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NEUTRON DOSIMETRY USING ELECTROCHEMICAL ETCHING*

by

Shian-Jang Su, Gary B. Stillwagon and Karl Z. Morgan, Ph.D.

School of Nuclear Engineering

Georgia Institute of Technology

Atlanta, Georgia 30332

MASTER

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Abstract

Registration of α-tracks and fast-neutron-induced recoils tracks by the electrochemical etching technique as applied to sensitive polymer foils (e.g. polycarbonate) provides a simple, sensitive and inexpensive means of fast neutron personnel dosimetry as well as a valuable research tool for microdosimetry. When tracks were amplified by our electrochemical technique and the etching results compared with conventional etching technique a striking difference was noted. The electrochemically etched tracks were of much larger diameter (∿ 100 μm) and gave superior contrast. Two optical devices — the transparency projector and microfiche reader — were adapted to facilitate counting of the tracks appearing on our poly-carbonate foils. The projector produced a magnification of 14X for a screen to projector distance of 5.0 meter and read's magnification was 50X. A Poisson distribution was determined for the number of tracks located in a particular area of the foil and experimentally verified by random counting of quarter sections of the microfiche reader screen. Finally, in an effort to determine dose equivalent (rem), a conversion factor is being determined by finding the sensitivity response (tracks/neutron) of recoil particle induced tracks as a function of monoenergetic fast neutrons and comparing results with those obtained by others.

Introduction

Gamma dosimetry is simpler than neutron dosimetry because many of the gamma dosimeters are relatively neutron insensitive and in many practical situations gamma fields are neutron free. However, in the case of neutron fields, gamma rays almost always accompany them with varying intensity depending on the nature of the source and its geometry, shielding conditions, etc. Therefore, a suitable neutron dosimetry system should be capable of determining both neutron and gamma absorbed dose separately as well as the dose equivalent of the mixture.

A good neutron personnel dosimeter system should be: 1) Sensitive to neutrons over a wide dose range to cover routine and accident dosimetry (i.e. from 0.001 to 1000 rad); 2) Insensitive to non-ionizing radiation and to other types of ionizing radiations such as X, beta, and gamma radiations, or it should have at least a good compensation system included in the design; 3) Provided with a wide energy response to follow kerma or rem curves recommended by appropriate legislative authority; 4) Independent of the orientation of the radiation impinging on the dosimeter since the direction of incident neutrons is not always known; 5) Possessed of nil or at least tolerable post-irradiation fading rate if operated as an integrating instrument, i.e. it must retain the radiation-induced effect for the period of interest; 6) Simple, rugged, and readily available; 7) Inexpensive and easy to read rapidly; 8) Designed to require minimal training for its operation; 9) Capable of providing the possibility for dosimetry intercomparison by mail and being applied to a variety of other areas of applications.

At this time there are several neutron and gamma dosimetry systems which have been proposed and used in many applications that meet some or most of the above desired characteristics: Existing neutron dosimeters which are classified as ionization chambers, gas filled counters (Geiger and proportional), solid state detectors, and activation detectors, provide suitable detectors for many applications. Discussion and detailed information on all existing techniques has been given in many textbooks such as those by Morgan and Turner[1] and Attix et al.[2]

Briefly, it can be stated that ionization chambers and gas filled counters can be regarded as one of the principal instruments for neutron dose measurements. However, their response to gamma rays, which may exist in many neutron fields, makes it necessary for these chambers to be coupled with a neutron-insensitive dosimeter (e.g. the phil single ion detector) or a dosimeter insensitive to X and γ radiation (e.g. Hurst proportional counter). Some thermoluminescence dosimeters (TLD) are competing with photographic film for personnel gamma dosimetry. Nevertheless, they have the disadvantage that the effect induced by ionizing radiations will be erased during a reading process. Thermo stimulated electron emission dosimeters (TSEE), although they have certain advantages for many applications, have this same disadvantage. From this point of view, Radiophotoluminescence (RPL) glasses are advantageous and can give the life-time integral dose, however, they have a high effective atomic number ($\overline{Z}$) which makes them very energy dependent for gamma dosimetry, and they are also sensitive to thermal neutrons. Nuclear track film, the only (n,p) track recorder currently used in personnel dosimetry, is in the process of being replaced by more suitable techniques due to its insensitivity, fogging, fadding effects, limited shelf life,etc. Solid state nuclear track foils may provide an alternative choice for this application, especially the fission fragment registration technique. This technique is also of interest for clinical applications and especially for depth-dose studies near interfaces where high spatial resolution as well as tissue equivalence in composition is of primary importance. Among other techniques in use, activation techniques (or threshold detectors) have been used as the principle method for neutron dosimetry and to provide spectral information for criticality accidents. It will be seen that although neutron dosimetry techniques have made some progress, there is still a great need for further investigation and development of new dosimetry techniques for particular applications. At this stage of dosimetry development, plastic track detectors show many advantages over the existing techniques, and seem to be capable of measuring steep neutron dose gradients such as those at bone-tissue interfaces.[3]

Counting Techniques

Conventional chemical etching in sensitive polymers such as polycarbonate, cellulose nitrate are small in size and usually have poor contrast leading to tedious and inaccurate microscopic counting.

Our current development of elecrochemical etching systems and amplification of recoil particle tracks in polymers has been amplified to the extent that they can be observed by the unaided eye making fast neutron dosimetry possible over a wide dose range.

Two new techniques were developed to facilitate counting of the polycarbonate foils. The microfiche reader and the overhead (transparency) projector. These two techniques offer several advantages over the microscope for low count density and thick foils. Advantages effected during utilization of these two techniques over earlier conventional microscope counting are:

1. A larger foil area is actually counted.
2. Image is viewed on a screen and not through an eyepiece causing less eye strain.
3. Less time is required per foil for counting.
4. No elaborate equipment is required.

To facilitate counting with the transparency projector a grid was constructed on the screen upon which the image was projected. The grid consisted of two concentric circles of radius 4.3 and 7.0 cm on the screen which were cut into sectors with radii drawn every 20^0 (18 total). This yielded 36 small areas which could be counted easily. Foil magnification was 14X with a screen to projector distance of 16 ft.5 in. and track diameters were about 0.6 mm (see Figure I). Of course, almost any magnification could be obtained depending on the distance of separation of the projector and screen.

The foil magnification of microfiche reader was 50X and track diameters were in the range of 2-4 mm. Since the magnification was 50X, the tracks were viewed in greater detail than when viewed with the transparency projector (see Figure II). The star-like outcroppings from individual tracks became visible, similar to the appearance of the tracks seen by the microscope.

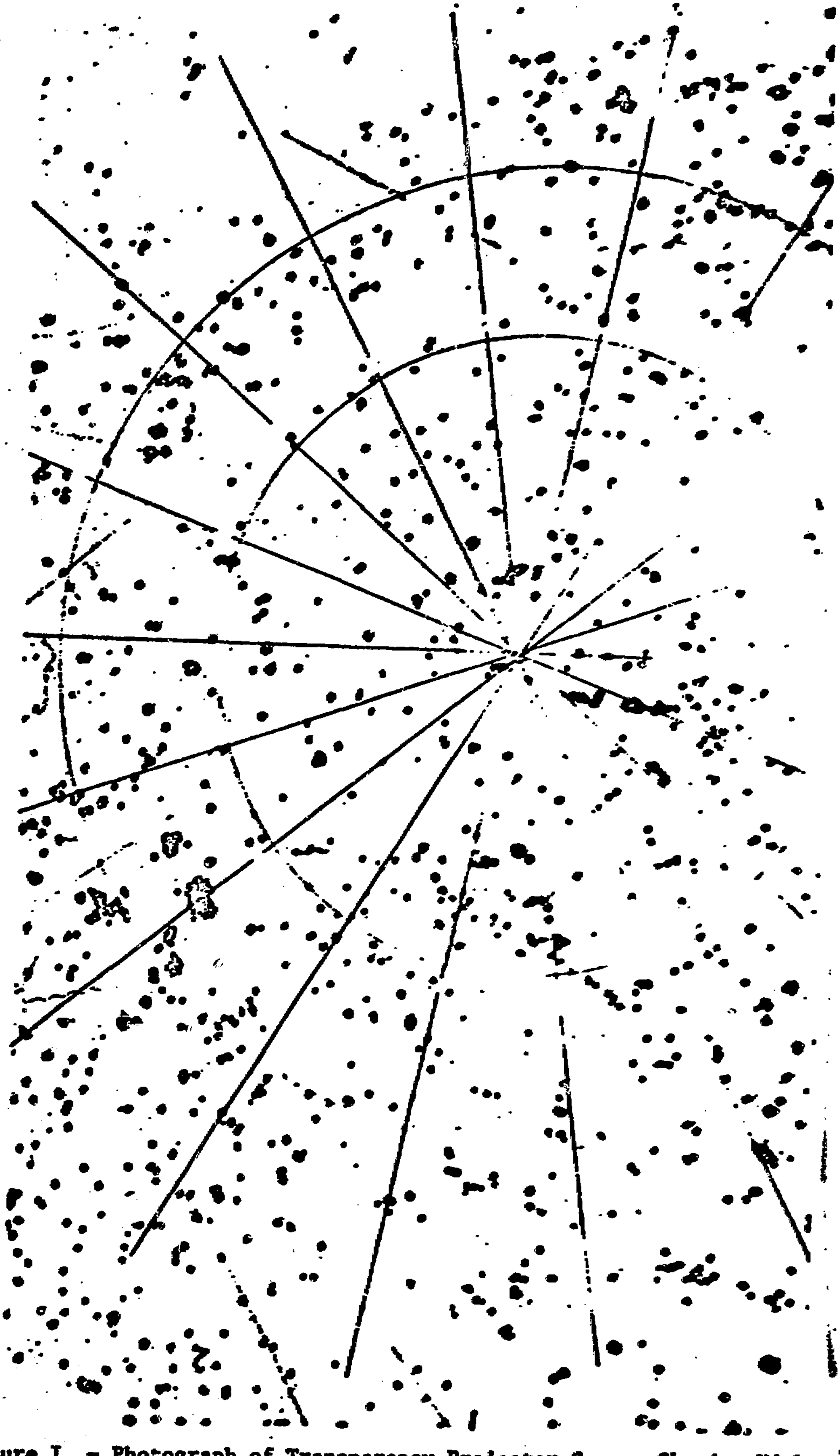

Figure I - Photograph of Transparency Projector Screen Showing High Background Foil

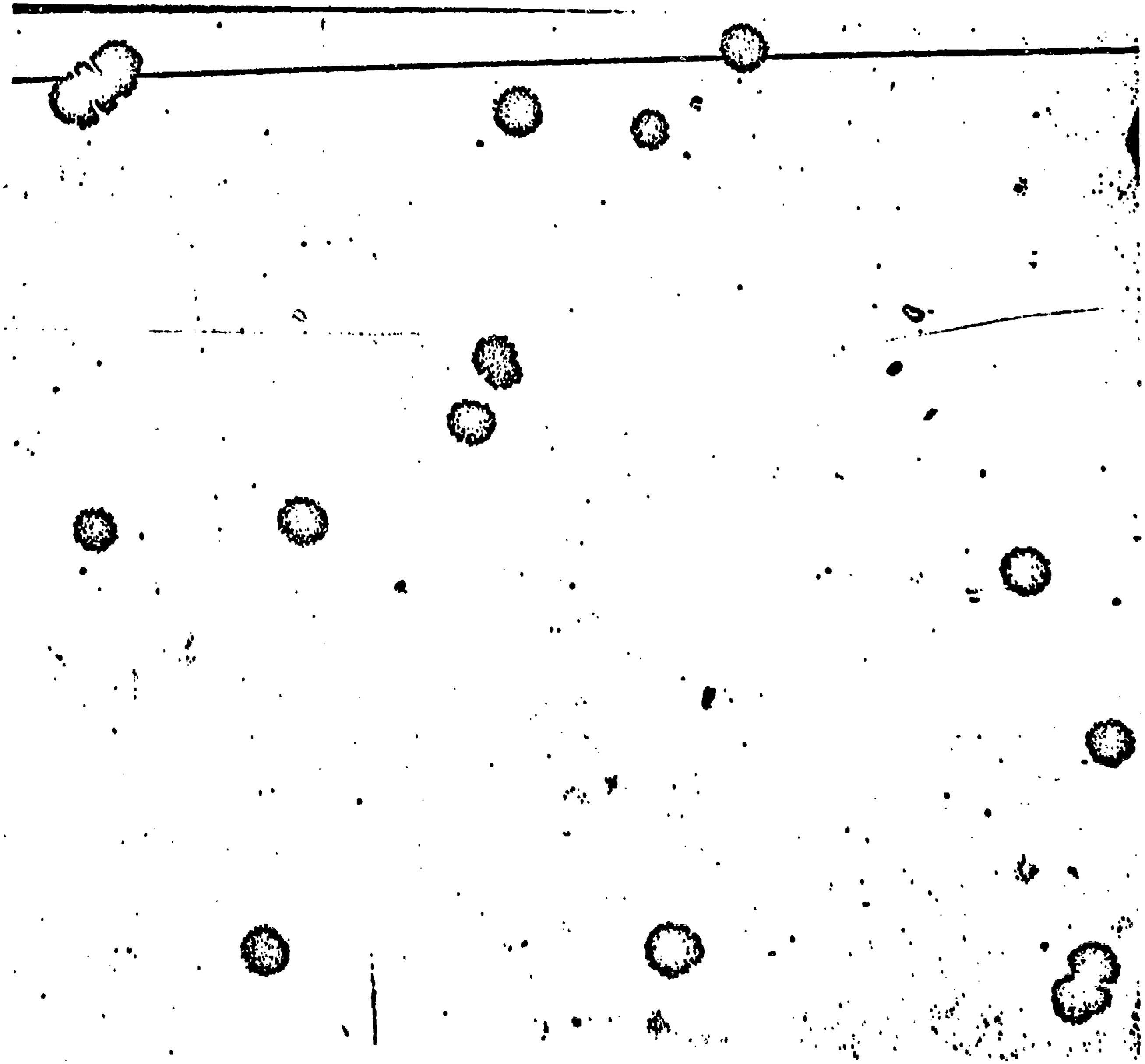

Figure II - Photograph of 17x13cm Area On Microfiche Reader Screen Showing Background Foil

For precision work, a great deal of effort must be expended during track counting to insure the elimination of any personnel bias which might exist. One assumption applied in this type of counting is the existence of a Poisson distribution describing the counts. The assumption was experimentally checked with data obtained from a series of measurements of one of the foils. For this measurement, the tracks were randomly scanned and counted over an area equal to one quarter of the microfiche reader screen. One hundred such random scans and countings were made producing a total of 3514 tracks, yielding a mean value of 35.14 tracks per scan. The frequency histrogram, representative of these data is shown on Figure III. The equivalent Poisson distribution is also shown on this figure and is

$$P_n = 500 \frac{m^n e^{-m}}{n!}$$

The normalization constant, 500, is obtained by multiplying five times the number of the data. The standard deviation can be obtained directly from the histogram and is about 7, and the value obtained for the standard deviation directly from the Poisson distribution is $(m)^{.5} = (35.14)^{.5} = 6$. Since these two values are so close we can conclude the Poisson distribution assumption employed in the present counting experiments is valid.

Neutron Energy Dependence

The first two neutron energy dependence studies by Becker and Piece were carried out using conventional etching methods. ..cker[4] has exposed Makrofol E. samples exposed to fission neutron from HF... at Oak Ridge National Laboratory and to monoenergetic 2.7 Mev, 4.5 Mev and 14 Mev fast neutron and estimated the numbers of tracks per neutron for a particular neutron energy. This energy dependence of detector sensitivity is about 1 MeV or more.

Piece[5] compared the neutron fluence values measured using Makrofol with those measured with a number of threshold detectors and stated that the neutron energy threshold for Makrofol recorders should lie between 0.75 Mev and 1.2 Mev, most probably around 1 Mev.

Griffith[6] used LLL cyclograph accelerator to produce monoenergetic neutron in the range 0.1 to 19 MeV to study the neutron response of the electrochemically etched polycarbonate sample. He concluded the threshold energy is greater than 1.5 Mev.

The neutron elastic collisions with atoms of polymers take place for neutrons of all energies. But not all recoil atoms can be registered. Carbon and oxygen recoils could form etchable tracks if their energy exceeds the limits of $2.6\sim 2.9 \times 10^{-2}$ MeV/A.M.U.[7] i.e. $0.32\sim 0.40$ MeV for carbon and $2.3\sim 2.5 \times 10^{-2}$ MeV/A.M.U. i.e. $0.37\sim 0.40$ MeV for oxygen. Maximum energy transfer in "head on" collision an[illegible] 0.222 for ne[illegible]-oxygen collision. Thus minimum neutron energy needed for carbon recoil registration in polycarbonate will be in the limits of $1.13\sim 1.23$ MeV, for oxygen recoil's $1.65\sim 1.80$ MeV.

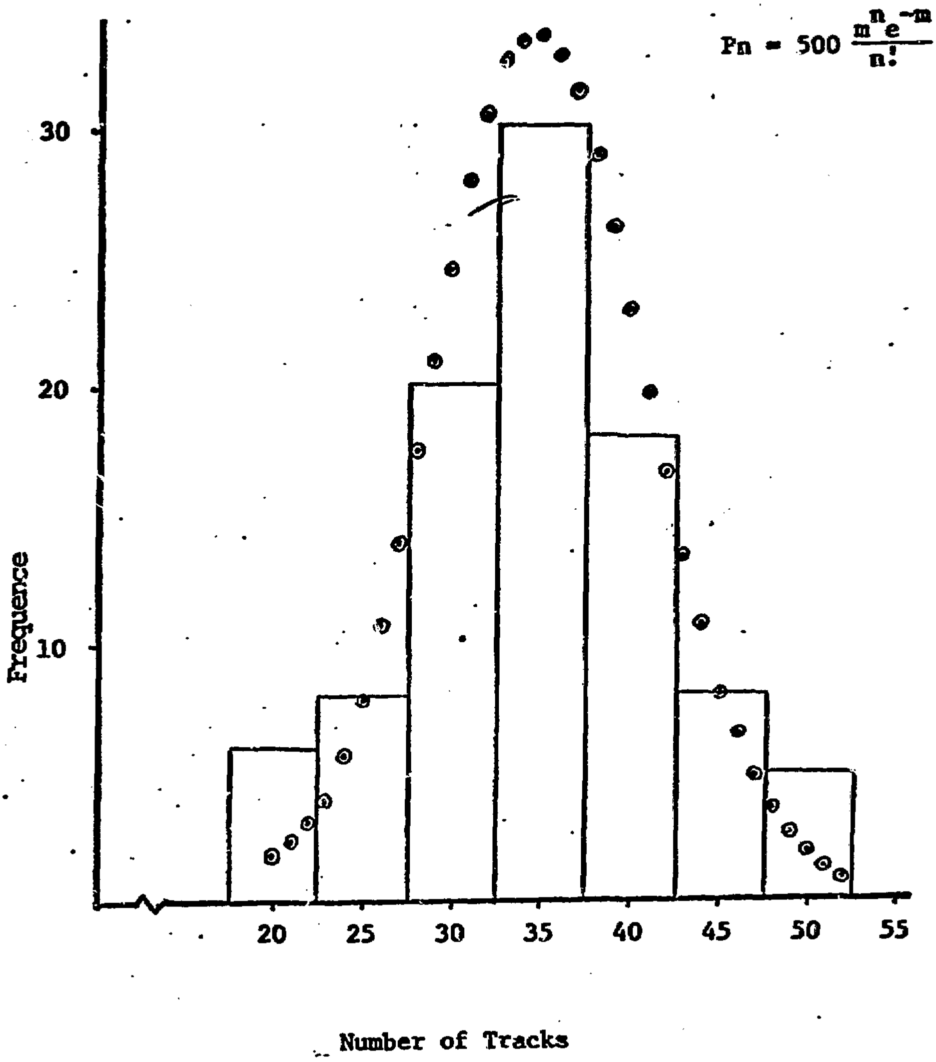

Figure III Comparison of the Frequency Histogram of Observed Number of Tracks Per View with the Poisson Distribution P_n Corresponding to the Observed Mean Value ($m = 35.14$)

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