PLASTIC TRACK DETECTORS FOR HIGH GAMMA DOSE MEASUREMENTS

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SUMMARY: This paper describes (a) the calibration of Makrofol-N, LR-115, CR-39, Marofol-E, Daicel, CA80-15, and CN-85 plastic track detectors in the dose range of 10^3-10^6 Gy, and (b) applications of these detectors for high gamma dose measurement. These calibrations are based upon the changes produced in (a) the general etching velocity 'V_g' and (b) the average width of the etch pits due to fission fragments after modification by the absorbed gamma dose. The present results show that CN-85 is the most sensitive plastic track detector for gamma dose determination in the above mentioned dose range. The detectors so calibrated have been applied for the estimation of gamma doses near a spent fuel element.

Key Words : High gamma dosimetry, plastic track detectors, general etching velocity.

INTRODUCTION

It is important to measure the absorbed gamma doses in (a) nuclear reactor structural materials (1) and (b) electronic components (2). Gamma measurements are also required during the gamma sterilization of different medical products and in food preservation (3). Such measurements are difficult to be made in situations such as in and around a reactor core, where besides the presence of high fluxes of neutrons, exist elevated temperatures (4,5).

Some efforts have already been made to develop solid state materials for the determination of high gamma doses (4-7). The limited experience gained from the use of solid state nuclear track detectors for high gamma dosimetry clearly confirmed that these detectors show a great promise for such an application. Particularly, the composition of plastic track detectors favors their use for in-core gamma dose measurements in water cooled and water moderated reactors (4-5), where the compositions of the detectors and of the surrounding environments are comparable. Another advantage of plastic track detectors is their use in the study of biological samples, where the equivalent compositions of the detecting and the surrounding materials produce an edge over other type of detectors in such applications. It may be mentioned at this juncture that the commonly available plastic track detectors have an added advantage of exposure conditions. They can be safely lowered into the water pool and can be held at definite positions with the help of simple tools.

We have observed that the physical properties such as the change in general etching velocity (V_g) of plastic track detectors and the dimensions (such as width) of etched tracks (produced before the gamma exposure) in these detectors, change with the gamma dose in a very systematic manner. Our previous work showed that these detectors can be usefully employed for high gamma dosimetry (4,5).

This paper described the calibration of some of the commonly available plastic track detectors for high gamma dose determination. The application of these detectors for dosimetric measurements can be easily carried out using simple instrumentation and the analysis can be performed off-line in a remote laboratory.

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Table 1: Some mathematical expressions for finding the gamma dose by using the method based upon etched track with variation.

Detector	Dose Range (MRads)	Etching Time (min)	Gamma Dose D (MRads)	Range of Applicability
CA80-15	1.0 -78.7	5	61.05 (In W_D/W_O - 0.062)	$1.082 \leq W_D/W_O \leq 3.86$
	5.75 - 94.6	15	69.3 (In W_D/W_O + 0.0153)	$1.07 \leq W_D/W_O \leq 3.86$
Makrofol-N	44.08 - 174.76	120	340 (In W_D/W_O - 0.044)	$1.92 \leq W_D/W_O \leq 1.6$
	8.01 - 148.2	120	187.3 (In W_D/W_O - 0.006)	$1.05 \leq W_D/W_O \leq 2.22$

EXPERIMENTAL DETAILS

Calibration of the Plastic Track Detectors

A ^{60}Co-gamma source having a strength of about 15.000 Ci was used by us for the calibration of a variety of plastic track detectors. A Fricke dosimeter (8) was employed to find out the dose rate at the position of the exposures. The dose rate was found to be about 1 Mrad/h. All the doses were measured in terms of the absorbed dose in a unit density material (water). The detectors employed in the present studies were Makrofol-N (9), LR-115 (10), CR-39 (11), Makrofol-E (9), Daicel (12), CA80-15 (10), and CN-85 (10).

At first, the general etching velocities of the seven track detectors employed in the present work were obtained without any exposures to gamma rays. Afterwards, the same detectors were exposed to Cobalt-60 gamma rays in the dose range of 10^3-10^6 Grays. The general etching velocity measurements were again carried out and the ratios of the general etching velocities after and before gamma exposures ($V_{g,D} / V_{g,O}$) were obtained. It was observed that in general the etching velocities were found to increase with increasing gamma dose. It was also observed that such increases strongly depend on the type of the plastic track detectors so employed.

In order to use the amount of the modification produced in a damage trail due to the absorbed gamma dose, fission fragment latent damage trails were produced before the exposure to gamma rays. In one of the experiments the modification in the latent damage trails of ^{208}Pb-ions having an energy of 7.1 MeV/nucleon (incident normally upon the detectors) was also studied and compared with the change in the width of the etched tracks due to fission fragments (incident in 2π- geometry). For etching, we used 10.7 NNaOH, maintained at $50 \pm 1°C$.

The possible causes of the variations (if any) in the calibration curves, obtained by exposing the detectors to gamma rays from a ^{60}Co-source were, wetness, temperature, etc. The effect has already been reported by us (13). The exposure conditions in these experiments were such that only one of the calibration curves depending upon the change in the width of etch pits in the plastic track detectors required a correction by a factor of 1.14 in the ultimately obtained value of the dose. It was found to be because of the wet exposure conditions in the spent fuel elements lying in a water bay (13).

High gamma dose measurements

In one set of the experiment, individual fuel elements were 'isolated' from the main containment in the stacks. The detectors were then lowered at various fixed positions and were analyzed by using the already obtained calibration curves. For every experiment with the spent fuel elements, the detectors were first checked for any possible contamination.

In another set of the experiment, the detectors were

Table 2: Some mathematical expressions for measuring gamma doses using relative transmission method.

Detector	Dose Range (MRads)	Gamma Dose D (MRad)	RT Limits
Lexan *(1400)	0.62 - 25.4	11.5 In (105.5 / RT)	$10.7 > RT \geq 100$
	25.4 - 50.3	45.6 In (18.7 / RT)	$6.2 \geq RT \geq 10.7$
CA80-15 *(320)	0.1 - 8.0	26.1 In (99.7 / RT)	$73.4 \leq RT \leq 99.3$
	8.0 - 50.00	66.8 In (82.7 / RT)	$39.1 \leq RT \leq 73.4$

RT : Relative Transmittance (%), * : Wavelength Employed

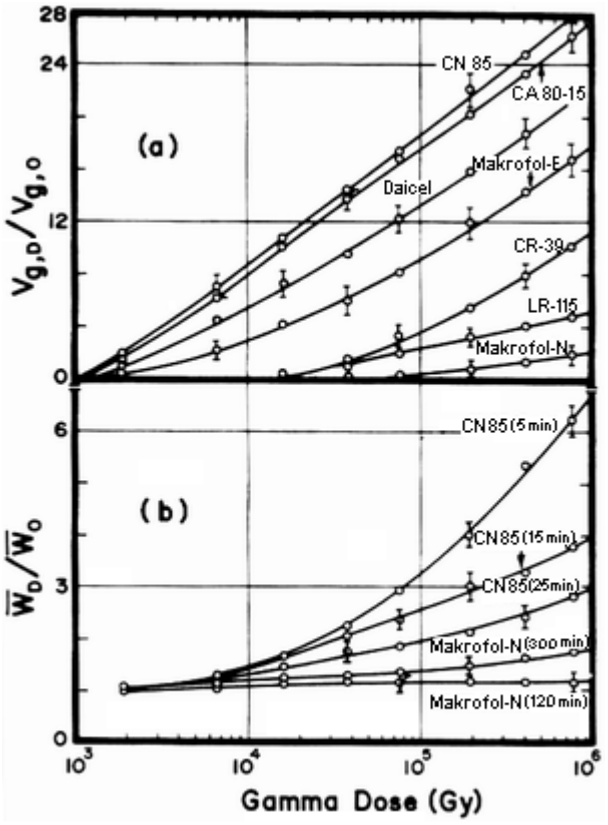

Figure 1: Calibration curves showing the variation of (a) $V_{g,D}/V_{g,O}$ and (b) W_D, and W_O, as a function of the gamma dose (Gy) - see text for details.

lowered through stringers, close to a stack containing a number of fuel elements. They were analyzed afterwards and the results obtained were converted into gamma dose rate. It was assumed that during these measurements the dose rate remained constant throughout the exposure time.

RESULTS AND DISCUSSION

Figure 1 shows the calibration results for the (already mentioned) seven plastic track detectors. The variation of $V_{g,D} / V_{g,O}$ (the ratio of the general etching velocity of the detectors obtained after exposure to gamma dose 'D' to the general etching velocity of the 'reference detector' as a function of the 'gamma dose' is given in Figure 1a. The dose was varied in the range of 10^3 to 10^6 Gy (10^1 to 10^2 Mrad). The results indicate that for almost all the detectors studied here, the variation of V_g-ratio as a function of the gamma dose is nearly (not exactly) linear. The 'Makrofol-N' detector did not show any increase in the V_g-ratio for

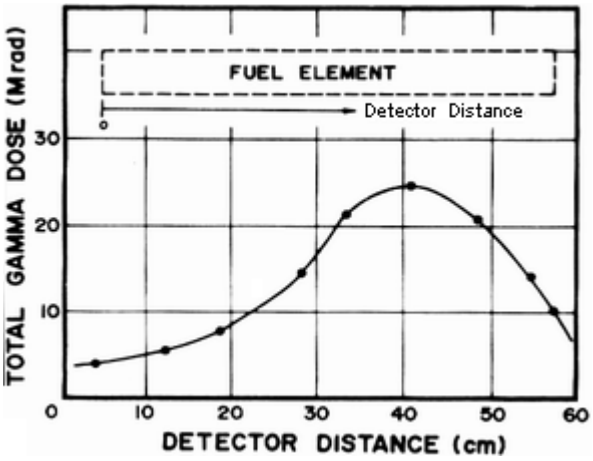

Figure 2: Gamma dose distribution along the length of a spent fuel element taken out of Pakistan Research Reactor (PARR), a 5 MW swimming pool type research reactor.

doses less than about 8×10^4 Gy. The maximum increase in the V_g-ratio observed for CN-85, cellulose nitrate track detector. The results for CA80-15 are fairly close to those obtained for CN-85. An increase in V_g-ratio is a useful parameter for the measurement of high gamma doses in the range of 10^3-10^6 Gy.

Another parameter used for high gamma dose measurement was the change in the dimensions of the damage trails due to a charged particle such as a fission fragment. The variation of the etched track average width ratio, W_D/W_O (the ratio of the average widths of the fission fragments damage trails obtained in a detector exposed to the gamma dose 'D' to that in a reference detector) as function of the gamma dose in the range of 10^3-10^6 Gy was studied for a CN-85 cellulose nitrate track detector and a Makrofol-N polycarbonate track detector. The measurements were made for different etching times. The results are shown in Figure 1b. It is interesting to note that a high slope is observed when the CN-85 track detector is etched for five minutes in 10.7N NaOH (kept at 50±1°C) as compared to the value obtained for the same detector etched for time intervals longer than five minutes. However, the trend is reversed for the Makrofol-N polycarbonate track detector which shows that better results are obtained when the etching is carried out for time intervals longer than 120 minutes. The results of Figure 1b were used to derive some simple mathematical expressions. Table 1 summarizes these expressions.

Both Figures 1a and 1b indicate that the changes produced in (a) the general etching velocity ratio, and (b) the etched track average with ratio are useful parameters for the measurement of high gamma doses in the dose range of 10^3-10^6 Gy.

A third parameter used by us for the measurement of high gamma doses was the Relative Transmission, RT (the ratio of the optical transmission of an exposed detector to that of an unexposed detector). It was observed that the Relative Transmission (RT) decreases as a function of the increasing gamma dose. The Relative Transmission besides depending upon the gamma dose and the type of the detector, is also a strong function of the wavelength employed. We have studied the RT-variation as a function of gamma dose for Lexan and CA80-15 plastic track detectors using two different wavelengths. The result have been summarized in Table 2.

A typical curve of the measurements, carried out with an isolated fuel element of a reactor is shown in Figure 2. The positions of the SSNTD (relative to the fuel element are also shown in the Figure). We have found a gradual rise in the gamma dose in this region. The most important factor for this increase in gamma dose is the neutron flux pattern to which the fuel element was subjected during its last (and the most effective) exposure. The storage history of the fuel element is also responsible for the existing gamma dose levels and the dose patterns.

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