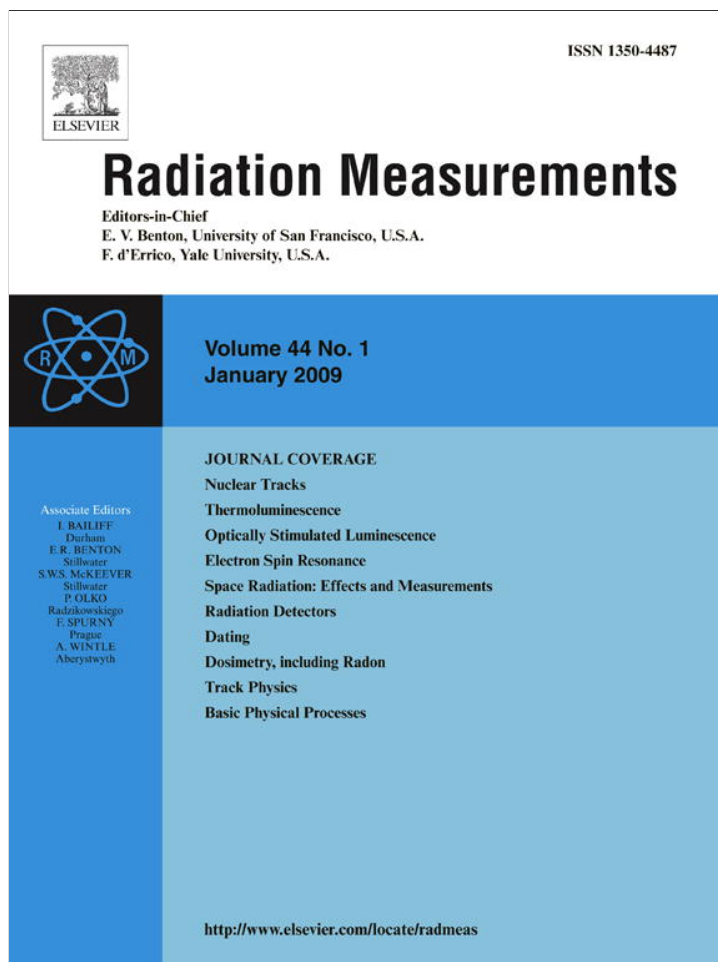


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## Radiation Measurements

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## First report on preparation of poly (nitro-carbonate) thermoset polymers for nuclear track detection

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## ABSTRACT

In an attempt to study the effect of various radiation sensitive groups in the polymer matrix and their relation to the sensitivity towards charged particles, we have designed two new monomers Allyl bis-(2-nitroxy-ethyl) carbamate (ABNEC) and prepared its copolymer with ADC. Since, the ABNEC monomer was not thermally much stable, we designed another novel monomer containing (–CNO<sub>2</sub>) group, called tris-(2,4-dioxa-3-oxohept-6-en-1-yl)nitromethane (TDONM) and prepared its homopolymer as well as copolymer with ADC. These are thermoset poly(nitro-carbonate) materials and are being reported as track detectors for the first time. The kinetics of polymerization for these monomers was studied. Due to thermal instability of ABNEC and TDONM monomers, special care is required during their polymerization. The preliminary studies carried out show that, the copolymers ABNEC-ADC and TDONM-ADC are almost comparable to PADC track detectors. A brief description of the study of some of the etching conditions, the effect of initiator concentration on the alpha sensitivity of the materials and also track detection efficiency studies in comparison with commercially available PADC (Pershore Moldings, UK) are reported.

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### 1. Introduction

Since the advent of Solid state nuclear track detection (SSNTD) technique (Young, 1958) a number of polymers have been used to detect charged particles. The most commonly used plastic materials as nuclear track detectors are the cellulose nitrate (LR-115)<sup>TM</sup>, poly allyl diglycol carbonate (PADC) (CR-39)<sup>TM</sup> and Bisphenol A polycarbonate (Lexan)<sup>TM</sup>. Poly allyl diglycol carbonate (PADC) polycarbonate (Cartwright et al., 1978) replaced most of the plastics due to its very high sensitivity to many charged particles, and superior optical properties. The relation between sensitivity of a particular material to charged particles and its structural features has always remained a matter of interest for SSNTD workers, though a few attempts in this direction are known (Fujii and Yokota, 1988; Fujii et al., 1990).

We have been working on the preparation of plastic materials as SSNTDs, since 1996 (Nadkarni and Samant, 1996). We have reported our preliminary efforts towards casting of homo and copolymers films from novel monomers (Nadkarni et al., 2003a, b) *N*-allyloxycarbonyl diethanolamine-bis(allyl carbonate) NADAC monomer along with allyl diglycol carbonate (ADC) monomer. In

continuation of our efforts to prepare more sensitive materials and to study the effect of various functional groups on the sensitivity of the films we synthesized two novel monomers. Since cellulose nitrate (LR-115)<sup>TM</sup> films containing the nitrate ester groups are found to have a good sensitivity towards alpha particles, the idea was to prepare thermoset materials by introducing nitrate ester (–ONO<sub>2</sub>) and nitro groups (–NO<sub>2</sub>) in the polymer (polycarbonate) matrix, and to study the effects of these groups on the sensitivity of the materials.

The first monomer, Allyl bis-(2-nitroxy-ethyl) carbamate (ABNEC) could not give its homopolymer and hence was copolymerized with ADC. This polymerization too, had some difficulties due to poor thermal stability of ABNEC under polymerization conditions (Nadkarni et al., 2004). As the thermal instability was considered due to ester (–ONO<sub>2</sub>) groups (similar to thermal instability of nitrocellulose), we thought of synthesizing a new monomer containing (–C–NO<sub>2</sub>) and compare its polymerization process and track detection characteristics with polymers derived from ABNEC. Tris-(2,4-dioxa-3-oxohept-6-en-1-yl)nitromethane (TDONM) was thus synthesized for this purpose.

In this paper, we present some preliminary results about the track detection properties of these novel homo and copolymers obtained from the aforesaid monomers. A brief description of the study of some of the etching conditions, the effect of initiator concentration on the sensitivity of the materials and also track

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detection efficiency studies in comparison with commercially available PADC (Persore Moldings, UK) are reported.

## 2. Materials and methods

Indigenously prepared ABNEC and TDONM monomers, iso propyl peroxydicarbonate (IPP) initiator were used for the preparation of homopolymer called poly-[tris-(2, 4-dioxa-3-oxohept-6-en-1-yl) nitromethane] i.e. PTDONM and copolymers of, ABNEC-ADC and TDONM-ADC. PADC films from Persore Molding (UK) of thickness 250  $\mu\text{m}$  and our indigenously prepared NADAC-ADC copolymer of thickness 500  $\mu\text{m}$  were used for comparative studies. Dioctyl Phthalate (DOP) plasticizer manufactured by S D Fine Chemicals, India was used as such. Glass plates (Schott, Germany), thin Teflon<sup>TM</sup> sheets, aluminium plates were used for assembling the polymerization moulds. The various steps involved in the synthesis and polymerization of the monomers are briefly described below. IPP was prepared in our laboratory and polymerization was carried out using a polymerization bath controlled using microprocessor based electronic temperature controller F25 HP, from Julabo, Germany.

### 2.1. Synthesis of monomers

#### 2.1.1. Synthesis of ABNEC monomer

The monomer was synthesized in a two step process. Diethanolamine was treated with allyl chloroformate wherein Allyl bis-(2-hydroxyethyl) carbamate was obtained which was followed by its nitration to give ABNEC monomer in 80% yield. The reaction was carried out at low temperature 0–5 °C and time duration of 0.5–2 h. The reactions are illustrated in Scheme 1.

#### 2.1.2. Synthesis of TDONM monomer

This monomer was synthesized by a two step process. Tris hydroxy methyl nitromethane was first prepared by formylation of nitromethane and was then treated with allyl chloroformate to yield TDONM (Scheme 2).

### 2.2. Preparation of mold

A square shaped gasket of Teflon of outer length 100 mm, with an inner window of length 80 mm, and thickness of 500  $\pm$  10  $\mu\text{m}$  was specially prepared for this purpose (Nadkarni et al., 2003a). It was sandwiched between two clean Schott brand optical glass plates of size 100 mm (l)  $\times$  100 mm (b).

### 2.3. Preparation of SSNTD films by cast polymerization

ABNEC and TDONM monomers were filtered carefully to remove any solid impurities. The monomers were stirred under nitrogen atmosphere to remove any dissolved air and oxygen, which hinder the process of polymerization. The mixture containing the

monomer, initiator and plasticizer was carefully injected into the mold using a syringe, through a previously prepared tiny hole in the Teflon gasket. Special care was taken to avoid any air bubbles in the liquid monomer film during the injection in the mold. The mold was then sandwiched between two flat aluminium plates of uniform thickness and pressurized using wing-nut bolts fitted at the four corners of aluminium plates. The entire assembly was then kept in the polymerization bath and heated as per predetermined temperature–time intervals which in turn, obtained after a careful polymerization kinetics study of TDONM and ABNEC monomer/mixture of monomers. The polymerization temperature–time profile used for the polymerization is shown in Figs. 1. The mold was then allowed to cool slowly for another 12 h and then opened. A clear transparent and yellowish film of 500  $\pm$  10  $\mu\text{m}$  was obtained in this way.

### 2.4. Studies of etching conditions

Small pieces of size 10  $\times$  10 mm<sup>2</sup> of homo and copolymer films prepared using 3.0% IPP initiator were used in the etching study. They were suspended vertically in an etching bath containing aqueous NaOH and the temperature was maintained using a constant temperature circulating water bath. The etching studies were carried out using varying concentration of NaOH and at three different sets of temperature.

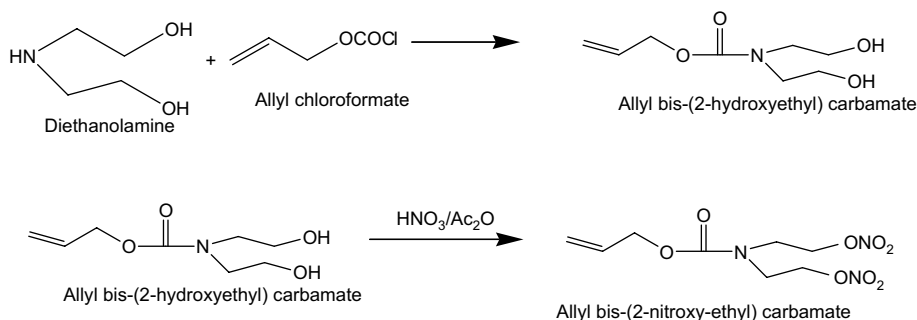
### 2.5. Determination of sensitivity of the films

The sample pieces of the homo and copolymer films were exposed to normally incident alpha particles and fission fragments from a <sup>252</sup>Cf in vacuum ( $\sim$ 0.1 Torr) at a distance of 50 mm from the source and etched in 6 N and 4 N NaOH at 60 and 70 °C. The etch pit diameters were determined using an optical microscope (Carl Zeiss) at magnification of 40 $\times$ . For the thickness measurement alpha meter (Para Electronics) with a least count of 1  $\mu\text{m}$  was used. All the weight measurements were carried out using a digital single pan balance (Sartorius) having least count of 10<sup>-4</sup> g.

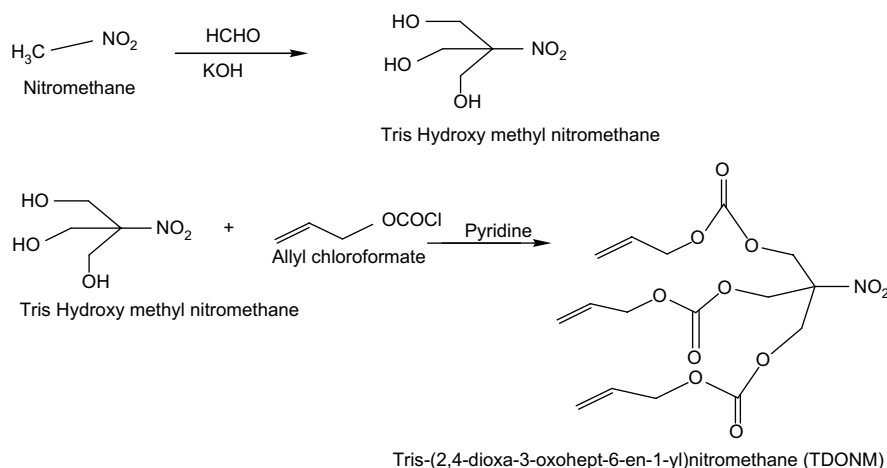
## 3. Results and discussion

### 3.1. Preparation of the polymer

We have previously demonstrated that the kinetic model for polymerization of ADC monomer could be extended to other allylic monomers (Nadkarni et al., 2003a, b). We thus applied the same concept to our newly synthesized monomers. Thus, kinetic study was undertaken to find a suitable heating profile for the polymerization. It was found that polymer becomes colored if the heating is continued beyond 65 °C for both ABNEC as well as TDONM. Hence, a heating profile as shown in Fig. 1 above was chosen for the polymerization. Thus, thermal instability appears to be



Scheme 1. Synthesis of ABNEC monomer.



Scheme 2. Synthesis of TDONM monomer.

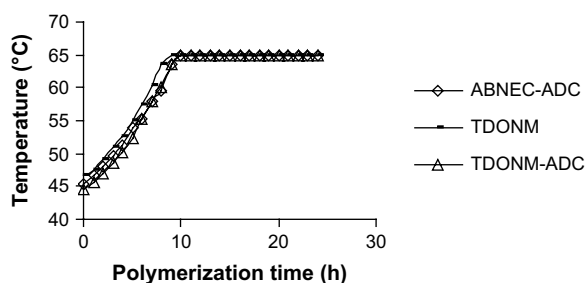


Fig. 1. Calculated constant rate polymerization cycle for homo and copolymerization.

a permanent problem associated with the  $-\text{NO}_2$  groups. The nitro group is also known to react with the free radicals. Further details of the thermal degradation process involved are being investigated using thermal analysis.

The monomers required for the preparation of homo and copolymers were first stirred under nitrogen for several hours to remove any dissolved air or oxygen. The IPP initiator was then added to the monomer, and the mixture was then transferred into the polymerization mold with the help of a syringe. The mold was then placed in a polymerization bath, and the polymerization was carried out using the heating time cycle and by periodic tightening the moulds. This is required since the allylic polymerization is an exothermic process accompanied by shrinkage in monomer volume, during the process of solid polymer formation (Dial and Gould, 1945; Dial et al., 1955). Using the constant rate polymerization cycle, homopolymer films of TDONM were prepared. The ABNEC monomer failed to give a hard/solid polymer film even after using an initiator concentration up to 15% and extended polymerization time. Copolymer films of ABNEC-ADC and TDONM-ADC were prepared having varying composition of 10:90–50:50 by weight of the monomers. The different type of polymers prepared and their composition is given in Table 1. As the monomers ABNEC and TDONM have been found to be unstable above  $70^\circ\text{C}$  under the polymerizing conditions, hence the polymerization of both the monomers was carried out at a constant temperature of  $65^\circ\text{C}$  for 12 h after the initial 12 h gradual heating profile was over.

### 3.2. Testing of homo and copolymer films for charged particle detection

Since the newly developed materials should have a 3-D cross-linked network (Stejny, 1987) similar to PADC plastic material, it

was decided to employ the etching conditions of PADC i.e. 6 N NaOH or KOH at  $70^\circ\text{C}$  to see whether the material would reveal alpha particle and fission fragment tracks as expected, and also to get an idea about track development time in comparison to PADC track detector (PM 250) and indigenously prepared NADAC-ADC copolymer plastic track detectors.

On etching the films under the above-mentioned conditions, the homo and copolymer films were found to develop fission fragment tracks, but only four polymer materials were found to develop the alpha tracks viz. PTDONM, TDONM-ADC (X and XI) and ABNEC-ADC (VI). The ABNEC-ADC films in all weight proportions had almost the same bulk etch rates as that of PADC films. The PTDONM (I) and TDONM-ADC copolymers (VII–XI) showed much higher bulk etch rates compared to that of ADC, and also showed signs of opacity. Hence, we decided to etch these films at lesser temperatures and with more dilute NaOH etchants. The PTDONM (I) and TDONM-ADC copolymers (VII–XI) also appeared hazy in nature after etching. The fission fragments in all the films were visible after 20–30 min of etching time in 6 N NaOH at  $70^\circ\text{C}$ . The alpha particle autoradiograph could be obtained only in the copolymer films whereas the PTDONM could reveal only low energy alpha particles similar to nitrocellulose detectors. Under these etching conditions, bulk etch rates ( $V_b$ ) values for the homo and copolymers were found and are given in Table 2. Most of the ABNEC-ADC copolymers were soft and relatively flexible (unlike PADC) and in the case of ABNEC-ADC copolymers (II–IV) track detectors it was observed that the developed tracks disappeared after 15–20 min on removal from the etching bath. On continuation of the etching further (for 15–20 min) the same tracks could be observed again. This appears to be due to relaxation/rubber like behavior of this polymer matrix after removal from etching bath. However, it was observed that the bulk etch rates and track development times for the ABNEC-ADC copolymers (II–VI) are comparable to that of the PADC track detector; hence the same etching conditions i.e. 6 N NaOH,  $70^\circ\text{C}$ , were used for these films.

### 3.3. Study of the etching conditions

It is known that the conditions under which plastic detectors are etched profoundly affect the response of the plastic to the charged particles. Though there are several etchants reported in the case of plastic SSNTDs, NaOH and KOH are the most commonly used. Since NaOH and KOH do not show any significant difference in their etching behavior, (Charvat and Spurny, 1988) NaOH was decided to be used for all the etching studies. Generally, the change in

**Table 1**  
Different polymeric materials prepared from the monomers ABNEC, TDONM and ADC.

Sr. No.	Polymer	Percentage composition (w/w)
1	PTDONM	100 (I)
2	ABNEC-ADC	50:50 (II)
		40:60 (III)
		30:70 (IV)
		20:80 (V)
		10:90 (VI)
3	TDONM-ADC	50:50 (VII)
		40:60 (VIII)
		30:70 (IX)
		20:80 (X)
		10:90 (XI)

**Table 2**  
Bulk etch rates of PTDONM, PM PADC, TDONM-ADC and ABNEC-ADC films with 6 N NaOH 70 °C.

Sr. No.	Polymer	$V_b$ ( $\mu\text{m}/\text{h}$ )
1	ABNEC-ADC	1.90
	a) 50:50 (II)	1.85
	b) 40:60 (III)	1.80
	c) 30:70 (IV)	1.65
	d) 20:80 (V)	1.60
	e) 10:90 (VI)	3.52
2	PTDONM	3.52
3	TDONM-ADC	3.15
	a) 50:50 (VII)	3.10
	b) 40:60 (VIII)	2.90
	c) 30:70 (IX)	2.80
	d) 20:80 (X)	2.80
	e) 10:90 (XI)	1.80
4	PM PADC	1.80
5	NADAC-ADC	1.68

thickness and the change in weight method are used for the determination of  $V_b$ . The change in thickness method involves the measurement of thickness at regular intervals of etching, whereas the change in weight method involves decrease in weight of the films upon etching. In order to use the thickness method the films should be of uniform thickness throughout. The films were studied for their initial thickness. It was observed that the homo and copolymer films had somewhat higher variation in the film thickness as shown in Table 3.

Taking into account the fact that, the change in thickness of the films upon etching was less than the standard deviation observed in the initial thickness of the films, it was decided to use the change in weight method instead of the change in thickness method for the evaluation of the bulk etch rate (Sharma et al., 1991). Eq. (1) given below was used for the  $V_b$  measurements.

$$V_b = (M_1 - M_2) \times t_i / 2M_1 \times t \quad (1)$$

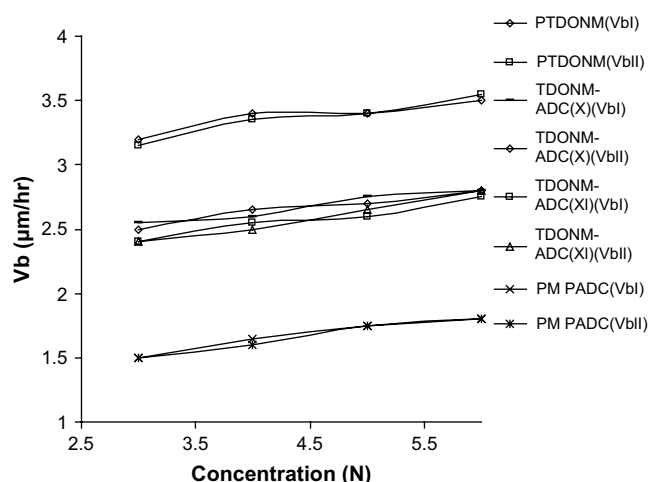
where  $M_1$  and  $M_2$  are the initial and final weights of the films,  $t$  is the etching time and  $t_i$  is the initial thickness.

### 3.4. Optimization of etching conditions for PTDONM and TDONM-ADC plastic track detectors

Three pieces each, of size  $10 \times 10 \text{ mm}^2$  from each of the two batches of the homo and copolymer films were cut and exposed to  $^{239}\text{Pu}$  alpha particle source at a height of 20 mm from the source and etched along with PM PADC. The films were etched at three different sets of temperatures 70, 65, 60 °C for varying concentrations 5–8 N NaOH solutions and  $V_b$  was calculated. The results

**Table 3**  
Comparison of the variation in thickness of PTDONM, PM PADC, TDONM-ADC, NADAC-ADC and ABNEC-ADC films.

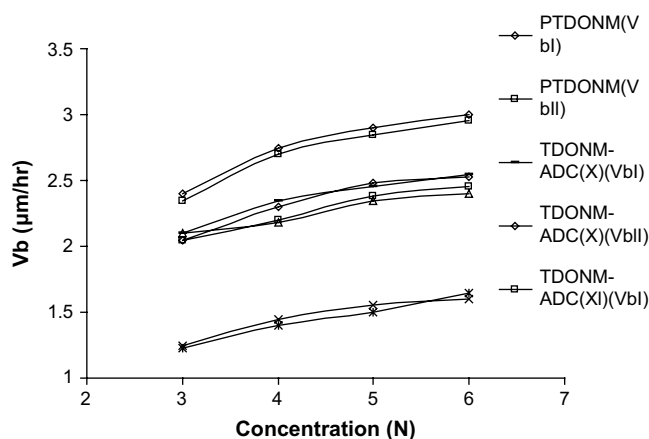
Polymer material	Average thickness ( $\mu\text{m}$ )	Standard deviation	% Variation
PTDONM (Batch I)	515.00	$\pm 5.25$	1.05
PTDONM (Batch II)	520.00	$\pm 5.45$	1.10
ABNEC-ADC (Batch I)	525.00	$\pm 5.50$	1.15
ABNEC-ADC (Batch II)	510.25	$\pm 5.15$	1.05
TDONM-ADC (Batch I)	507.50	$\pm 5.08$	1.15
TDONM-ADC (Batch II)	515.25	$\pm 5.15$	1.20
NADAC-ADC (Batch I)	549.00	$\pm 7.00$	1.27
NADAC-ADC (Batch II)	553.25	$\pm 6.38$	1.15
PM PADC	251.25	$\pm 2.29$	0.90



**Fig. 2.** Variation of the bulk etch rates of PTDONM, TDONM-ADC and PM PADC films with 3–6 N NaOH at 70 °C.

are shown in Figs. 2–4. The track revelation time for the alpha particles is also studied in comparison to PM PADC and is given in Table 4.

As can be observed from the data obtained, the copolymer films had higher bulk etch rates compared to that of PM PADC, but at higher temperature the films turned opaque, so moderate etching conditions were i.e. 4 N NaOH at 60 °C can be considered as the optimum etching conditions.



**Fig. 3.** Variation of the bulk etch rates of PTDONM, TDONM-ADC and PM PADC films with 3–6 N NaOH at 65 °C.



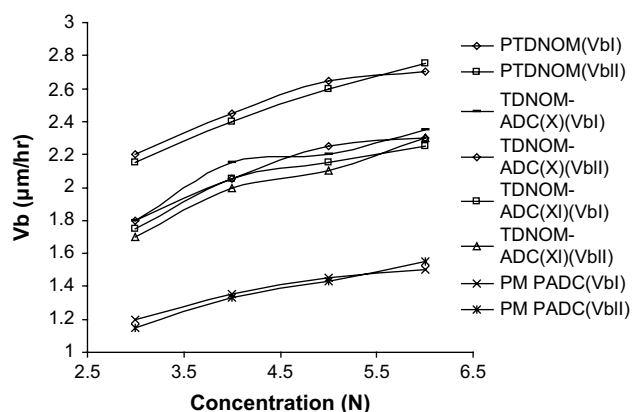


Fig. 4. Variation of the bulk etch rates of PTDONM, TDONM-ADC and PM PADC films with 3–6 N NaOH at 60 °C.

Table 4

Alpha track revelation time by chemical etching for varying concentration of etchant and temperature for PTDONM, PTDONM-ADC and PM PADC films. (Films exposed to <sup>239</sup>Pu source at a distance of 2 cm from the source for 2 min.)

Conc. of etchant (N)	Temp. (°C)	Track revelation time (h)		
		PTDONM		PM PADC
		(I)	(X) (XI)	
3	60	5.0	5.0	8.0
4		4.0	4.0	4.5
5		4.0	4.0	4.5
6	65	4.0	4.0	4.5
3		5.0	5.0	7.0
4		4.0	4.0	4.0
5	70	4.0	4.0	4.0
6		4.0	4.0	4.0
3		4.0	4.0	6.0
4		3.0	3.0	3.0
5		3.0	3.0	3.0
6		3.0	3.0	3.0

3.5. Determination of sensitivity of alpha particles in the copolymer films, and its dependence on the initiator concentration

The TDONM films were able to detect only low energy alpha particle (20 mm from the source) hence its alpha particle sensitivity studies according to method described (Durrani and Bull, 1987) was not possible. Among the copolymers, only three materials viz. ABNEC-ADC (VI) and TDONM-ADC (X and XI) were able to detect the alpha particles from a <sup>252</sup>Cf source, hence the studies pertaining to the sensitivity of alpha particles were restricted only to these films. The dependence of sensitivity on the initiator concentration was also studied by preparing films with different initiator concentration in the range 2–9%. The films were etched under the respective optimum conditions. Figs. 5–7 show the variation in average etch pit diameter of the fission fragments with respect to the etching time. It can be seen that the response of the detectors is linear with respect to the etching time for a given amount of the initiator concentration. It is well known in the case of PADC track detector, sensitivity is dependant on the etching time. Studies pertaining to variation of the sensitivity values with respect to the initiator concentration and the optimum etching time were also performed for additional two batches of the copolymer films; the results are shown in Figs. 9 and 10.

The sensitivity (S) and V<sub>b</sub> were calculated using Eqs. (2) and (3) (Durrani and Bull, 1987).

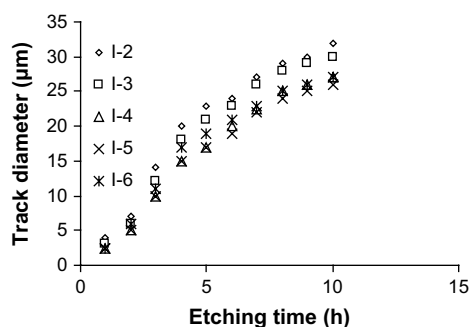


Fig. 5. Variation of the fission fragment track diameter in ABNEC-ADC (VI) copolymer films as a function of etching time using 6 N NaOH at 70 °C, I-2–I-6 indicate ABNEC-ADC (VI) films prepared using 2–6 % IPP initiator, respectively.

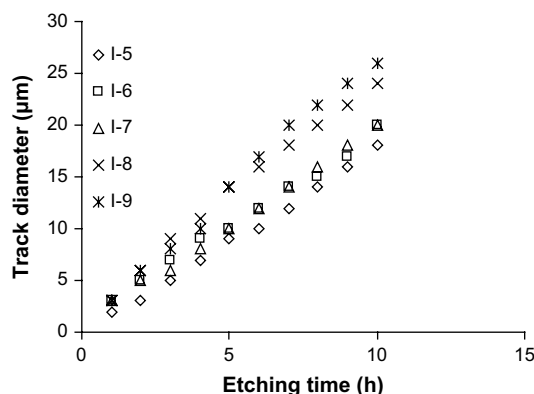


Fig. 6. Variation of the fission fragment track diameter in TDONM-ADC (X) copolymer films as a function of etching time using 4 N NaOH at 60 °C, I-5–I-9 indicate TDONM-ADC (X) films prepared using 5–9 % IPP initiator, respectively.

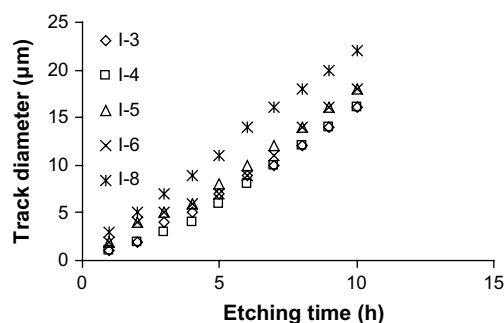


Fig. 7. Variation of the fission fragment track diameter in TDONM-ADC (XI) copolymer films as a function of etching time using 4 N NaOH at 60 °C, I-3–I-7 indicate TDONM-ADC (XI) films prepared using 3–7 % IPP initiator, respectively.

$$S = V_t/V_b = \left(1 + (D_a/D_f)^2\right) / 1 - (D_a/D_f)^2 \quad (2)$$

$$V_b = D_f/2t \quad (3)$$

where D<sub>a</sub> and D<sub>f</sub> are the track diameters of alpha particles and fission fragments, respectively and D<sub>f</sub>/t is the slope of the curve plotted in Figs. 5–7.

From the data given in Fig. 8, it appeared that the sensitivity was maximum at different initiator concentration viz. 4, 5 and 6% for ABNEC-ADC(VII), TDONM-ADC(X) and TDONM-ADC(XI) respectively. The PADC and NADAC-ADC films prepared showed maximum sensitivity using 3.0% initiator concentration which is in

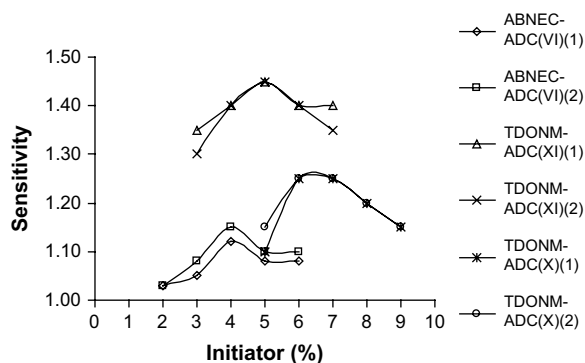


Fig. 8. Variation of sensitivity of ABNEC-ADC and TDONM-ADC copolymer films with the amount of initiator. 1 and 2 indicate two different batches.

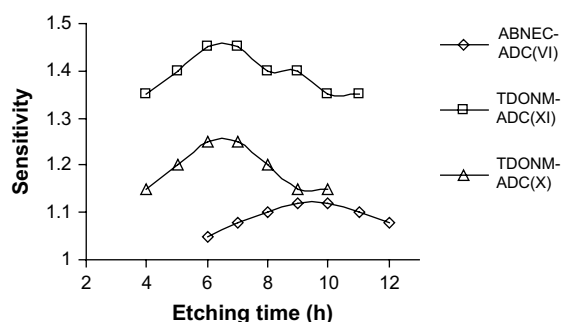


Fig. 9. Variation of sensitivity as a function of etching time at their respective optimum etching conditions.

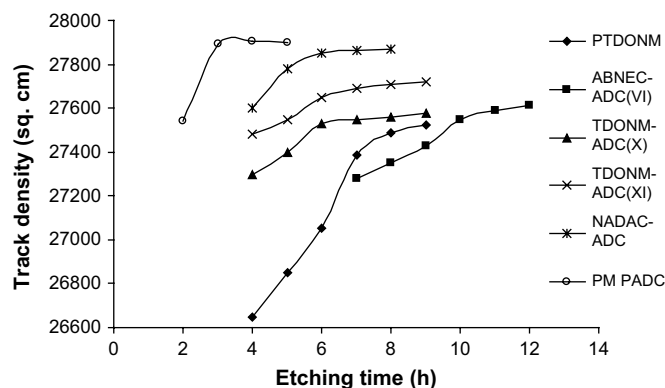


Fig. 10. Variation of  $\alpha$  track density with etching time.

agreement with studies carried out by Portwood and Stejny (1984) and Somogyi et al. (1986). In the present study, higher initiator concentration had to be used due to the presence of nitrate ester and nitro groups in the monomer, which are responsible for degradation of the initiator radicals. The sensitivity of ABNEC-ADC (VII), TDONM-ADC (X) and TDONM-ADC (XI) copolymer films prepared with optimum initiator concentration was found to be 1.12, 1.25 and 1.45 respectively as compared to 1.25 for PM PADC and 1.60 for NADAC-ADC track detectors. The sensitivities of the newly developed polymers are comparable to that of PM PADC track detector. It can also be seen from Fig. 9 that the optimum etching time in order to have a maximum sensitive value was 6 h for the TDONM-ADC copolymers and 10 h for ABNEC-ADC copolymers.

### 3.6. Alpha track detection efficiency

The alpha track detection efficiency under  $4\pi$  exposure conditions was studied. Hence it was necessary to study the variation of density of alpha tracks with respect to etching time, in order to find the optimum etching time that can be followed for the development of all the registered tracks by chemical etching. For this small pieces of films, of size  $20 \times 20 \text{ mm}^2$  were exposed to 703 703 dpm source strength  $^{239}\text{Pu}$  alpha particles at a distance of 20 mm from the source for 2 min. The pieces were then etched under the previously determined optimum etching conditions of homo and copolymer films. The tracks were counted till a constant value of tracks/cm<sup>2</sup> was obtained. The results were also compared with PM PADC and NADAC-ADC copolymer under its standard etching conditions. The results are shown in Fig. 10.

The background tracks were also found and were subtracted from the actual count of tracks. It was observed that the homo and copolymer films had high background track density compared with that of PM PADC. The values are given in Table 5. This may possibly be due trapping of dust particles during monomer preparation and filling of the moulds. Also the process of polymerization involves the decomposition of initiators to give gases like carbon dioxide or nitrogen oxides which may be trapped in the polymer matrix. The track detection efficiency of the homo and copolymers towards alpha particle tracks was determined by exposing the films at different distances from a source, but for a fixed optimum etching time as found in the previous experiment. The tracks were then counted using an optical microscope. A total of 100 views were counted and then averaged to find the track density. The results were compared to commercially available PM PADC and indigenously prepared NADAC-ADC track detectors under similar exposure conditions. The results are shown in Table 6. The track registration efficiency is given in Table 7. It can be seen that the track registration efficiency of homo and copolymer compare well with that of PM PADC and NADAC-ADC track detectors.

### 3.7. Measurement of alpha to fission branching ratios by sequential chemical etching of alpha and fission tracks in homo and copolymer films

The sequential etching method for revelation of alpha and fission tracks in PADC materials have been carried out by Pandey et al. (1993). This method of revelation of alpha particle and fission fragment tracks can be used for studies of half lives, alpha to fission branching ratios and identification of radionuclides, using a single detector. The alpha particles and fission fragment tracks can be differentiated unambiguously if there are significant differences in their size and appearance time in a given detector. The newly developed copolymer materials fully meet the requirements for the sequential etching conditions due to their considerable differences in the track diameters as well as appearance time. In order to find the alpha to fission ratio for  $^{252}\text{Cf}$  source the films were kept at 5 mm from the source in  $2\pi$  geometry for 5 min. The results are shown in Table 8.

Table 5  
Background tracks for different polymers.

Sr. No.	Track Detector	Background tracks (cm <sup>-2</sup> )
1	PTDONM	245
2	ABNEC-ADC (VI)	240
3	TDONM-ADC (X)	250
4	TDONM-ADC (XI)	250
5	NADAC-ADC	300
6	PM PADC	90

**Table 6**  
Tracks registered for the homo and copolymers.

Distance of exposure (cm)	Time (min)	Tracks expected (cm <sup>-2</sup> )	Tracks observed (cm <sup>-2</sup> )					
			PTDONM	ABNEC-ADC (1:9)	TDONM-ADC (2:8)	TDONM-ADC (1:9)	NADAC-ADC (1:1)	PADC
1	0.5	28 173	–	27 700	27 625	27 750	27 895	27 925
2	2.0	28 173	27 525	27 615	27 575	27 720	27 860	27 890
2.5	2.0	18 030	17 480	17 620	17 600	17 650	17 620	17 630

**Table 7**  
Comparison of alpha track registration efficiency.

Distance of exposure (cm)	Efficiency (%)						
	From the alpha source	PTDONM	ABNEC-ADC (1:9)	TDONM-ADC (2:8)	TDONM-ADC (1:9)	NADAC-ADC (1:1)	PADC
1	–	98.32	98.05	98.49	99.01	99.21	99.21
2	97.69	98.01	97.87	98.39	98.88	98.99	98.99
2.5	96.94	97.77	97.61	97.89	97.72	97.78	97.78

**Table 8**  
 $\alpha$ /F.F branching ratio of <sup>252</sup>Cf in ABNEC-ADC, TDONM-ADC < NADAC-ADC and PM PADC.

Detector	Fission tracks, per mm <sup>2</sup>	Alpha tracks, per mm <sup>2</sup>	$\alpha$ /F.F in 2 $\pi$ geometry	$\alpha$ /F.F in 4 $\pi$ geometry
ABNEC-ADC(VII)	1.44 × 10 <sup>4</sup>	21.84 × 10 <sup>4</sup>	15.15	30.30
TDONM-ADC(X)	1.45 × 10 <sup>4</sup>	22.02 × 10 <sup>4</sup>	15.20	30.40
TDONM-ADC(XI)	1.46 × 10 <sup>4</sup>	22.35 × 10 <sup>4</sup>	15.30	30.60
NADAC-ADC	1.45 × 10 <sup>4</sup>	22.35 × 10 <sup>4</sup>	15.41	30.82
PM PADC	1.46 × 10 <sup>4</sup>	22.35 × 10 <sup>4</sup>	15.30	30.60

Expected value for <sup>252</sup>Cf 15.75 in 2 $\pi$  geometry and 31.56 in 4 $\pi$  geometry.

It can be seen that the values obtained for the copolymers compare well with PM PADC and NADAC-ADC track detectors. This shows that the copolymer films can be used unambiguously for determination of  $\alpha$ /fission fragments branching ratio.

#### 4. Conclusions

Some novel thermoset polymers containing nitro and carbonate groups were designed and successfully used as SSNTDs. A preliminary study of track detection characteristics of these materials shows that they could be conveniently used for detection of alpha particles and fission fragments. The thermal instability appears to be a permanent problem associated with nitro monomers and hence their polymerization should be carried out at as low temperature as possible. As a result, it is not possible to apply the calculated constant rate polymerization cycle above 65 °C. This preliminary work shows that the three copolymers, ABNEC:ADC (1:9), TDONM:ADC (2:8) and TDONM:ADC (1:9) compare well with PADC track detector while the PTDONM homopolymer is slightly

lesser sensitive material. The proton recoil track detection studies are in progress and will be discussed separately. From the studies carried out on different thermoset polymers containing different types of radiation sensitive groups so far, we feel that in case of thermoset polymers, the structure and sensitivity correlation for a track detector material is dependent on the density of cross-links and the number of radiation sensitive groups available in the polymer and not merely depend upon the presence of particular radiation sensitive groups and certain linkages present in the polymer, as indicated in the literature. However, this still needs to be ascertained by preparing more materials.

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