THE NRPB CR-39 FAST NEUTRON PERSONAL DOSEMETER

D T Bartlett and J D Steele
National Radiological Protection Board
Chilton, Didcot, Oxon OX11 ORQ, UK

1. INTRODUCTION

The United Kingdom National Radiological Protection Board provides a postal neutron personal monitoring service. Until recently the service relied solely on the nuclear emulsion dosemeter[1], which is sensitive to thermal neutrons and fast neutrons above a threshold of about 500 keV. Although this energy threshold does not present a problem for the users of small neutron sources (used with relatively little or no shielding), when combined with the photon sensitivity of the emulsion, it can become restrictive on the use of the nuclear emulsion dosemeter in some applications. The operation of a nuclear emulsion dosemeter service also involves great care to prevent oxidation (fading) of the latent image and also tedious but highly skilled microscope scanning. For these reasons a dosemeter utilising the proton response of CR-39 plastic is being introduced.

CR-39 (Columbia Resin-39) is the commercial name for the thermoset plastic which is the polymeric form of diethylene glycol bis(allyl carbonate). It has widespread commercial use as it is extremely transparent and mechanically rigid. In 1978 its excellent nuclear track recording properties were discovered by Cartwright, Shirk and Price[2]. CR-39 will record particles with $z^2/\beta^2 > 36$, for example all natural alpha particles at full energy and protons up to 18 MeV[3]. Tracks are revealed by etching in alkaline solution (NaOH or KOH) followed by examination under an optical microscope using magnification of up to x1000. Tracks revealed by chemical etching may be enlarged by the technique of electrochemical etching developed by Tommasino in 1979[4] to the point where tracks are visible to the naked eye and may be conveniently counted at low magnification (x20 to x40).

2. THE NRPB DOSEMETER

2.1 Dosemeter Design and Detector Processing

The detector consists of a flat piece of CR-39 plastic approximately 25 mm x 40 mm and of thickness in the range 500 μm to 700 μm. The detector is supplied by the manufacturer, and issued, covered on both sides with a thin layer of opaque plastic. This reduces handling problems. Before issue the detectors are uniquely binary encoded by laser cut holes in an 8 x 4 location matrix. Detectors are stored in a dry nitrogen atmosphere and before issue are hermetically sealed inside polythene/aluminium laminate pouches. This reduces any oxidation effects and radon ingress. The pouch is numbered and is fitted inside a simple polypropylene holder with an open window through which this number is presented.

Only the back surface of the CR-39 detector is electrochemically etched. For this surface the detector itself is the proton radiator for all energies less than about 10 MeV. At greater energies some contribution to the response will be from protons produced in the polypropylene dosemeter holder and from (n,p) and (n,np) reactions in the aluminium of the pouch. Etching the back surface of the detector has the advantage that the response is, in general, uninfluenced by the detector covering or by any cleaning etches which may need to be introduced. Also, it has been reported that the electrochemical response is more consistent for the rear surface[5].

The processing of detectors consists of a chemical pre-etch of one hour, an electrochemical etch of sixteen hours and a post-etch of three hours (no applied

field). This regime has proved operationally convenient.

The current method of readout is to mount the detector in a photographic slide mount and back project the image onto a semi-opaque screen. The readout is being automated using a relatively inexpensive image analysis system. Areas of about 1 cm^2 are scored. The upper limit to dose equivalent which can be readily assessed is a few rem. For higher doses, it is necessary to examine, at high magnification, areas of the detector not electrochemically etched and score the chemically etched pits.

2.2 Dosemeter Performance

Batches of CR-39 plastic have been obtained from Pershore Mouldings Ltd (PM) and Bristol University (BU) with either di-isopropyl peroxydicarbonate (IPP) or di-cyclohexyl peroxydicarbonate (CHPC) initiator, and with di-octyl phthalate (DOP) plasticiser. The use of CHPC has advantages in that it is more convenient to store. Background levels and low energy response are dependent (inter alia) on the applied field strength. Background pit density increases with increasing field strength, low energy neutron response decreases with decreasing field strength. Adequate low neutron energy response with acceptably low backgrounds are obtained for field strengths between 20 and 25 kV cm^{-1}. The background levels and standard deviations shown in Table 1 are representative of those found for the fifteen batches of CR-39.

Table 1 Performance of Dosemeter

		Response (pits cm^{-2}) of dosemeter on phantom per unit depth dose equivalent at 10 mm, normalised to 1.5 at 0.57 MeV			
En (MeV)	Angle to normal (^{o})	BU Batch F 4½% IPP/0.2% DOP		BU Batch L 7% CHPC/0.2% DOP	
0.15	0	0.43	(0.21)	0.47	(0.06)
	45	0.2	(free air)		
0.57	0	1.5	(0.23)	1.5	(0.09)
	45	0.59	(0.14)	0.64	
	75	0.17	(0.05)	0.32	(0.04)
1.06	0	1.31	(0.08)	0.94	(0.11)
	45	0.55	(0.08)	0.56	(0.04)
	75	0.28	(0.04)		
5	0	0.50	(0.14)	0.47	(0.11)
	45	0.39	(0.10)	0.30	(0.08)
	75	0.23	(0.04)	0.22	(0.02)
14.7	0	0.53	(free air irradiation)		
Background (^{252}Cf equiv.) (pits cm^{-2} Sv^{-1} 10^5)		15	(8)	10	(5)

Table 1 shows results of investigations of the dependence of response of the dosemeter on neutron energy and angle. Irradiations were carried out at the National Physical Laboratory. For the phantom irradiations, dosemeters were

mounted on the front surface of a 20 cm x 30 cm elliptical cylindrical polyethylene water filled thorax phantom. The figures in parentheses give the standard deviations for the dosemeters irradiated. The uncertainties in the fluences were less than 5%. These fluences were converted to depth dose equivalent at 10 mm in the ICRU tissue equivalent sphere[6,7]. The dosemeter results are expressed as pits cm^{-2} per unit depth dose equivalent at 10 mm, normalised to a value of 1.5 for 0.57 MeV neutrons.

A series of free-air irradiations have been carried out to investigate batch variations in energy dependence of response. When normalised to the individual batch sensitivity to a ^{252}Cf spectrum, the mean values and standard deviations of the response per unit depth dose equivalent at 10 mm for seven batches of BU and PM plastic were as follows: 0.15 MeV : 0.37 (0.12); 0.57 MeV 1.6 (0.3); 1.06 MeV : 1.2 (0.3); 2.5 MeV : 0.95 (0.18); 5 MeV : 0.52 (0.11). Extensive investigation of the angular dependence of response per unit incident planar neutron fluence of different batches for monoenergetic neutrons has been carried out. These show general agreement with the results shown in Table 1 for phantom irradiations and are consistent with a series of ^{252}Cf irradiations at different angles. For a ^{252}Cf energy spectrum, the response is approximately independent (within $\pm$20%) of the planar fluence for angles to the normal up to 75^{o}.

Table 2 Calculated Response of Dosemeter to Some Representative Neutron Spectra

Neutron Spectrum	Calculated response (pits cm^{-2}) per unit dose equivalent at 10 mm in ICRU sphere relative to uncollided fission spectrum	
	BU Batch L 7% CHPC/0.2% DOP On phantom	PM Batch R 1.6% IPP/0.2% DOP Free air
Uncollided fission	1	1
Fission neutrons thro' 10 cm D_2O	0.93	0.9
Fission neutrons thro' 40 cm concrete	0.96	0.96
Fission neutrons thro' 10 cm iron	1.2	0.98
Fission neutrons reflected 20 cm concrete	1.1	1
Spectrum A	0.76	0.68
Spectrum B	0.81	0.66

Responses have been calculated for several appropriate neutron energy spectra[8], and two measured spectra A and B (Table 2). These latter spectra are 'soft' spectra (~40% of dose equivalent below 100 keV) measured in a nuclear facility. The responses of the NRPB CR-39 fast neutron dosemeter measured in these spectra are in good agreement with the calculated responses and indicated field angular distributions.

3. FUTURE DEVELOPMENTS

Development is continuing to improve both the plastic quality and processing techniques. It is expected that CR-39 of lower intrinsic background and better uniformity will become available which, when combined with modifications in processing will result in dosemeters of higher sensitivity, lower detection limit and lower neutron energy threshold. To extend the range of the dosemeter, the inclusion of an additional CR-39 detection element is being considered. When combined with a suitable n/α converter, this will enable the estimation of the dose equivalent contribution in the range of neutron energies from thermal to about 20 or 30 keV[9].

Acknowledgements

The authors wish to acknowledge helpful discussions and exchange of data with the UK Track Etch Group, viz: J R Harvey and A R Weeks (CEGB), K G Harrison and R M Haigh (Harwell), R Proud (BNFL), D L Henshaw and T W Turner (Bristol University), A G Ramli (Birmingham University) and J C H Miles (NRPB).

References

1. Bartlett, D T, Bird, T V and Miles, J C H (1980). The NRPB Nuclear Emulsion Dosemeter, NRPB Report R-99 (HMSO, London).

2. Cartwright, B G, Shirk, E G and Price, P B (1978). A Nuclear Track-Recording Polymer of Unique Sensitivity and Resolution. Nucl. Instrum. Meth. 153, pp. 457-460.

3. Henshaw, D L (1982). Applications of Cr-39 Nuclear Track Detector in Medicine and Technology. Phys. Technol. 13, pp. 266-280.

4. Tommasino, L. (1970). Electrochemical Etching of Damaged Track Detectors by H V Pulse and Sinusoidal Waveforms. CNEN Report RT/PROT.

5. Harrison, K G and Haigh, R M (1982). Personal communication.

6. Chen, S Y and Chilton, A B (1979). Calculation of Fast Neutron Depth-Dose in the ICRU Standard Tissue Phantom and the Derivation of Neutron Fluence to Dose Index Conversion Factors. Rad. Res. 78, pp. 335-370.

7. Chilton, A B and Shiue, Y L (1981). Progress Report on Studies Concerning Doses in the ICRU Sphere Resulting from Neutron Beams. In: Proc. 4th Symp. on Neutron Dosimetry, Munich-Neuherberg, June, pp. 79-79, EUR 7448 EN.

8. Ing, H and Makra, S (1978). Compendium of Neutron Spectra in Criticality Accident Dosimetry. IAEA Tech. Report, 180. (IAEA, Vienna).

9. Bartlett, D T (1983). Measurement of Neutron Dose Equivalent from Thermal Energies up to 10 keV. Health Phys. 45, (1), p. 181.