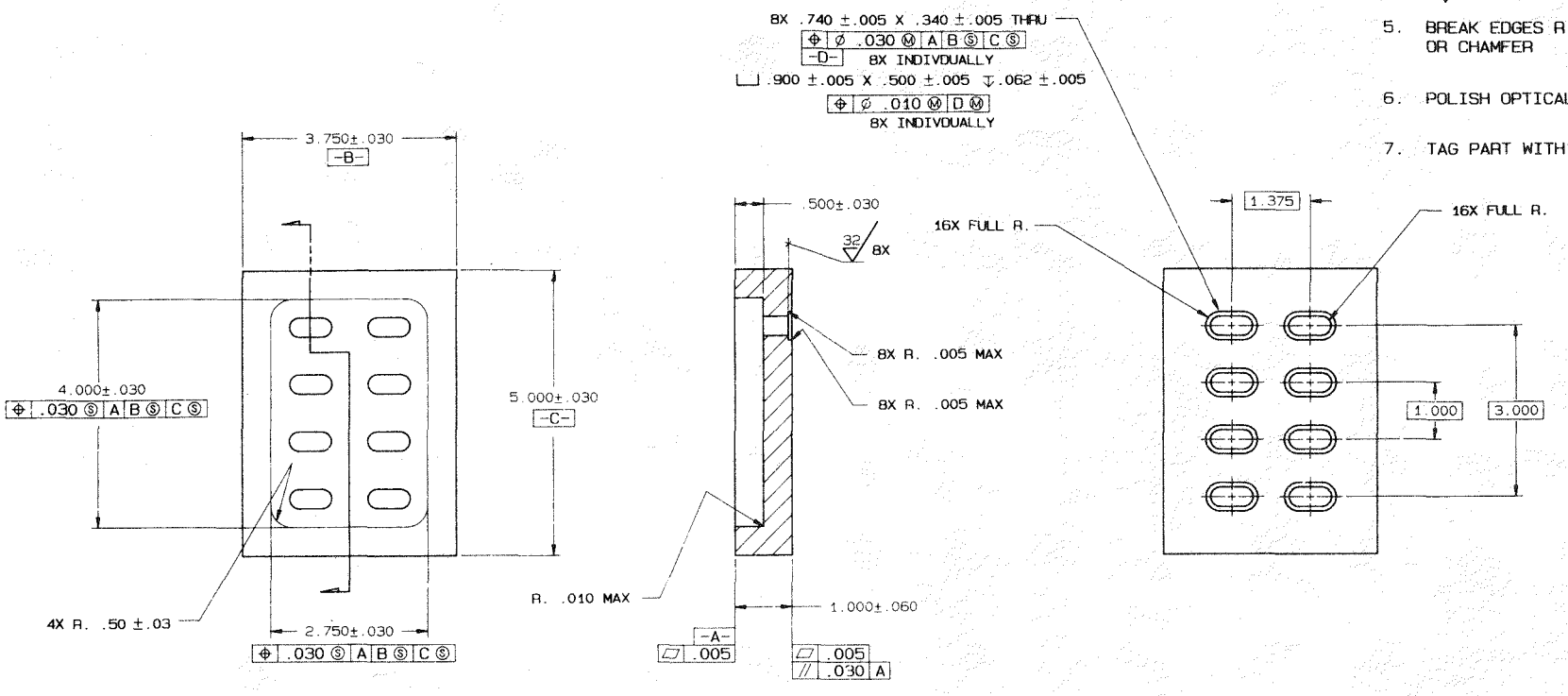
6. POLISH OPTICALLY CLEAR.
7. TAG PART WITH DWG. NO.



36

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DWN D. MAULDIN 8-85
CHK 3/85
APVD 4/85
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MAJOR UNIT HOMANN TYPE ELECTROCHEMICAL ETCH CELL
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DETAIL O-RING PLATE
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NOTES
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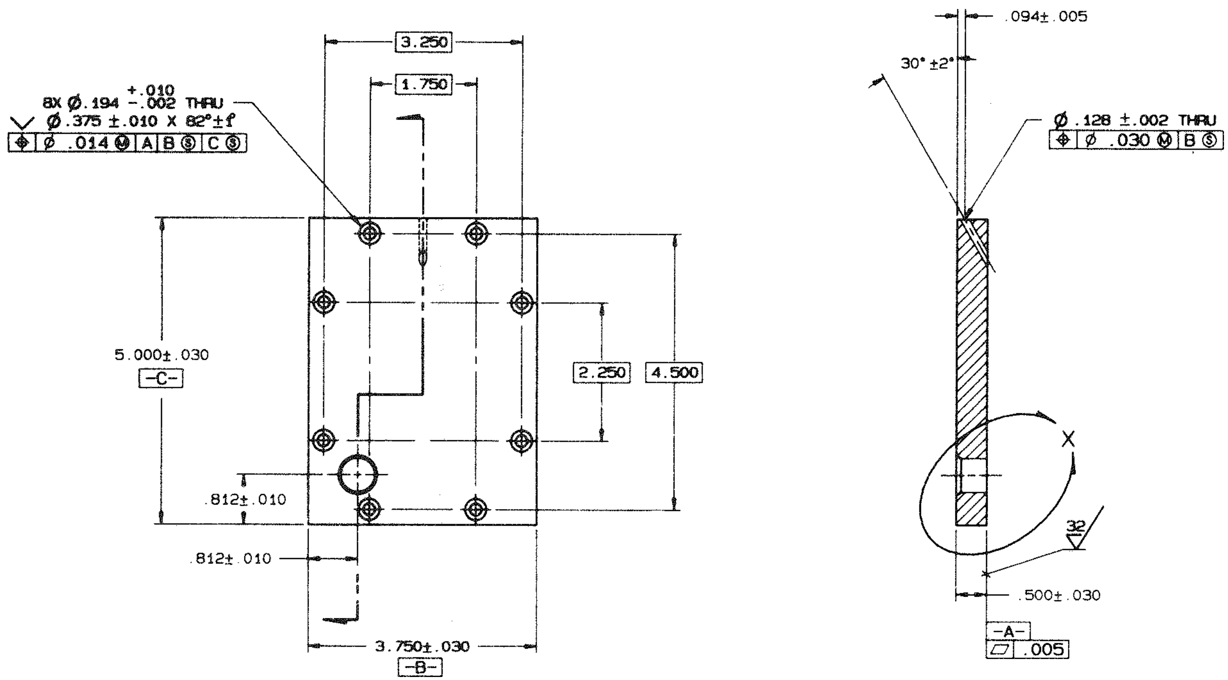
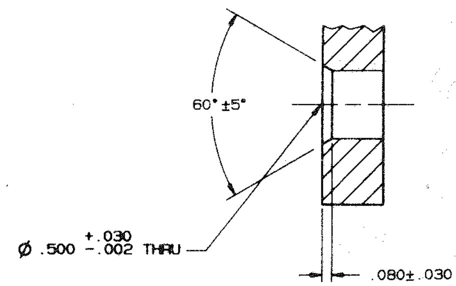
2. SURFACE TEXTURE PER ANSI B46.1-1978.
3. ALL DIMENSIONS ARE IN INCHES
4. 63 & STOCK
5. BREAK EDGES R .020 MAX. OR CHAMFER
6. POLISH OPTICALLY CLEAR.
7. TAG WITH DWG. NO.





DETAIL "X"

37

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DWN D. MAULDIN 8-85	CHK	APVD	CLASSIFIED BY: / TITLE / DATE
CLASSIFICATION	THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF CALIFORNIA LAWRENCE LIVERMORE LABORATORY. REPRODUCTION PROHIBITED WITHOUT PERMISSION OF THE MECHANICAL ENGINEERING DEPARTMENT.		
MAJOR UNIT	HOMANN TYPE ELECTROCHEMICAL ETCH CELL		
SUBASSY			
DETAIL	BOTTOM PLATE		
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UNLESS OTHERWISE SPECIFIED:

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2. SURFACE TEXTURE PER ANSI B46.1-1978.
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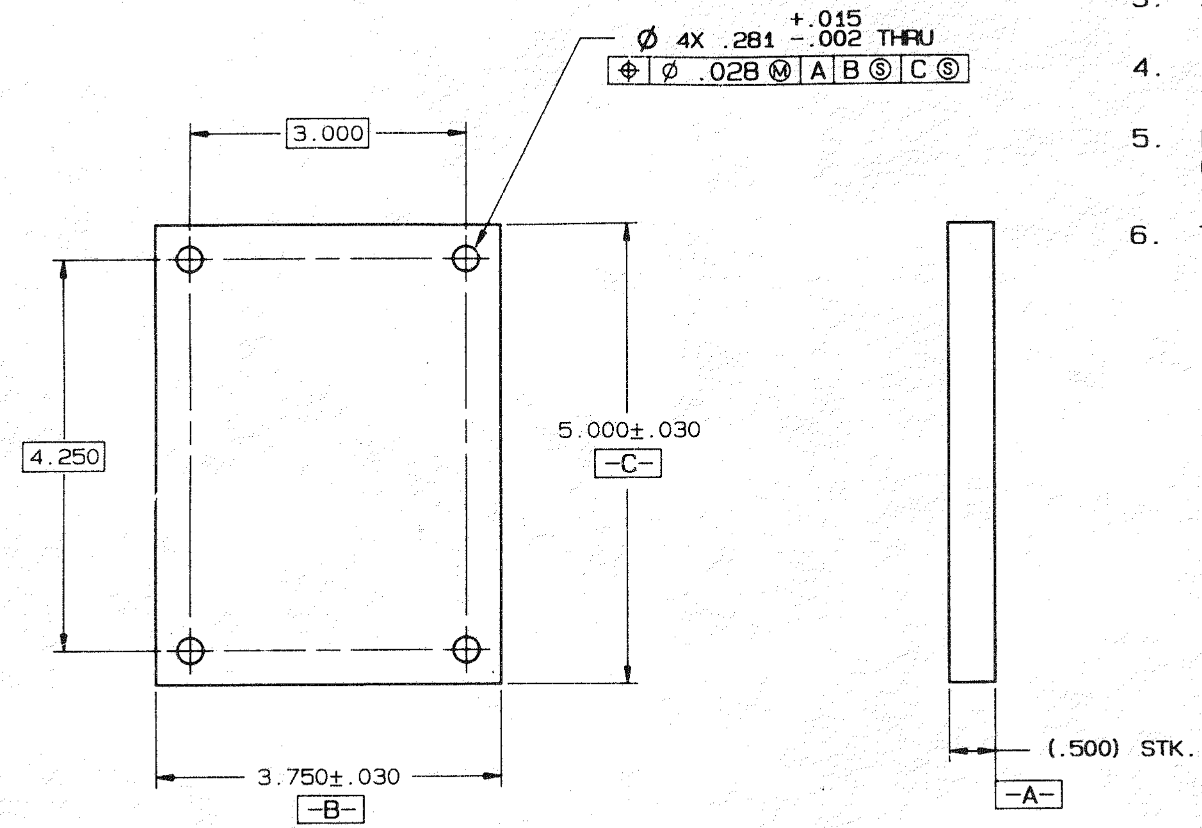
6. TAG PART WITH DWG. NO.



38

NO REQD	PART/LLNL STK NO	DESCRIPTION/MATERIAL	SPEC NO	ITEM
		ACRYLIC, UVT, CAST SHRUNK, .500" THK SHT.		

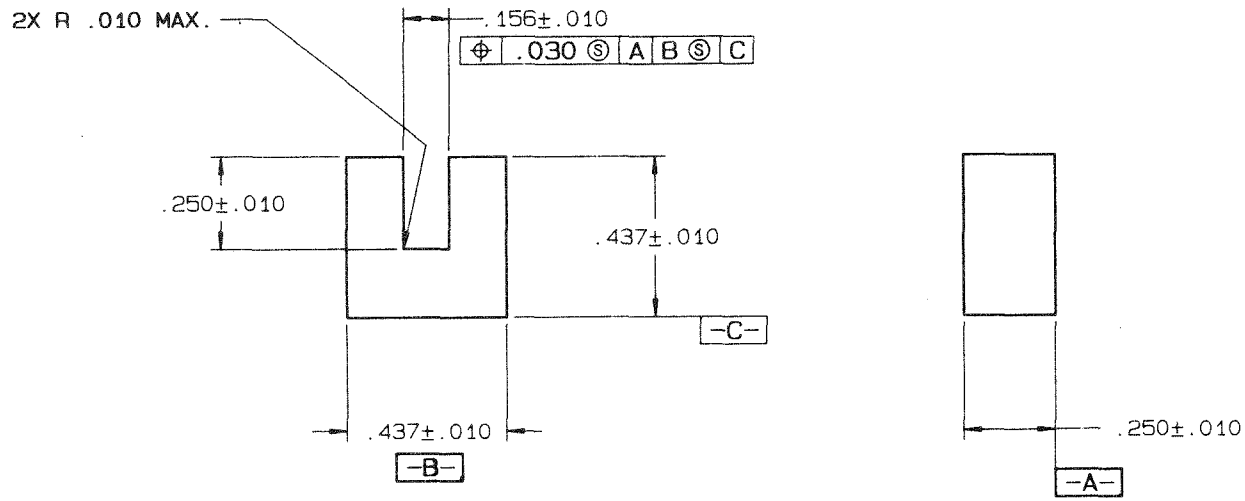
DWN D. MAULDIN 7/85	CLASSIFICATION	MAJOR UNIT	HOMANN TYPE ELECTROCHEMICAL ETCH CELL
CHK Tom [signature] 9/85		SUBASSY	
APVD [signature] 9/85	THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF CALIFORNIA, LAWRENCE LIVERMORE LABORATORY. REPRODUCTION PROHIBITED WITHOUT PERMISSION OF THE MECHANICAL ENGINEERING DEPARTMENT.	DETAIL	PRESSURE PLATE
CLASSIFIED BY:		SHOWN ON AAA 85-109457	DRAWING NO AAA 85-109440-00 COPY
TITLE / DATE		ACT 0774-93	
LAWRENCE LIVERMORE NATIONAL LABORATORY MECHANICAL ENGINEERING DEPT UNIVERSITY OF CALIFORNIA		SCALE 2.00"	SHEET 1 OF 1

LTR	DWN	CHK	DATE	ZONE	CHANGE

LL 1665-1 (Rev. 6/63)

NOTES
UNLESS OTHERWISE SPECIFIED:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M-1982.
2. SURFACE TEXTURE PER ANSI B46.1-1978.
3. ALL DIMENSIONS ARE IN INCHES.
4. 63 OR STOCK.
5. BREAK EDGES .020 MAX.
6. TAG PART WITH DWG. NO.



NO REQD	PART/LLNL STK NO	DESCRIPTION/MATERIAL	SPEC NO	ITEM
		ACRYLIC, UTV, CAST SHRUNK		

DWN D. MAULDIN 8/85
CHK Tom Lowman 8/85
APVD D. Salmi 9/85
CLASSIFIED BY
TITLE DATE

LAWRENCE LIVERMORE NATIONAL LABORATORY
MECHANICAL ENGINEERING DEPT
UNIVERSITY OF CALIFORNIA

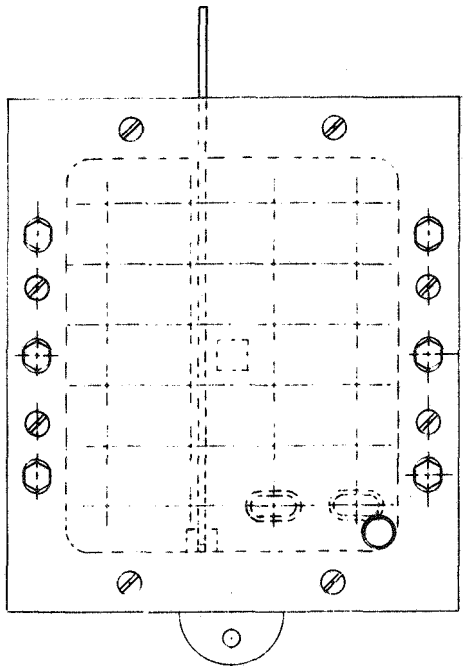
CLASSIFICATION

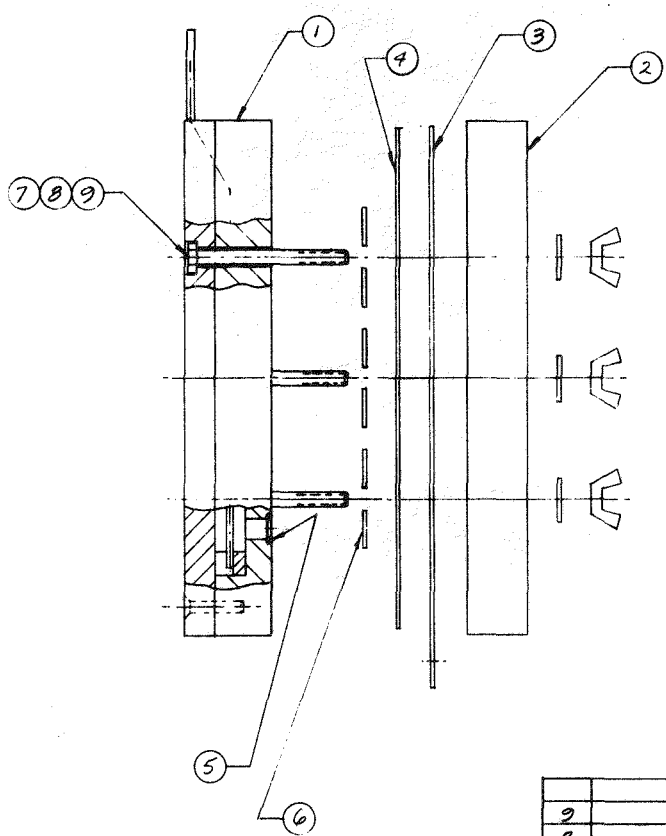
MAJOR UNIT: HOMANN TYPE ELECTROCHEMICAL ETCH CELL
SUBASSY
DETAIL: ELECTRODE CLIP
SHOWN ON AAA 85-109439
ACT 0774-93
DRAWING NO AAA 85-109456-00
COPY
SCALE .5
SHEET 1 OF 1

LTR	DWN	CHK	DATE	ZONE	CHANGE

39

LL 1885-1





ITEM	PART NO.	MATERIAL / DESCRIPTION	REQ'D	SPEC. NO.	L.L.L. STOCK NO.
9		NUT, WING :- 1/4-20 UNC-2B BRASS	6		
8		WASHER, FLAT :- 1/4 STD STL	6		
7		SCR. :- .250-20 UNC-2A HEX HD X 2 1/2 LG STL	6		
6		FOILS :- Nº CR-39 (SUPPLIED BY LLNL)	24		
5	PARKER No 2-113	"O"-RING :- .562 I.D. X .094 W. BUNA-N	24		
4		SHEET :- .010 THK X 5.50 +.1 -.0 X 8.25 +.1 -.0 POLYETHYLENE	1		
3	86-114983	COVER SHEET	1		
2	86-114984	PRESSURE PLATE	1		
1	86-114981	"O"-RING PLATE ASSEMBLY	1		

LET.	DRN.	CH.	DATE	ZONE	CHANGE

NO. REQ'D PER ASSY.

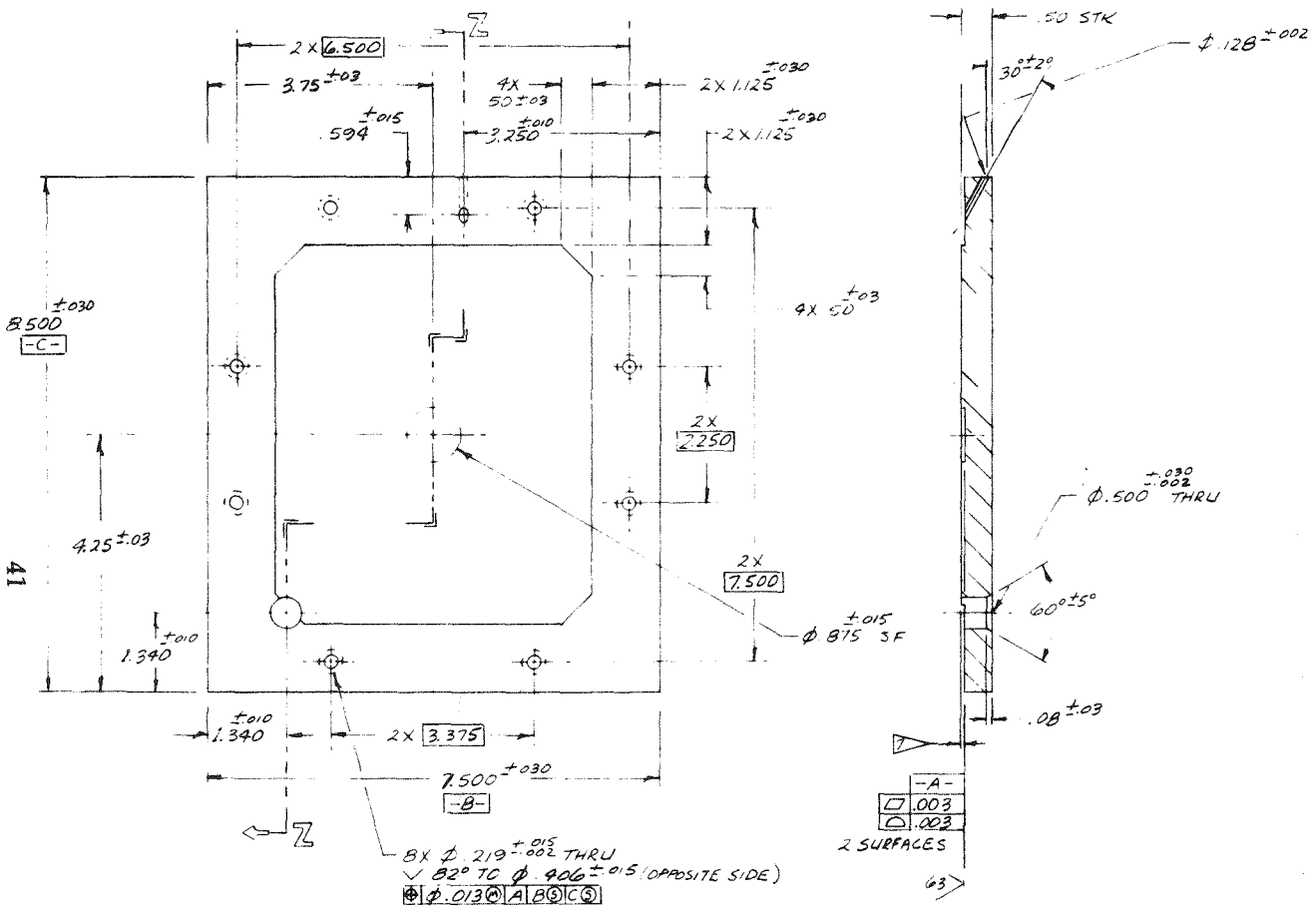
DR. K.A. SURRYHNE	9-86
CHK. J.T. KESTNER	9/86
APPROVED D.E. Hamilton	9/15/86
SHOWN ON	DATE

LAWRENCE LIVERMORE NATIONAL LABORATORY
MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF CALIFORNIA

CLASSIFICATION

MAJOR UNIT	HOMANN TYPE ELECTROCHEMICAL 24 EXCHCELL
SUB ASSY.	
DETAIL	ASSEMBLY
A.O.	
COPY	
DRAWING NO.	AAA86-114982-00 ①
ACCT. NO.	0774-93
SHEET	1 OF 1

40



SECTION Z-Z

NOTES:-

1. DIM & TOL PER ANSI Y14.5M-1982.
2. SURFACE TEXTURE PER ANSI B46.1.
3. ALL DIMS ARE IN INCHES.
4. $\sqrt{}^{.25}$ UNLESS NOTED.
5. REMOVE ALL BURRS & BREAK CORNERS .020 MAX.
6. STOCK SURFACES TO BE OPTICALLY CLEAR.
7. MINIMUM MACHINING TO ACHIEVE .005 FLATNESS.

ITEM	PART NO.	MATERIAL / DESCRIPTION	REQ'D	SPEC. NO.	LLL STOCK NO.
		ACRYLIC, UVT, CAST SHRUNK			

DR. K.A. SURRYHNE	9-86	CLASSIFICATION	MAJOR UNIT HOMANN TYPE ELECTRO CHEMICAL ZAETCH CELL
CHK. J.T. KISTNER	9/86	THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF CALIFORNIA LAWRENCE LIVERMORE NATIONAL LABORATORY. REPRODUCTION PROHIBITED WITHOUT PERMISSION OF THE MECHANICAL ENGINEERING DEPARTMENT.	SUB ASSY.
APPROVED [illegible]	11/1/86		DETAIL BOTTOM PLATE
SHOWN ON 86-114981	DATE		J.O. DRAWING NO. AAA86-114985-00
NO. REQ'D PER ASSY.			COPY
			ACCT. NO. 0774-93 SHEET 1 OF 1

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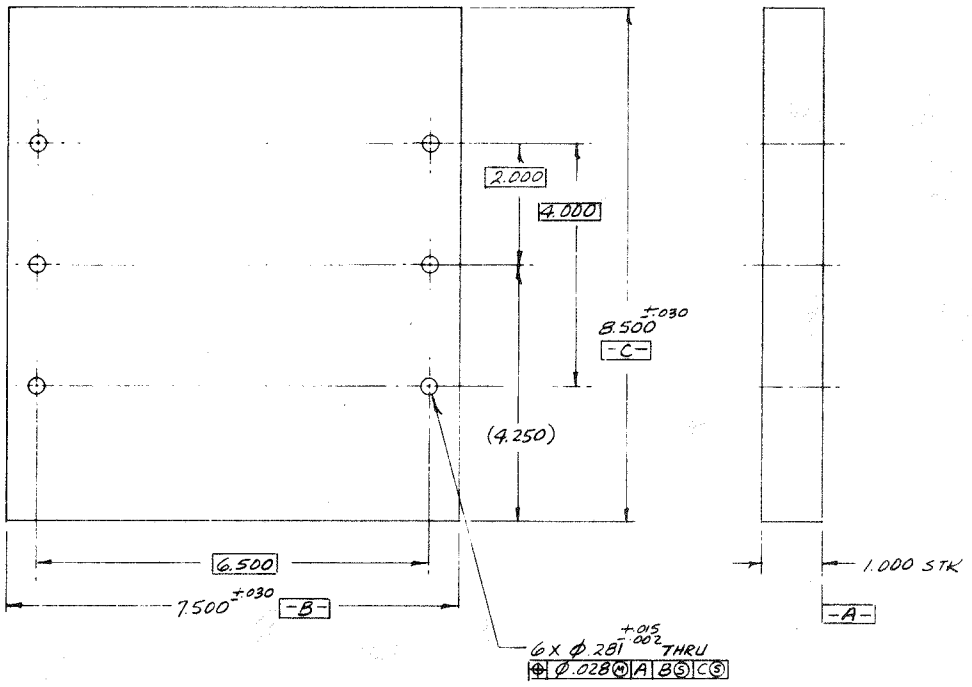
MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF CALIFORNIA

LET.	DRN.	CH.	DATE	ZONE	CHANGE



NOTES:-

1. DIM & TOL PER ANSIY14.5M-1982.
2. SURFACE TEXTURE PER ANSIB46.1.
3. ALL DIMENSIONS ARE IN INCHES.
4. 125 √ ALL MACHINED SURFACES.
5. REMOVE ALL BURRS & BREAK CORNERS .020 MAX.
6. TAG PART WITH DWG NO

42

ITEM	PART NO.	MATERIAL / DESCRIPTION	REQ'D	SPEC. NO.	LLL STOCK NO.
		SHEET.-1.000THK ACRYLIC,UVT,CASTSHRUNK			

LET.	DRN.	CH.	DATE	ZONE	CHANGE

NO. REQ'D PER ASSY.

DR. K.A. SURRYHNE 2-86
CHK. J.T. KESTNER 9/16
APPROVED D.E. Hawkins 11/1/86
SHOWN ON 86-114982 DATE

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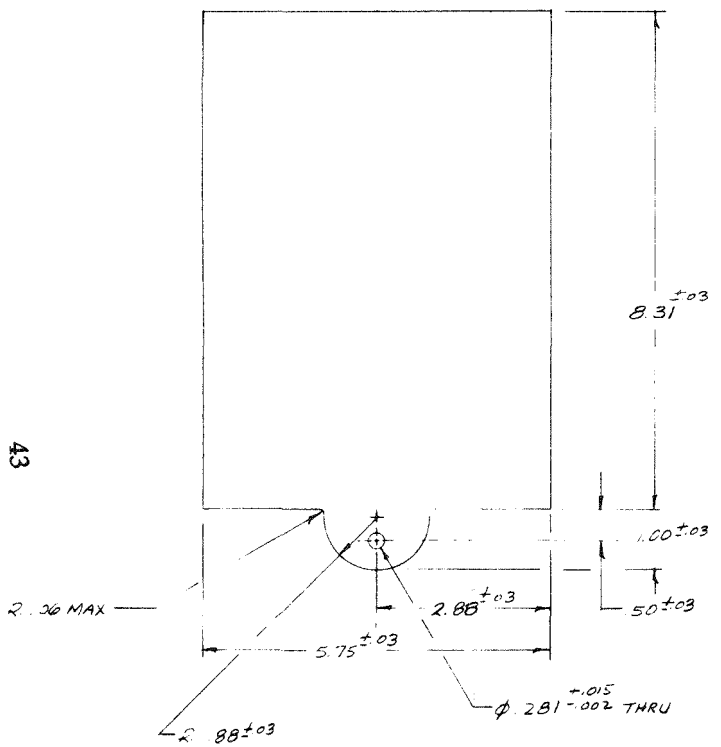
UNIVERSITY OF CALIFORNIA

CLASSIFICATION

MAJOR UNIT HOTMANN TYPE ELECTROCHEMICAL 2¢ ETCH CELL
SUB ASSY.
DETAIL PRESSURE PLATE
J.O.
COPY
DRAWING NO. AAA86-114984-00 B
ACCT. NO. 0774-03
SHEET 1 OF 1

E D C B A



NOTES:-

1. DIM & TOL PER ANSI Y14.5M-1982.
2. SURFACE TEXTURE PER ANSI B46.1.
3. ALL DIMS ARE IN INCHES.
4. 25/ ALL MACHINED SURFACES.
5. REMOVE ALL BURRS & BREAK CORNERS .010 MAX.
6. TAG PART WITH DWG Nº

ITEM	PART NO.	MATERIAL / DESCRIPTION	REQ'D	SPEC. NO.	LLL STOCK NO.
		SHEET:-031 AL 6061-T6			

DR. K.A SURRYHNE	9-86	CLASSIFICATION	MAJOR UNIT HOMANN TYPE ELECTROCHEMICAL ETCH CELL
CHK. J.T. KESTNER	9/86		SUB ASSY.
APPROVED: E Hawkins	9/15/86		DETAIL COVER SHEET
SHOWN ON 86-114982	DATE		J.O.
NO. REQ'D PER ASSY.			COPY
			ACCT. NO. 7774-93

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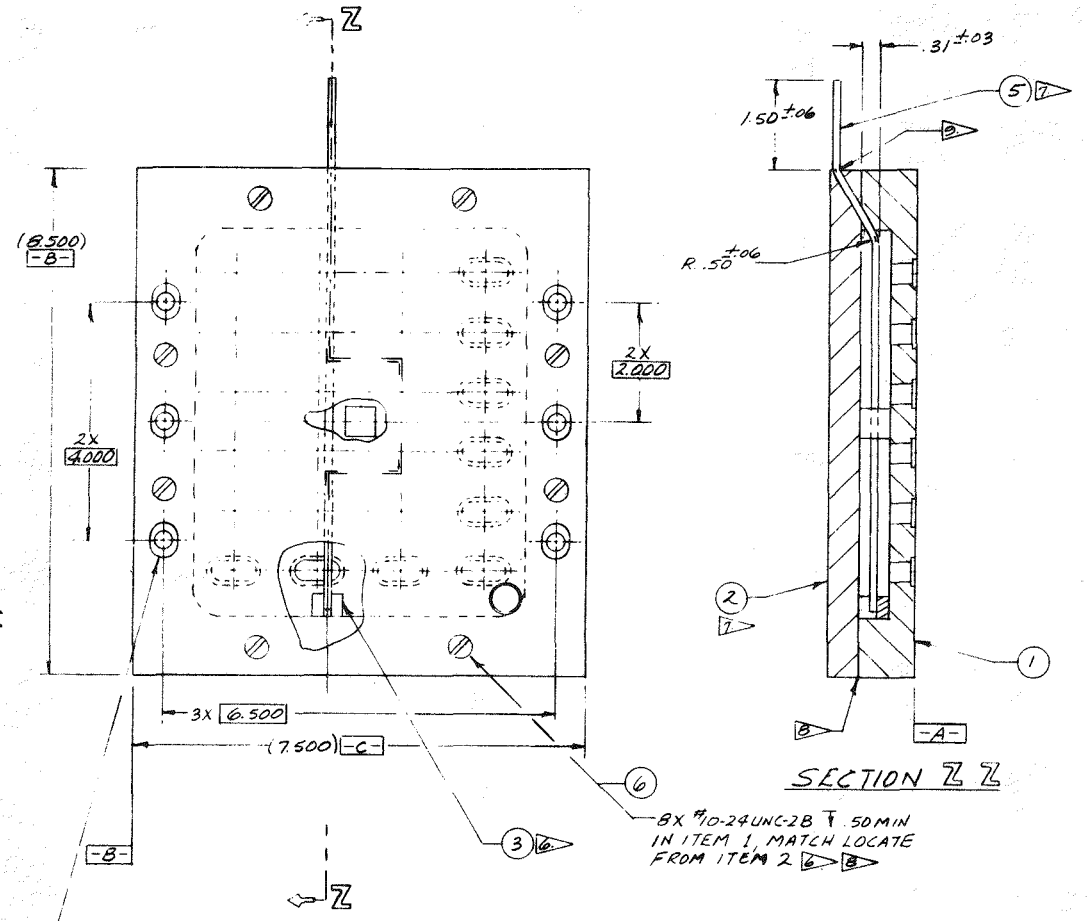
MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF CALIFORNIA

DRAWING NO. AAA86-114983-00 0

SHEET 1 OF 1

LET.	DRN.	CH.	DATE	ZONE	CHANGE

43



SECTION Z Z

VOTES:-

1. DIM & TOL PER ANSI Y14.5M-1982.
2. SURFACE TEXTURE PER ANSI B46.1.
3. ALL DIMS ARE IN INCHES.
4. 125 √ ALL MACHINED SURFACES.
5. REMOVE BURRS & BREAK CORNERS .03 MAX
6. BOND ITEM 3 TO ITEM 1 SHOWN WITH ETHYLENE DICHLORIDE
7. BOND ITEM 5 TO ITEM 2 WITH EPOXY BEFORE NOTE 8
8. BOND ITEM 2 TO ITEM 1 WITH ETHYLENE DICHLORIDE. USE ITEM 6 (8 PLCS) TO CLAMP PARTS TOGETHER.
9. USE DOW CORNING RTV-732 ADHESIVE SEALANT TO SEAL ITEM 5 TO ITEM 2.

ITEM	PART NO.	MATERIAL / DESCRIPTION	REQ'D	SPEC. NO.	LLL STOCK NO.
6		SCR:- #10-24UNC-2A FLT HD X 1.00 LG BRASS	8		
5		ROD:- Ø.125 316 CRES	AS REQ'D		
4					
3	85-109456	ELECTRODE CLIP	1		
2	86-114985	BOTTOM PLATE	1		
1	86-114986	'O'-RING PLATE	1		

LET.	DRN.	CH.	DATE	ZONE	CHANGE

NO. REQ'D PER ASSY.

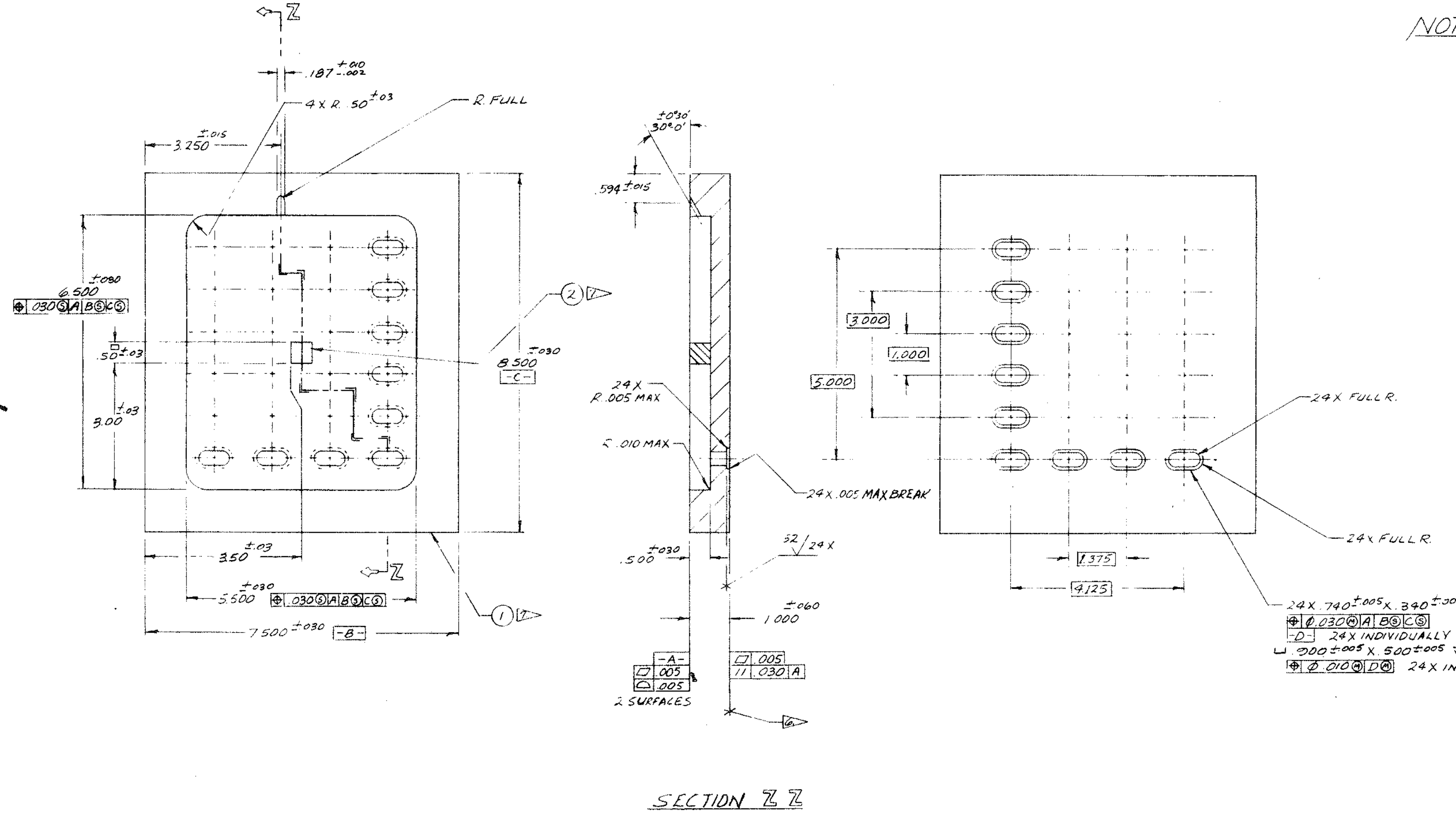
DR. K.A. SURRYHNE 9-86
CHK. J.T. KESTNER 9/86
APPROVED D.E. Hawkins 9/15/86
SHOWN ON 86-114282 DATE

LAWRENCE LIVERMORE NATIONAL LABORATORY
MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF CALIFORNIA

CLASSIFICATION

MAJOR UNIT HOMANN TYPE ELECTRO CHEMICAL 24 ETCH CELL
SUB ASSY. 'O'-RING PLATE ASSEMBLY
DETAIL
J.O.
COPY
DRAWING NO. AAA86-114981-00 B
ACCT. NO. 0774-93
SHEET 1 OF 1

45/46



NOTES:—

1. DIM & TOL PER ANSI Y14.5M-1982
2. SURFACE TEXTURE PER ANSI B46.1.
3. ALL DIM ARE IN INCHES.
4. .63√ ALL MACHINED SURFACES.
5. REMOVE ALL BURRS & BREAK CORNERS .020 MAX U/N NOTED.

6. BOND ITEM 2 TO ITEM 1 SHOWN WITH ETHYLENE DICHLORIDE.

ITEM	PART NO.	MATERIAL / DESCRIPTION	REQ'D	SPEC. NO.	LLL STOCK NO.
2		ACRYLIC, UTV, CAST SHRUNK	1		
1		ACRYLIC, UTV, CAST SHRUNK	1		

LET.	DRN.	CH.	DATE	ZONE	CHANGE

NO. REQ'D PER ASSY.

DR. K.A. SURYANIE 9-8…
CHK. J.T. KESTNER 9/…
APPROVED D.G. Hankins 9/15/…
SHOWN ON 86-114981 DATE

LAWRENCE LIVERMORE NATIONAL LABORATORY
MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF CALIFORNIA

CLASSIFICATION

MAJOR UNIT HOMANN TYPE ELECTROCHEMICAL 24 ETCHCELL
SUB ASSY. "O"-RING PLATE
DETAIL
J.O.
COPY
DRAWING NO. AAA86-114986-00
ACCT. NO. 0774-93
SHEET 1 OF 1

DO NOT MICROFILM
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Appendix B
Operating Procedures for Electrochemical Etching of CR-39

Loading of the Etch Chambers

1. Check the oven temperature and adjust to 60°C if necessary. Check etch chamber O-rings for improper seating or damage. O-rings should be replaced monthly.

2. Write down the information relating to the foils and etching parameters in the etch log book for identification:

a. Etch number (assign consecutive identification numbers for each etch)
b. Etch chamber identification
c. Etching date
d. KOH normality
e. Temperature of oven
f. Each cycle of the etch:
   - High voltage
   - Frequency (Hz)
   - Etching time
g. Identification number to be used on each foil (unique foil numbers can be laser etched at time of cutting).
h. Identify exposure to foils (worn by, placed at, background, calibration dose, etc.)

Each etch should contain at least four standard foils that have been exposed to a known neutron rem value.

3. With a scalpel or knife, remove the protective polyethylene cover from the top of the foil. If necessary, write the identification number on the foil (outside of the etch area) using a permanent marker. When etching more than one chamber, be sure that the foil identification number is unique for each foil in the etch.

4. Remove the protective polyethylene covering from the back of each foil.

5. Using the CR-39 positioner, place the foils face down on the O-ring of the cell opening. Be sure to fill all chamber slots with foils.

6. Connect the chamber to house vacuum using the chamber's vent hole, then use the positioner's seating aid to seal the foils to the O-rings. Remove positioning equipment and check the seal by listening for vacuum leaks. The vacuum will hold the foils securely while the etch chamber is being assembled.

7. Place one of the 10-mil pieces of polyethylene over the foils. These should also be replaced monthly.

8. Place one of the aluminum plates on top of the polyethylene. This aluminum plate is the second electrode.

9. Place the lucite pressure plate on top of the chamber and secure it to the chamber body with bolts and wing nuts. The wing nuts should be securely fastened (but finger tight only).

10. Shut off the vacuum and remove the hose. Plug the sphygmomanometer (blood-pressure gauge) into the vent hole to test the chamber for leaks. The pressure will remain constant over a minute or two if a good seal has been made and the chamber does not leak.

11. Place the chamber(s) and the KOH bottle(s) in the oven where they should remain overnight. Remove the chamber(s) and the KOH from the oven the next morning and immediately partially fill (~250 ml) each chamber with KOH through the vent hole. Secure a rubber stopper (with a 1/16-in. hole) in the vent hole. This prevents spillage when the cell is tipped but still allows air expansion to vent.

12. Attach the high-voltage leads to the electrodes (submerged rod and aluminum plate) using alligator clamps or banana connectors. If a second chamber is being used, additional high-voltage leads or jumper cables will be required.

13. Place the chamber in a plastic photo tray with the vent hole positioned at the front of the oven. The oven racks must slant slightly to the rear of the oven. This prevents the KOH from being forced out through the small hole in the stopper during expansion.

14. Check the power-supply parameters that are in the HP-41 calculator by pressing the yellow button and then the EDIT button. The calculator will display the parameters in sequence each time the R/S button is pressed. If a change is required, enter the new value in the calculator and press the R/S button. To check input, repeat the readout procedure for the etch parameter. To start the etch, press the yellow key and then the RUN key.

15. Check the oven temperature and high voltage periodically during the etching cycles.

16. Leave the chambers in the oven for a 15-minute post-etch following completion of the etch cycles.

Unloading of the Etch Chambers

Empty the chamber of KOH by removing the stopper and pouring the KOH back into the bottle. Use a funnel to prevent excessive spillage. Rinse the chamber with water at least twice. Then take the chamber apart, rinse all the parts, and leave them to air dry. Soak and rinse the foils in water for about five minutes. Then remove the foils and blot dry using paper towels. Before reading, clean the foils using a wet cloth followed by dry cloth to remove lint and debris.

Counting Procedure

1. Allow video equipment to warm-up for half an hour.

2. Add a background image to the computer memory using an etched foil with very few or no tracks. This background image is used to remove light intensity deviations across the foil surface.

3. Calibrate the image analyzer using an independent standard foil. Position the foil so that the same ~0.2 cm^2 area on the foil is counted. When properly adjusted, the image analyzer will indicate a similar number of tracks within the same area bins. If necessary, adjust the light source to compensate for any camera deviations. Exact matches are not necessary, as each etch chamber has a set of standards that will be used to determine the dosage.

4. Reading foils

- *Automatic reader*—load extraction chamber with clean, lint-free foils. Activate counting program.

- *Manual method*—clean each foil using a wet cloth followed by a dry cloth. Obtain three readings from each foil using the 2× magnification, usually starting at the top of the foil and progressing down the center for each unique position.

Appendix C
Equipment Required

Oven with digital temperature controller	$ 2,000
Power supply	$ 6,700
Personal computer that includes: 80386 CPU, image analyzer, frame-grabber board, extended memory, 20Mbyte hard disk, and related software	$ 12,000–15,000
Microscope (with auto stage control)	$ 3,000 (28,000)
Etching chambers	$ 500–800 each
KOH pellets	
Plastic squeeze bottles for KOH	
Funnel to return KOH to squeeze bottle	
Paper towels and cloths for drying foils	
Scalpel	
Aluminum plate (1/16 in. thickness) electrode	
Polyethylene sheets (10 mil) between electrode and foils	
Permanent ink pens to mark foils for identification	
Photo trays to protect oven from spills	
Beakers for rinsing foils and etch chambers	
Graduated cylinders for mixing KOH	
Blood-pressure gauge for leak testing	
Glassine bags to store etched foils after reading	
Hydrometer to measure a specific gravity of 1.276	

Appendix D

The distribution of CR-39 track events is well represented by the Normal distribution. Consequently, the limit of sensitiivty, LOS, is defined as follows:

$$\text{LOS (mrem)} = \frac{\left[k^2 + 2k\left[\text{sdev}\left(N_b\right)\right]\right]}{S}$$

where: $k = k_\alpha = k_\beta$

k_α = the absicissa of the standardized Normal distribution corresponding to the probability level, $1 - \alpha$.

k_β = the abscissa of the standardized Normal distribution corresponding to the probability level, $1 - \beta$.

sdev (Nb) = standard deviation of the CR-39 foil background (tracks/cm^2)

S = sensitivity of the CR-39 foils (tracks/cm^2·mrem).

For our CR-39 dosimetry system, k = 1.645 ($\alpha = \beta = 0.05$), the standard deviation of the background is 8 tracks, and the sensitivity is 5 tracks/cm^2•mrem. Therefore, using the above equation,

$$\text{LOS} = \frac{\left[1.645^2 + 2(1.645)\,(8)\right]}{5}$$

LOS = 6 mrem.

For an observed dose of 6 mrem, the probability of stating the dose is *greater* than background, when in fact it *is* background, is 5%. The probability of stating that the observed count is less than background, when in fact is is greater than background, is also 5%.