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Development of an Environmental Radon Monitoring System Using CR-39 Nuclear Track Detectors

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Abstract: *An environmental radon monitoring system, comprising a radon-chamber, an etching system, and a track counting system, was constructed. The radon chamber is a detector chamber with an internal diameter of58mm and a height of20mmin combination with a CR-39 detector. Carbon is impregnated in the bodies of the detector chamber to avoid problem of an electrostatic charge. The optimized etching condition for the CR-39 exposed to a radon environment turned out to be a 6.25 N,NaOH solution at 70ºC during a 7hours' period. According to the calculations, the dosimeter can detect minimum Radon concentration equal to 18.66Bq.m^{-3} after 30 days. The bulk etch rate under the optimized condition was 1.14±0.03 µm h^{-1}. The diameter of the tracks caused by radon and its progeny were found to be in the range of 10~25 µm under the optimized condition. The track images were observed with a track counting system, which consisted of an optical microscope, a color charged couple device (CCD) camera, and an image processor. The calibration factor of this system is obtained to be 0.105 ± 0.006 tracks cm^{-2} per Bq m^{-3}d.*

The calibration factor for optimized conditions was gained150 tracks.cm^{-2}(Bq.lit^{-1}.day)$^{-1}$.

Keywords: *Radon Gas, Solid State Nuclear Track Detector (SSNTD), Chemical Etching, Electro-chemical Etching, Diffusion Chamber.*

1. Introduction

Radon is the largest and most variable contributor of public exposure to radiation. It is estimated that the annual effective dose by radon and its progeny from the inhalation of air is about 50% of natural public exposure dose rate and prolonged exposure to high levels of radon can cause lung cancer [1]. In recent years, interest in this subject has been increasing rapidly because of news that the radon concentration of underground water in some regions and air of some subway stations is higher than action guideline level [2-4]. Measurement of radon exposure has gained added significance because of the increased potential for lung cancer caused by the combined effects of radon, air pollution, and smoking [5]. The environmental radon concentration is a function of time and climate conditions. To monitor radon, both active and passive techniques have been developed. Active methods are usually used for short-term measurements of radon and for detailed investigations of individual sites under inspection. Passive methods are more suitable for the assessment of radon exposure over long time scales and can be used for large-scale surveys at moderate cost. For that reason, many radiation protection departments have performed large-scale radon surveys using passive monitoring devices, have been assessed the public exposure dose rate from radon, and have adopted appropriate actions for protection against radon exposure [6-9]. Therefore, the construction of reliable and inexpensive radon monitoring system to assess the radon exposure level should be done. In this research, radon detector chamber using solid-state nuclear track detector (SSNTD), which have the ability to integrate over multiple day-long intervals of time at dwelling and buildings developed along with a track counting system. Additionally, the optimum etching condition is also found. The proposed monitoring system can be used for large-scale surveys of environmental radon exposure.

2. Methods and Materials

2.1. Standard Radioactive Source: RN-1025

The standard source was from Canadian Pylon Electronic Inc. model RN-1025, containing^{226} Rawithactivity about285, 175kBq (%4±) (fig.1), using this standard source system could be determining radon level due to the exposure of Ra.

Figure1. *Standard radioactive source RN-1025*

2.2. Detection Material

As the most principal detection material of the SSNTDs group, CR-39, was selected because of its good sensitivity, stability against various environmental factors, and high degree of optical clarity. Large sheets of CR-39 were supplied by Track Analysis System Co. Ltd. England. Sheets of 750 μm thickness were used for robustness and to avoid the possibility of tracks on the back surface being detected by the image analyzer. These sheets were cut into rectangular shapes sized 4mm × 10 mm.

2.3. Radon Chamber

A radon chamber used for radon exposure assessments is made up of detection material and its container chamber. A radon chamber used over long time scales with large-scale surveys must be small, low cost, and easy to both handle and read [10]. The sensitivity of a radon chamber is not only dependent on the material and volume of the detector chamber, but also, the position of the detection material which there is inside of the detector chamber, and the filter that shuts out radon progeny.

The CR-39 was used as the detector on the bottom of the detector chamber where it is fixed by holder to reduce any error that might be caused by its movement. Radon enters the holder with a half-time for entry about 1 minute, which is short compared with the radon half-life of 3.82 days. This means that the radon concentration inside the detector chamber quickly approaches that outside. It can be shown that the long-term average radon concentration inside the detector chamber is the same as that outside, despite any variations in the outside concentration. But the radon concentration may be overestimated because the short halftime for entry will allow some thorn to enter the detector [11].

2.3.1. Aeoi Detector Cup

For the implementation of methods by comparison, have been selected a detector chamber which is a cylindrical cup of 64.6mm in diameter and 83.3mm in height and volume of 249 cm^3. This cup is sealed with glass-fiber filter that discriminates short-lived thorn by delaying the entry of gases into the chamber, limits access of moisture, and blocks the entry of radon progeny and dust present in the ambient air [11-13]. AEOI Radon dosimeter was designated in National Radiation Protection Department (NRPD) of Atomic Energy Organization of Iran (AEOI), (Fig.2).

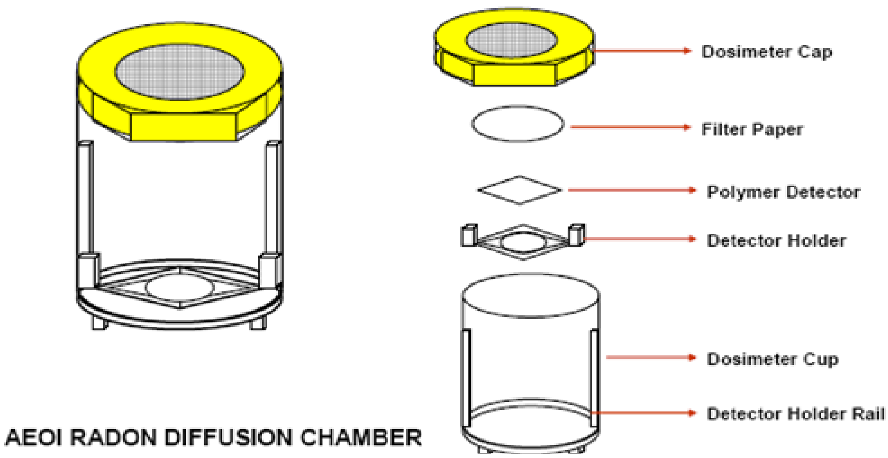

Figure2. *Different parts of a Radon Diffusion Chamber*

2.3.2. National Radiological Protection Board (Nrpb) Radon Chamber

This chamber has been developed considering following construction specification as shown in fig.3and fig.4 as a case with 20mm height, 58mm diameter, CR-39 detector located in a cylindrical container with 6mm high and 54 mm diameter, without any filter to prevent air entrance, the sensibility of this dosimeter depends on etching conditions and physical characteristics of detector considering; material, dimension, shape, and position of detector which was mounted in chamber. Carbon is impregnated in the wall material, to enhance electrical conductivity and to avoid the problem of electrostatic charge.

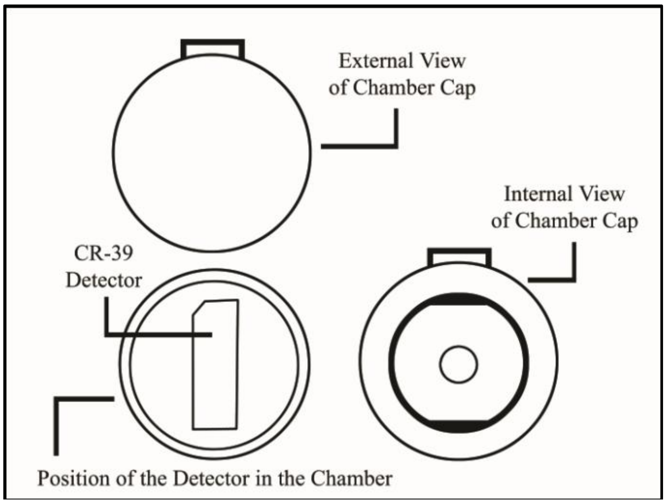

Figure3. *Schematic design of NRPB Radon chamber*

Figure4. *NRPB Radon chamber structure with different parts of it.*

2.4. Track Etching System

The optimal use of any track detector is largely dependent on standardization of various etching parameters, such as the bulk etch rate (Vb) and track etch rate (Vt),both of which must be experimentally determined under suitable conditions. A set of systematic experiments was carried out to find the optimal etching condition. CR-39samples were irradiated using a standard source typeRN-150(PYLON ModelTH-1025) alpha (0.5-5MeV), 175.285 kBq.

Electrochemical Etching (ECE) Process: Irradiated CR-39 samples were etched in a NaOH solution, which is the selected etchant and has been extensively studied [14]; varying concentrations of NaOH solution were used, from 3~10 N, at temperatures ranging from 40 to 80 ºC, during periods of 4 to 10 hours. After etching, the CR-39 samples were cleaned in running water for 20 minutes and dried flat between tissues wipes to remove the etchant and etch products from the surface of the detector. The optimum etching condition for the CR-39 used in this study turned out tobe etching the CR-39 in a solution of (6.25 N)NaOH solution at 85 ºC over a 5hours period (fig. 5).

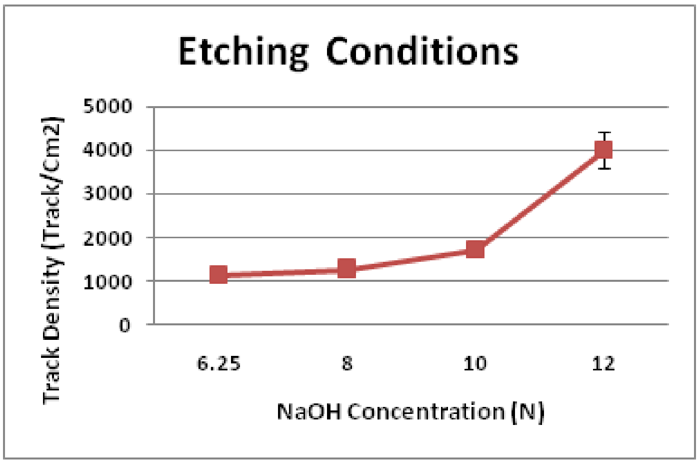

Figure5. *Graf of track density variation versus NaOH concentration- temperature: 85 °C, time: 5 h*

2.5. Track Counting System

The etched tracks were observed using an optical microscope fitted with an objective lens of 149 times magnification. At this magnification one counting field covers an area of 0.99 mm2. The microscope image was viewed witha high-quality monochrome charge coupled device (CCD) TV camera, which is connected to a PC-based image analyzer (Image-Pro Plus version 4.0). The image analyzer displays images on a monitor. Tracks are counted automatically in 10 different fields around center of the detector (covering 9.9 mm2). For unexposed detectors used for the assessment of background track density, 20 different fields were scanned. The tracks appeared as dark spots on a clear white background, and grey-level threshold detection was performed to separate the tracks from the clear CR-39. Tracks were not accepted as genuine unless their areas and round nesses (perimeter2/(4*π*area)) fell within the acceptance criteria. The upper and lower limits for area of acceptable tracks were 50 and 450 μm^2 and for roundness1 and 1.8, respectively, where a roundness of 1 refers to adisc.

2.6. Calibration and Intercomparison

Calibration experiments were carried out to evaluate the relationship between the track density recorded and the radon concentration. Reliable measurements of radon concentrations with an integrating device depend sensitively on the soundness of the calibration procedure. Exposure to radon was done at the National Radiological Protection Board (NRPB) radon chamber. This facility has been the national reference laboratory for radon measurements under an intercalibration and inter comparison scheme organized by the IAEA.

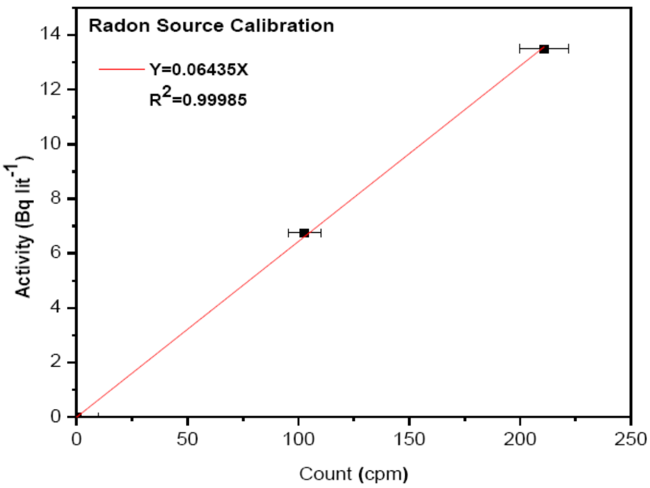

Figure6. *Calibration graph for Radon measurement using ^{226}Ra as the radioactive standard source*

The radon level varied between 65 kBq hm^{-3} and 397 kBq hm^{-3}, the corresponding track density for the CR-39 varied from 291.8±58 tracks cm^{-2} to 1763.7 ± 88 tracks cm^{-2}. Figure7 shows the relationship between track densities and radon concentrations. The straight line represents the least squares fit of the data. A mean value obtained from the experiment was gained about 110 tracks.cm^{-2}(Bq.lit^{-1}.day)$^{-1}$.

Before using this system for a large survey program, it is essential to test the limit of the application at higher exposure levels. For that reason, exposure to radon was done at the Research Institute. The radon level varied between 396 kBq hm^{-3} and 795 kBq hm^{-3} with 5 radon-cups at 4 different level points. Figure 7 shows the result of the linearity test. It is clear from this figure that the detector response is maintained to about 800 kBq hm^{-3} with good linearity.

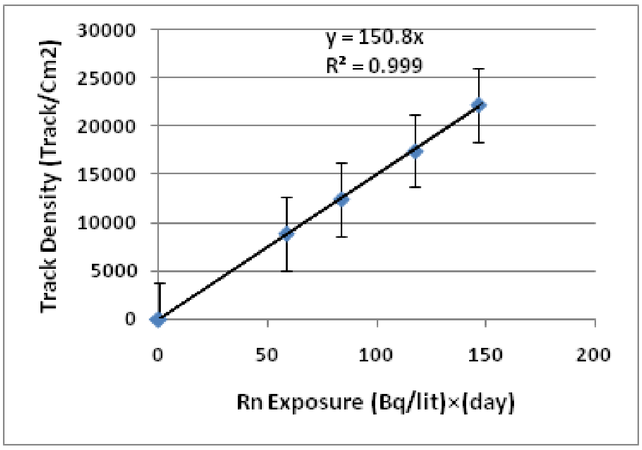

Figure7. *Passive Radon Detector Sensibility Curve for NRPB chamber*

2.7. Determination of Minimum Detection Limit (MDL)

This principal factor of evaluation of sensibility could be determined considering the detection system efficiency of solid state polymer detectors according to following specification:

- Sensibility to Alfa radiation
- Optimizing of experimental conditions due to type of solution and etching conditions
- Effects of environmental conditions on detector materials
- Required time of exposure which depends on the radon density of air

Figure 6 presents the variation of track density according to the time of exposure, as MDL factor.

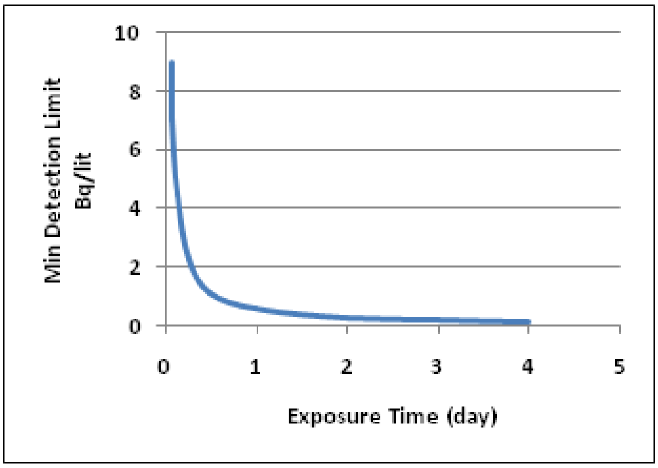

Figure6. *Minimum Detection Limit of Radon in Air*

3. Conclusion

For large-scale surveys of radon levels in the living environment, a measurement tool should be low cost, easy to distribute, readily available, and simple to evaluate.

The proposed environmental radon monitoring system composed of a radon chamber, a chemical etching system, anda track counting system was constructed. The developed radon chamber is a chamber in combination with a CR-39detector [15], [16].

The optimized etching condition for the CR-39exposed in a radon environment turned out to be a (6.25 N) NaOH solution at 85 ºC over a 5 hours period. The bulk etch rate under the optimized condition was 1.14 ± 0.03 μm h^{-1}.

The images of tracks were observed by the track counting system, which consisted of an optical microscope, a CCD camera, and an image processor. The calibration factor of this system was obtained to be 0.105 ± 0.006 tracks cm^{-2}per Bq m^{-3} d

Calibration Factor for optimized conditions was gained 150 $tracks.cm^{-2}(Bq.lit^{-1}.day)^{-1}$. It was gained that the sensitivity of NRPB Radon dosimeter was more than eleven times higher than the sensitivity of AEOI Radon dosimeter.

The radon concentration measured by the developed radon cup was in acceptable agreement with the values obtained by another device at inter comparison experiment.

The proposed radon monitoring system can be used to investigate radon levels to estimate the annual effective dose to the public by radon. The data on the survey using this system will be used as the baseline data to decide the action level for radon. Finally, this system will contribute effectively for the reduction of lung cancer caused by radon.

Minimum Detection Limit (MDL) of Radon concentration by using special method was calculated. According to the calculations, the dosimeter can detect minimum Radon concentration equal to $18.66Bq.m^{-3}$ after 30 days. The sum equation shows that MDL is versus exposure time of the detector.

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