RELATIVE RESPONSES OF BARE AND ENCLOSED CR-39 ALPHA-TRACK DETECTORS UNDER CONDITIONS OF HIGH AND LOW PARTICLE CONCENTRATION

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Abstract

Six bare CR-39 detectors were placed in contact with filters that had been used to make grab radon progeny measurements from the Bowser-Morner radon chamber; the number of filters per detector ranging from 1 to 6. The net track density on these detectors increased as a function of the number of filters with which they were in contact. This provided compelling evidence that alpha particles emitted from radon progeny on the surface of CR-39 produce observable tracks in that material. Deposition of radon progeny on surfaces, including bare alpha-track detectors, should be greater when the particle concentration in the air is small than when it is large. A study was conducted to determine how particle concentration would affect the relative responses of bare and enclosed CR-39 alpha-track detectors in the Bowser-Morner radon chamber. Forty bare CR-39 alpha-track detectors and ten enclosed detectors of the same type were exposed in the Bowser-Morner chamber for twenty days with a very low particle concentration and thus low equilibrium of radon progeny. Another set of forty bare detectors and ten enclosed detectors was exposed for fifteen days with particles added to the air to create an equilibrium condition of about 60%. In the latter case, the resulting track densities observed on the bare detectors averaged a factor of 1.99 greater than the track densities observed on the enclosed detectors. In the former case with a very low particle concentration, the average track density on the bare detectors was significantly greater, averaging 3.35 times that of the enclosed detectors. The response of the bare detectors at low equilibrium was found to be 69% greater than at a higher equilibrium. The results of the study provide evidence of the following: 1) alpha particles emitted from radon progeny on the surface of CR-39 produce observable tracks, 2) when the particle concentration in the air is small, radon progeny deposit more on surfaces than when the particle concentration is high and 3) the response of bare CR-39 alpha-track detectors is highly dependent upon the concentration of particles in the air.

Introduction

Previous studies (for example, George, et al., 1983) have shown that radon progeny require particles on which to attach in order to stay suspended in air. When the particle concentration in the air is low, radon progeny migrate to, and deposit on, whatever surfaces are available, thus lowering their concentration in the air and lowering their equilibrium with the parent radon in the air. That being the case, bare plastic material used to measure alpha particles by etching to form tracks should also have more radon progeny deposited on them when the particle concentration in the air is low than when it is high and would thus have a higher track density provided that alpha particles emitted from radon progeny on the surface of the detector produce observable tracks. However, some plastic materials, such as cellulose nitrate (LR-115) have a high linear energy transfer (LET) threshold for the formation of tracks, and therefore alpha particles emitted from radon progeny deposited on the surface are too energetic to produce tracks until they have lost energy by passing through a portion of the plastic. In other words, etching the surface would not detect tracks in cellulose nitrate from alpha particles emitted from radon progeny deposited on the surface. However, allyl diglycol carbonate (CR-39) has a much lower LET threshold for the formation of tracks. One reference (Ng et al., 2007) states that CR-39 has no "relevant threshold" energy for alpha particles for the formation of tracks. In other words, alpha particles emitted from radon progeny, even though at a relatively high energy, should produce tracks from the surface of CR-39.

In an undocumented previous study, bare alpha-track detectors and enclosed detectors of the same type were exposed simultaneously in Bowser-Morner's radon chamber. The results of that exposure showed that the track densities on the bare detectors were significantly greater than on the enclosed detectors. This was an indication that alpha particles emitted by radon progeny that had deposited on the surface of the bare detectors produced observable tracks. This preliminary study was done with no particles introduced into the chamber air, and thus at a low equilibrium. The authors wished to conduct a more detailed study 1) to verify that alpha particles emitted from radon progeny on the surface of CR-39 produce observable tracks and 2) to observe the effect that two very different particle concentrations in the Bowser-Morner chamber would have on the deposition of radon progeny and thus the relative response of bare and enclosed CR-39 detectors. Also of interest was any effect that orientation of bare detectors inside the chamber might have.

Method

In order to verify that alpha particles emitted from radon progeny on the surface of CR-39 produce observable tracks, bare CR-39 detectors were placed in contact with filters that had been used for grab radon progeny measurements from the Bowser-Morner chamber. After each grab measurement was analyzed for radon progeny concentration, a bare CR-39 detector was placed in contact with the filter and left there overnight; long enough for all of the radon progeny to decay. Six bare detectors were exposed in this manner, one to one filter, one to two filters, etc. with the maximum being six filters. These detectors were sent to the manufacturer's laboratory for analysis along with four bare detectors as blanks.

To measure the relative response of bare and enclosed CR-39 detectors, forty bare CR-39 alpha-track detectors were randomly assigned, eight each to the top and four sides of a cardboard box. Ten enclosed alpha-track detectors of the same type were also randomly assigned, two each to the same surfaces of the box. The box was placed inside the Bowser-Morner radon chamber, as shown in Figure (1), about 1.2 m (4 ft) from the chamber door. The detectors were exposed for a period of twenty days. During this period, no particles were injected into the chamber air, so the particle concentration in the air was very low. No particle counter was used, and no measurements of radon progeny were made during this period. However, in the past, with these same conditions, the particle concentration in the chamber was measured to be less than 50 per cm^3, and the radon progeny equilibrium was measured to be about 5%. After the exposure period, the detectors were sent to the manufacturer's laboratory for processing along with ten bare detectors and three enclosed detectors as blanks.

Figure (1): Box with bare and enclosed detectors placed inside chamber

The entire exposure was repeated as stated above, this time with a particle generator injecting an aerosol of sodium chloride particles into the chamber air. Again, no particle counter was used, but in the past with this condition the particle concentration was measured to be greater than 10^4 particles per cm^3. The radon decay product equilibrium was measured to be approximately 60%. The detectors were exposed for a period of fifteen days. The detectors were sent to the manufacturer's laboratory for processing along with nine bare detectors and two enclosed detectors as blanks.

Results

The results of the six bare detectors that were placed in contact with filters used to make radon progeny grab measurements are presented in Table 1. The average blank track density, 0.56 tracks/mm^2, was subtracted from each of the reported track densities for these detectors; the individual blank values were 0.46, 0.54, 0.57, & 0.65 tracks/mm^2. These results are shown graphically in Figure (2).

Table 1. Net track density (tracks/mm^2), bare detectors, exposed to indicated number of filters

1	2	3	4	5	6
19.48	39.88	55.15	70.49	81.81	85.62

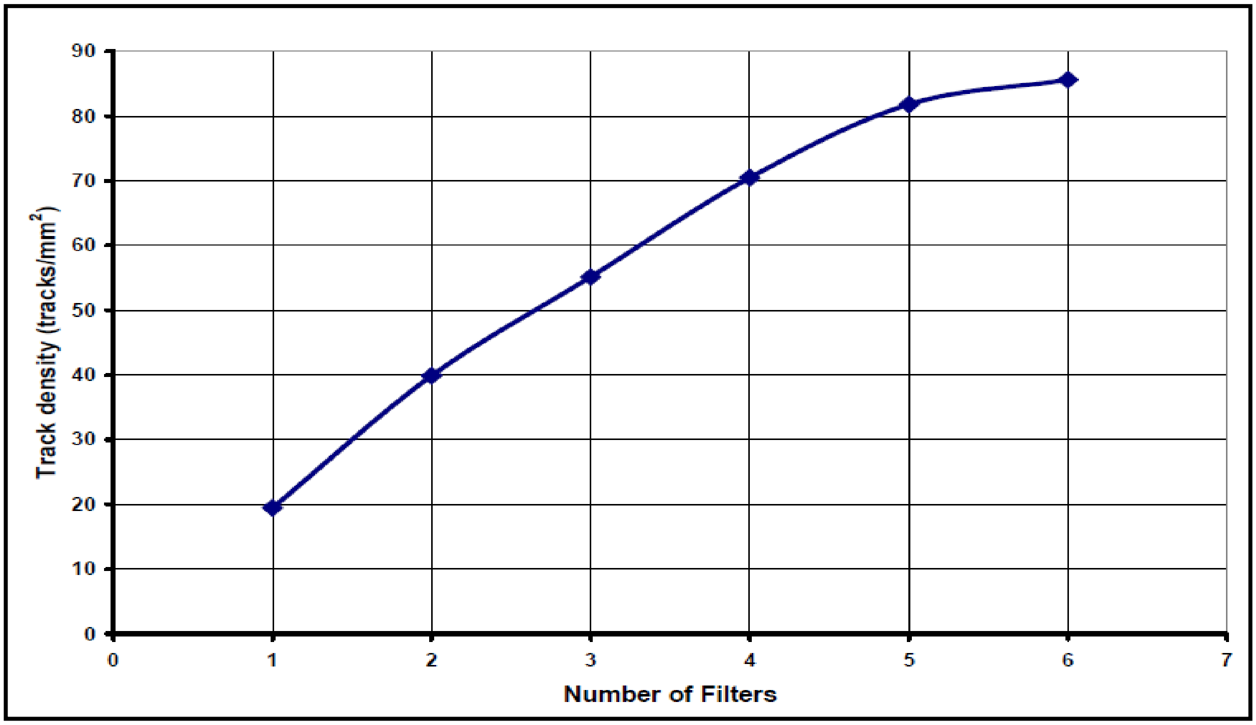

Figure (2): Net track density as a function of number of filters to which the detector was exposed.

The results from the first set of bare detectors exposed in the Bowser-Morner chamber when no particles were added to the chamber air are presented in Table 2 in terms of net track density in tracks/mm^2. The average blank track density, 0.34 tracks/mm^2, was subtracted from each of the reported track densities; the individual blank values were, 0.26, 0.28, 0.31, 0.31, 0.31, 0.32, 0.34, 0.34, 0.35, & 0.57 tracks/mm^2. In Table 2, the surfaces of the box are labeled A through E, as shown in Figure (3), with A being the top of the box and B facing the chamber door. The Positions 1 – 8 are the order in which the detectors were placed on the surface; for Surfaces B – E Position 1 is the top detector and Position 8 is the bottom detector and for Surface A, Position 1 is farthest from the chamber door and Position 8 is closest to the door. A statistical analysis indicated that there was no significant effect due to Position, so the data were analyzed using a one-way Analysis of Variance (ANOVA) with Surface being the only independent variable. This analysis indicated a significant effect due to Surface. In other words, the track density was affected by the orientation of the bare detectors in the chamber. Although this effect was statistically significant, the largest difference in average net track density between two surfaces was only 8.4%. The net track density averaged over all forty detectors was 76.69 ± 3.56 tracks/mm^2 (unless otherwise stated, average values are reported with ± one standard deviation).

The results from the first set of enclosed detectors when there was a low particle concentration in the chamber air are presented in Table 3 in terms of net track density. In Table 3, the variables Surface and Position are defined in the same manner as in Table 2, just with fewer detectors. The average track density for the enclosed blanks was 0.46 tracks/mm^2; the individual blank values were 0.47, 0.48 & 0.43 tracks/mm^2. A statistical analysis again indicated that there was no effect due to Position. A one-way ANOVA indicated that there also was no effect due to

Surface. In other words, the orientation of these detectors had no significant effect on their response, as was expected since they were enclosed with filtered openings and should not have been affected by radon progeny outside of the enclosure. The net track density averaged over all ten enclosed detectors was 22.86 ± 0.88 tracks/mm^2. The relative response of the bare detectors to the enclosed detectors was therefore (76.69 ± 3.56)/(22.86 ± 0.88), or a factor of 3.35 ± 0.20.

Table 2. Net track density (tracks/mm^2), bare detectors, low particle concentration

Position	A	B	C	D	E
1	70.60	83.56	77.88	76.49	83.57
2	74.01	82.45	77.25	74.53	82.67
3	75.11	79.34	68.08	74.21	81.12
4	76.41	79.74	76.24	73.89	78.61
5	76.59	77.44	77.44	71.86	77.97
6	75.89	77.70	75.90	73.19	77.04
7	76.72	77.80	74.38	74.18	79.79
8	70.88	80.61	73.73	72.69	80.22
Average	74.53	79.83	75.11	73.88	80.12
Std Dev	2.50	2.27	3.19	1.38	2.27

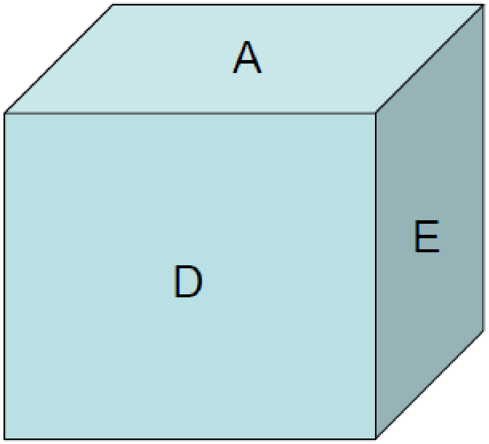

Figure (3): Relative positions of the surfaces

Table 3. Net track density (tracks/mm^2), enclosed detectors, low particle concentration

Position	A	B	C	D	E
1	23.14	22.12	21.65	23.66	22.89
2	23.51	22.42	24.23	23.37	21.60
Average	23.32	22.27	22.94	23.52	22.25
Std Dev	0.26	0.21	1.82	0.21	0.91

The average net track densities for the bare and enclosed detectors for the first exposure are shown graphically in Figure (4). In that figure, the error bar on each column is ± two times the standard deviation around the average net track density.

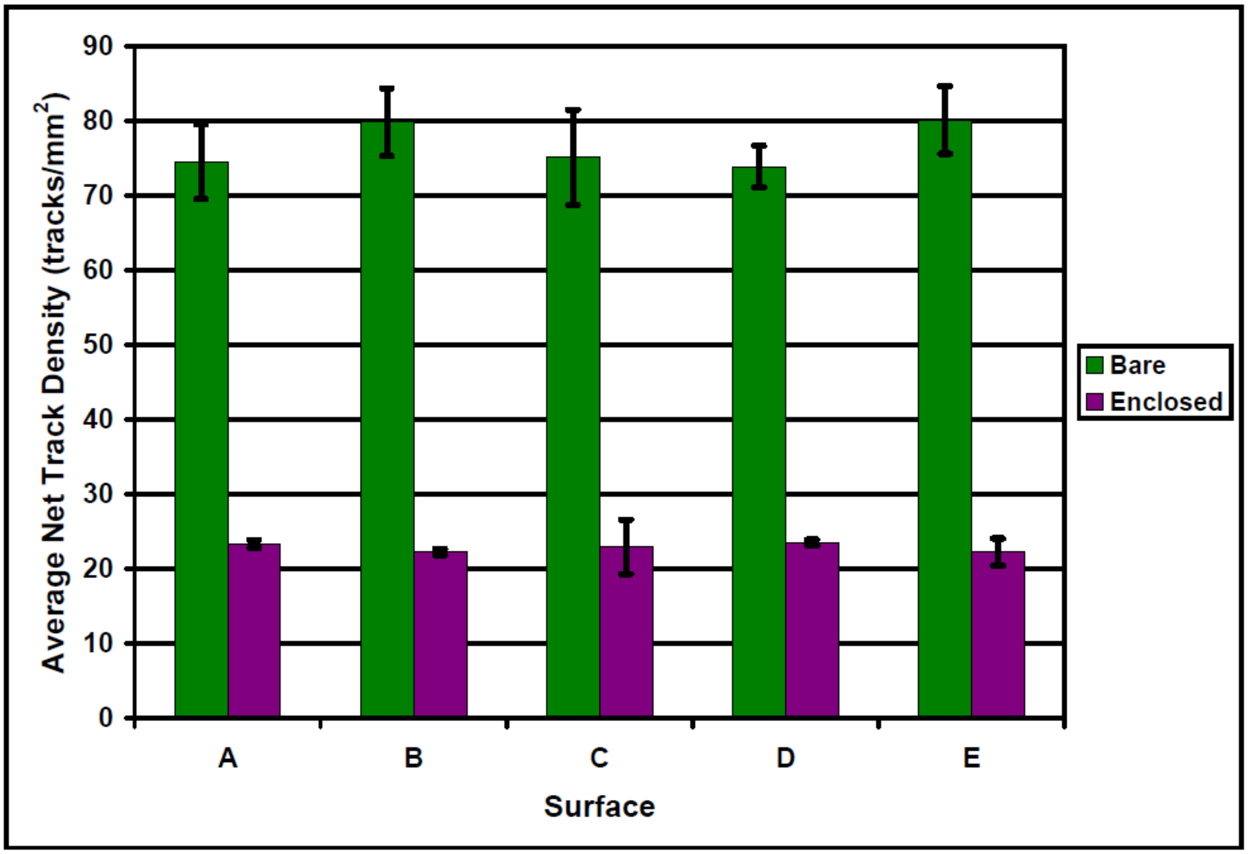

Figure (4): Average net track densities with low particle concentration

The results from the second set of bare detectors when particles were added to the chamber air are presented in Table 4 in terms of net track density in tracks/mm^2. The average blank track density, 0.26 tracks/mm^2, was subtracted from each of the reported track densities for the exposed detectors; the individual blank values were 0.11, 0.17, 0.19, 0.19, 0.22, 0.27, 0.33, 0.37, & 0.46 tracks/mm^2. In Table 4, the surfaces and positions are as described above for Table 2. Unfortunately, the laboratory indicated that the surfaces of nine of the forty bare detectors were damaged and therefore the reported values of track density should be ignored. Although several of these values were very close to the average track density for the others on the same surface, they were excluded from any of the analyses, as indicated in Table 4. A statistical analysis indicated that there was no significant effect due to Position, so the data were analyzed using a one-way ANOVA with Surface being the only independent variable. This analysis indicated a significant effect due to Surface. In other words, the track density was affected by the orientation of the bare detectors. Although this effect was statistically significant, the largest difference in average net track density between two surfaces was only 5.7%. The net track density averaged over the 31 detectors was 33.94 ± 1.61 tracks/mm^2.

Table 4. Net track density (tracks/mm^2), bare detectors, high particle concentration

Position	A	B	C	D	E
1	33.92	34.19	*	32.02	35.19
2	34.73	31.52	33.61	*	36.15
3	*	33.25	33.87	31.51	*
4	37.28	*	34.90	*	*
5	35.04	*	34.57	32.85	33.95
6	35.23	30.04	34.47	32.15	34.66
7	36.53	32.71	*	32.48	34.27
8	35.64	33.77	33.70	32.33	35.53
Average	35.48	32.58	34.18	32.23	34.96
Std Dev	1.13	1.55	0.53	0.45	0.82

* Damaged detector, measurement excluded.

The results from the second set of enclosed detectors when there was a high particle concentration in the chamber air are presented in Table 5 in terms of net track density. In Table 5, the surfaces and positions are as described above for Table 3. The average track density for the enclosed blanks was 0.71 tracks/mm^2; the individual blank values were 0.69, & 0.73 tracks/mm^2. A statistical analysis again indicated there was no effect due to Position. A one-way ANOVA indicated that there also was no effect due to Surface. In other words, the orientation of the enclosed detectors had no significant effect on the response of the detectors, as in the first exposure. The net track density averaged over all ten enclosed detectors was 17.05 ± 1.00 tracks/mm^2. The relative response of the bare detectors to the enclosed detectors was therefore (33.94 ± 1.61)/(17.05 ± 1.00), or a factor of 1.99 ± 0.15.

Table 5. Net track density (tracks/mm^2), enclosed detectors, high particle concentration

Position	A	B	C	D	E
1	17.63	17.08	16.59	17.17	16.42
2	18.67	14.87	17.74	17.00	17.39
Average	18.15	15.97	17.17	17.08	16.90
Std Dev	0.74	1.56	0.81	0.13	0.69

The average net track densities for the bare and enclosed detectors for the second exposure are shown graphically in Figure (5). In that figure, the error bar on each column is ± two times the standard deviation around the average net track density.

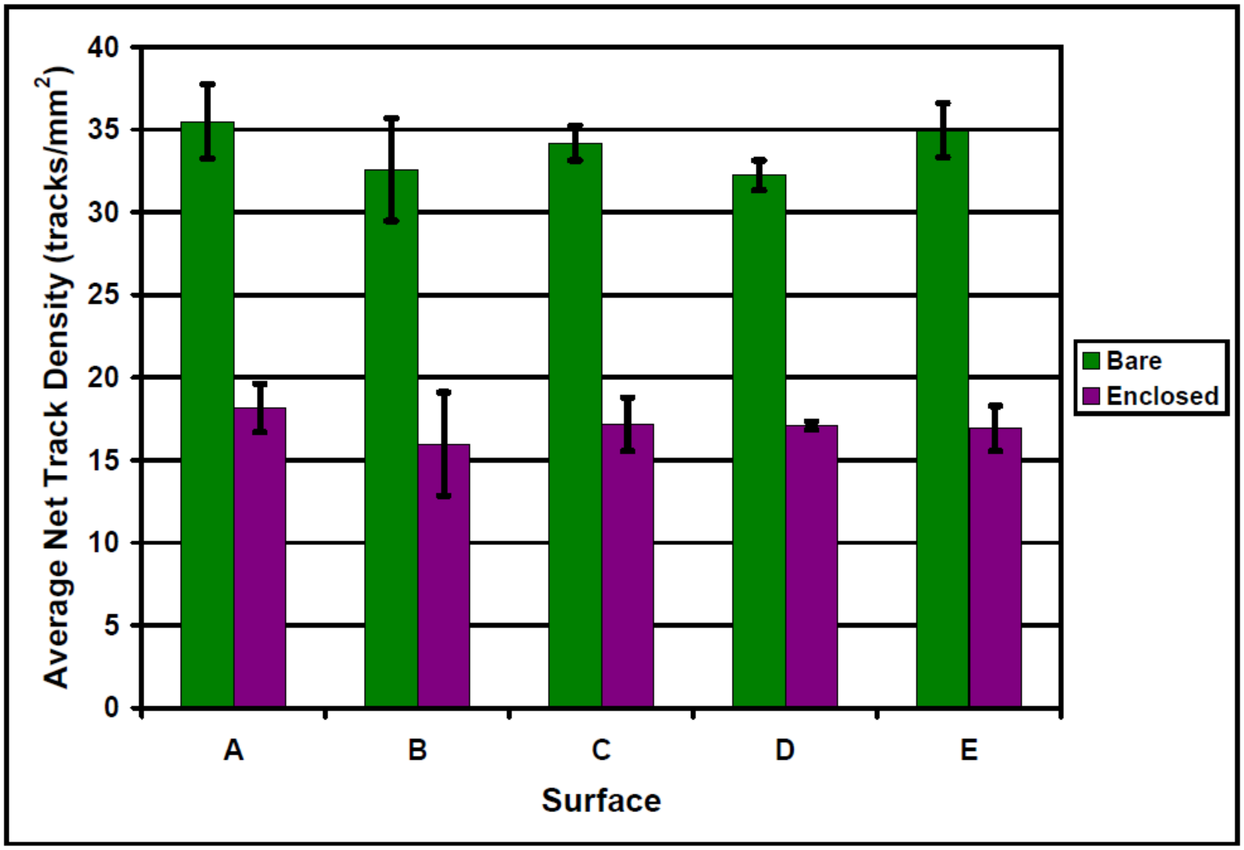

Figure (5): Average net track densities with high particle concentration

Discussion

The results shown in Table 1 and Figure (1) indicate a definite trend of increasing track density with the number of filters to which the detectors were exposed. This is a clear indication that alpha particles emitted by radon progeny on the surface of the detectors do indeed result in observable tracks in the CR-39 material. The leveling off of track density with increasing number of filters, obvious in Figure (1), was due to a combination of two factors; 1) the detectors in contact with 4, 5 and 6 filters were each in contact with one filter that had a slightly less activity of radon progeny on it compared to all the other filters and 2) with increasing track density some tracks are lost in the counting process due to overlapping. This can be seen in Figure (6) where with increased track density some pairs or groups of overlapping tracks would be counted as only one track. If the track density values had been converted to exposure in Bq-hours/m^3 (pCi-days/liter), an algorithm would have been applied to correct for this loss.

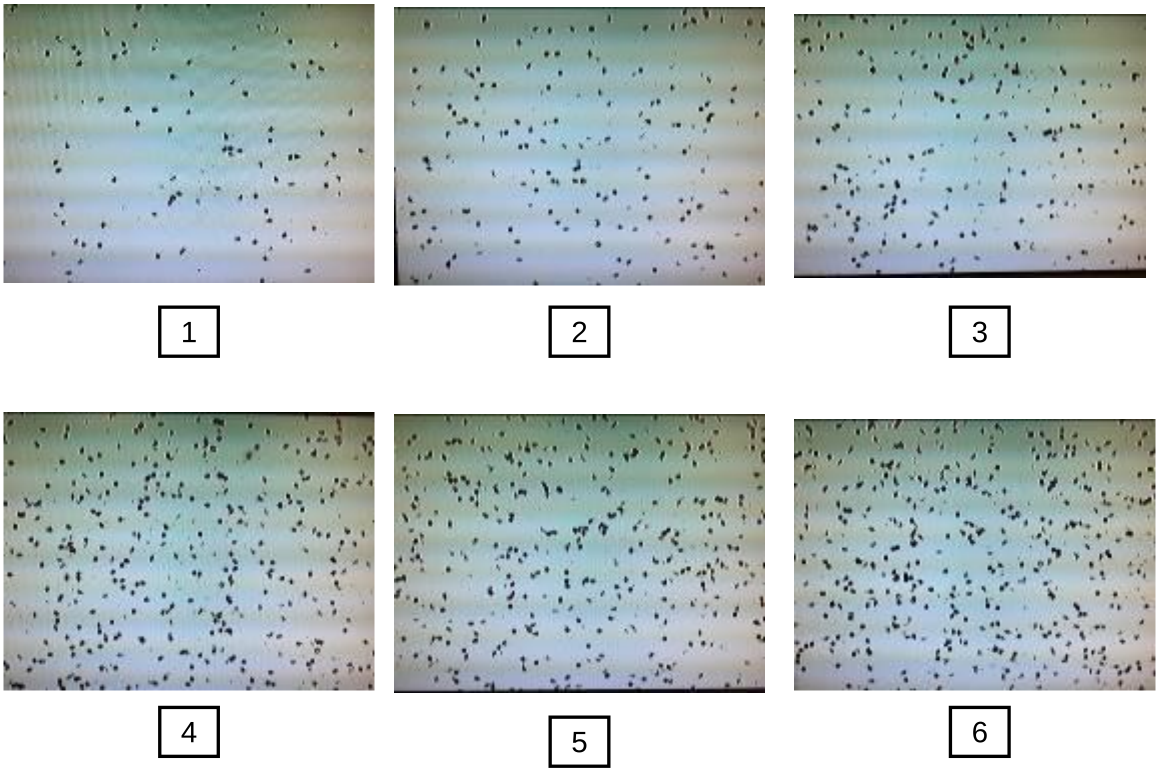

Figure (6): Magnified tracks in CR-39 with the number of filters indicated to which each detector was exposed. Note overlapping tracks at higher track density.

From Tables 2 and 4, it is obvious that the net track densities observed on the bare detectors were different between the two exposure periods. Likewise, from Tables 3 and 5 the same is obvious for the enclosed detectors. This is because the total exposures to radon in terms of Bq-hours/m^3 (pCi-days/liter) were different between the two exposure periods. What is of interest here is the relative responses between the bare and enclosed detectors for each exposure period. Table 6 shows, for each surface and each exposure period, the ratio of the average net track density of the bare detectors to that of the enclosed detectors. These values are shown graphically in Figure (7). In that figure, the error bar on each column is ± two times the standard deviation around the value of the ratio.

Table 6. Ratio of net track density, bare detectors to net track density, enclosed detectors

Particle Conc.	A	B	C	D	E
Low	3.20 ± 0.11	3.58 ± 0.11	3.27 ± 0.29	3.14 ±0.06	3.60 ±0.18
High	1.96 ± 0.10	2.04 ± 0.22	1.99 ± 0.10	1.89 ± 0.03	2.07 ± 0.10

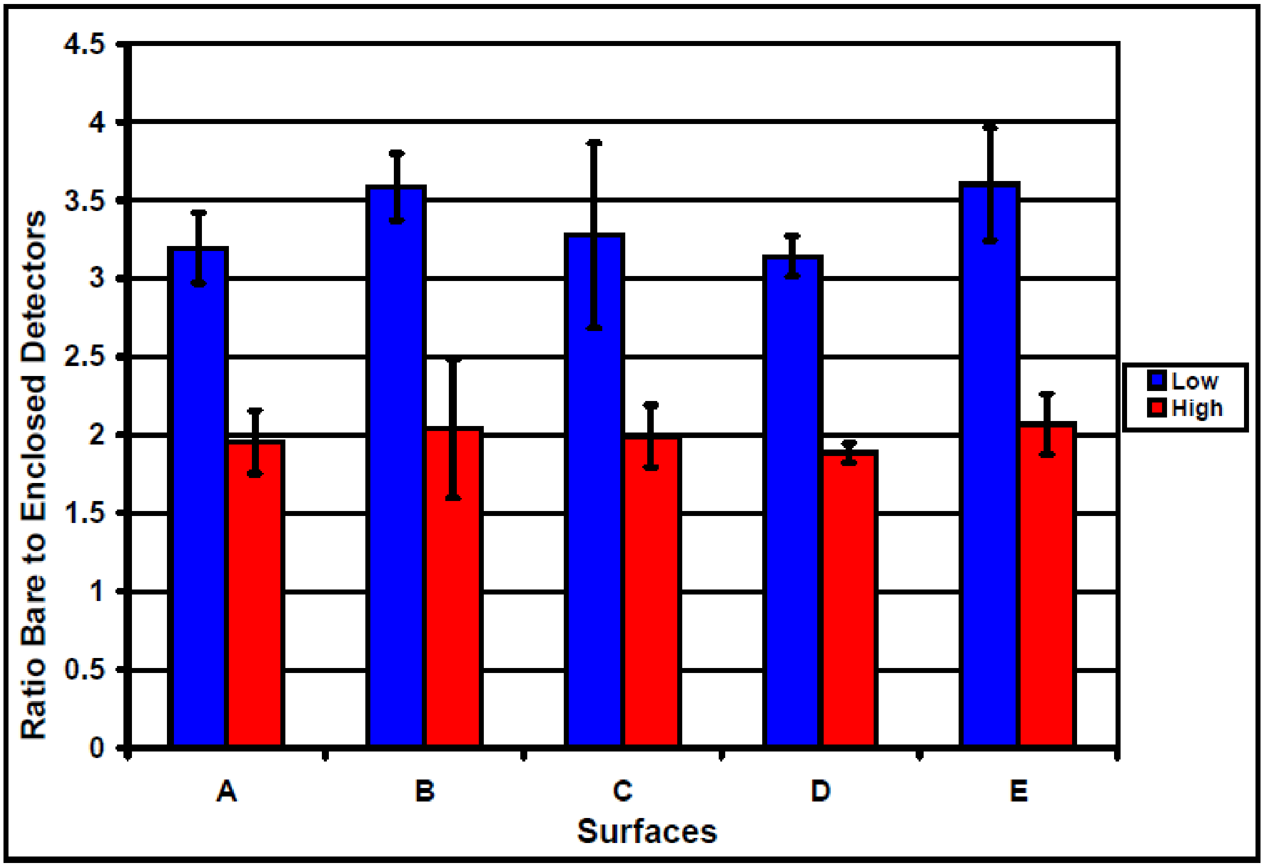

Figure (7): Ratios of average net track densities of bare to enclosed detectors with low and high particle concentrations

It is seen from Figure (7) that there is some variation among the surfaces in the ratio of bare to enclosed detector responses. Just from inspection of the error bars, it appears, for the exposure with low particle concentration, that the ratios for Surface B and D may be significantly different. No statistical analyses were done to determine this. Even if true, it is difficult to interpret what that might mean. But it is interesting to note from Figures (4) through (5) that the variation across Surface D was consistently smaller than the variation across the other surfaces. Surface D was the farthest from the chamber door, but it was also the farthest away from shelves in the chamber. It is not clear if this was a factor, or perhaps if the pattern of air flow in the chamber was a factor.

What is most important to note is the obvious difference in the ratios of bare to enclosed detectors between the two exposure periods with different conditions of particle concentration and radon progeny equilibrium. Ignoring any differences among surfaces, the overall ratio of the responses of the bare to enclosed detectors for the exposure with a low particle concentration was 3.35 ± 0.20; whereas, the same ratio for the exposure with a high particle concentration was 1.99 ± 0.15. Because the enclosed detectors respond only to radon diffusing through filters, they should not be affected by radon progeny outside of the enclosures. Therefore, this difference is due to the effect of particle concentration, and radon progeny equilibrium, on the bare detectors. The average difference observed in the study was (3.35 ± 0.20)/(1.99 ± 0.15) or a factor of 1.69 ±

0.16. In other words, the response of bare detectors was 69% larger when the particle concentration and radon progeny equilibrium were low than when they were high. This difference in response was due to the increased deposition of radon progeny onto the surfaces of the bare detectors.

Conclusions

The results of this study provide evidence that alpha particles emitted from radon progeny on the surface of CR-39 produce observable tracks. Also, the response of bare CR-39 detectors is significantly affected by the concentration of particles in the air due to the tracks from radon progeny deposited on their surfaces. This is due to more deposition of radon progeny when the concentration of particles in the air is low than when it is high. There is some evidence that the orientation of detectors in relation to nearby shelves and perhaps the pattern of air flow in the Bowser-Morner chamber, both of which could affect the amount of deposition of radon progeny, may also have affected the responses of the bare CR-39 detectors.

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References

Ng FMF, Nikezic D, Yu KN. Long-term measurements of equilibrium factor with electrochemically etched CR-39 SSNTD. Nuclear Instrum Meth B, 263, 279-283, 2007.

George AC, Knutson EO, Tu KW. Radon Daughter Plateout – I. Measurements. Health Phys 45, 439-444, 1983.