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Development of an energy discriminate CR-39® nuclear track etch dosimeter for Radon-220 gas measurements

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ABSTRACT

An energy discriminate CR-39® nuclear track etch dosimeter for use in a ^{220}Rn and ^{222}Rn gas monitor has been developed and experimentally assessed. It utilises a thin film of Mylar® C to attenuate the alpha particle energies to allow only the damage tracks created by the 8.785 MeV alpha particles emitted from ^{212}Po of the ^{232}Th decay chain to be registered in the CR-39® plaque, allowing for the direct measurement of ^{220}Rn gas concentrations. The dosimeter was developed through a combination of experimental investigations and theoretical simulations using the Monte Carlo ion transport modelling program Stopping and Range of Ions in Materials (SRIM 2008). A film thickness of 54 μm has been shown to attenuate all alpha energies less then 7.7 MeV.

1. Introduction

International studies of radon indoors and in the workplace have shown that the dose contribution due to the inhalation of ^{220}Rn and its short-lived decay products have been detected as a significant component of the total radon contribution (UNSCEAR, 2008; Steinhäusler, 1996). Future measurement studies should therefore consider the contribution of both ^{220}Rn and ^{222}Rn and their daughter products. With the concentrations of radon and their progeny being seasonally variable, long sampling times are required to accurately assess their long term average levels. A common method for the measurement of ^{222}Rn gas concentrations in the environment over seasonal and annual measurement intervals is the application of solid state nuclear track dosimetry (Durrani and Ilić, 1997).

To measure both ^{222}Rn and ^{220}Rn gas concentrations in the environment, solid state nuclear track dosimeters are commonly used in dual chambered passive diffusion monitors (Eappen and Mayya, 2004; Doi et al., 1994; Dwivedi et al., 2001). Within these dual chamber dosimeters are placed nuclear track detectors such as CR-39®, Makrofol® or Lenax® (Balestra, 2007). It is possible to differentiate between ^{222}Rn and ^{220}Rn gas due to the relative differences in their half-lives which are 3.82 days and 55.6 s respectively. By using different filters or chamber opening sizes the diffusion time of the gases into each of the chambers can be controlled (Shweikani et al., 1997). Constructing one of the chambers with a diffusion time of greater than 10 min will result in the complete decay of ^{220}Rn gas, allowing for only ^{222}Rn gas to diffuse in and register on the nuclear track detector (Balestra et al., 2007). The other chamber is designed with a short enough diffusion time for both ^{222}Rn and ^{220}Rn gas to diffuse in and be detected (Eappen and Mayya, 2004). The difference in the total number of counts from each of the nuclear track detectors from both chambers can provide the ^{220}Rn gas concentration. For levels of ^{220}Rn in the presence of ^{222}Rn, the statistical uncertainties from subtracting two large numbers from each other results in a high level of experimental uncertainty. The present work has been undertaken to improve on these methods by directly measuring ^{220}Rn gas concentrations, avoiding the statistical effect which causes the high level of experimental uncertainty in determined ^{220}Rn gas concentrations.

The exposure of nuclear track detectors to alpha radiation emitted from the decay of ^{222}Rn, ^{220}Rn and their progeny produces small damage tracks of the radiations path in the detector (Durrani and Ilić, 1997). Initially these tracks are far too small to be observed with the human eye, even with optical magnification equipment. To enlarge these tracks the nuclear track detectors are etched by

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a hydroxide solution (Balestra et al., 2007). The etching process enlarges the damage tracks to an approximate size of 25 μm (Langroo et al., 1990). In this process a layer of the nuclear track detector is removed. The thickness of this layer is dependent on the material type and etching conditions (Balestra et al., 2007). The removal of this layer eliminates the damage tracks caused by the incident radiation on the nuclear track detector below a specific energy level, specified as the energy detection threshold of the nuclear track detector.

In the ^{222}Rn decay chain the highest energy alpha particle radiations emitted is 7.687 MeV from ^{214}Po, where for the ^{220}Rn gas chain the highest alpha energy is 8.785 MeV from ^{212}Po (NuDat, 2008). By utilising the energy detection threshold from the etching process and using an additional film to adsorb the necessary kinetic energy of the alpha particle it is possible to directly discriminate between damage tracks caused by the ^{222}Rn and ^{220}Rn alpha decay. The present paper discusses the methodology and development processes undertaken in the design of an energy discriminate CR-39® nuclear track etch dosimeter.

2. Method and results

2.1. Assessment of Mylar® C stopping power

2.1.1. Method

The material that was selected for the attenuating film was Mylar® C supplied by Polymers International Australia Pty Ltd, a subsidiary of DuPont Tenijin Films™. Mylar® C has been specifically designed to be used as a capacitor dielectric and its physical properties make it an ideal material for this specific application. The properties of Mylar® are well known, with experimental and theoretical studies into accelerated ions and radiation interaction (Sharma et al., 2000; Chekirine and Ammi, 1999). The different variations of Mylar® are almost chemically identical except for the introduction of a dopant to alter its electrical and physical properties. Mylar® C is a patented material and information of the amount of added doping material is not readily available.

The stopping power of Mylar® C for alpha particles was measured as a function of thickness using an electro-deposited ^{241}Am source of activity 5.5 kBq placed in a Canberra Quad Alpha Spectrometer Model 7404 under vacuum. The alpha detectors used were Canberra models A450-20AM PIPS detectors. The PIPS are fully depleted low background detectors with an area of 450 mm^2 and have a resolution of 20 keV for alpha particles of 5.5 MeV emitted from ^{241}Am. The Mylar® C sample that was provided was 2.90 μm thick by weight. A total of eight thicknesses of Mylar® C were investigated from 2.9 to 23.2 μm, with each thickness being constructed from a number of 2.90 μm film layers. Since the thickness of the Mylar® C sample are extremely thin, a special sample holder was constructed to ensure that the layers of film remained in place under vacuum. Its design is shown in Fig. 1.

A comparison of the experimental results to a theoretical simulation using the Stopping and Range of Ions in Matter Monte Carlo code (SRIM 2008) was not possible for the Mylar® C used in the experiment due to uncertainties in the chemical composition. Previous SRIM 2008 studies using standard Mylar® has shown good agreement between experimental and simulations data for alpha particle interaction (Sharma et al., 2000; Chekirine and Ammi, 1999). A comparison of the experimental stopping power of Mylar® C and simulated results of standard Mylar® enabled an assessment of the level of variation between the two materials.

2.1.2. Results

Fig. 2 shows a comparison of the level of variation in stopping power for experimental results for Mylar® C and simulated results of standard Mylar® for incident 5.486 MeV alpha particle radiation. The experimental results for Mylar® C and the simulation results for standard Mylar® of their stopping power for alpha particle radiation follow a similar trend. The data points of the simulated data for standard Mylar® falls within the experimental uncertainty of the determined stoping power of Mylar® C. The effect of the slight difference in the chemical composition of Mylar® C (the dopant added to alter its electrical and physical properties) and standard Mylar® had no impact on its stopping power within experimental uncertainties. On this basis, simulations using SRIM 2008 for the standard Mylar® were used as an initial starting point for determining the thickness required of Mylar® C for the design of an energy discriminate CR-39® nuclear track etch dosimeter for ^{220}Rn gas measurements.

2.2. Energy detection threshold of etched CR-39® plaques for alpha particle radiation

2.2.1. Method

The CR-39^c plaques used in the present work were supplied by Page Moulding (Pershore) Ltd, Unit 21b, Trading Estate, Pershore, Worcestershire, United Kingdom. The CR-39 material was fabricated using: a 32 h cure, with 2.6% isopropyl peroxydicarbonate and 1% plasticiser dioctyl phthalate (DOP). The 0.5 mm thick CR-39® plastic sheet is cut into rectangular plaques, 35 mm by 20 mm (700 mm^2) plaques. Plaques which have been exposed to concentrations of ^{222}Rn and ^{220}Rn gas were etched in a 6.25 M potassium hydroxide solution at 70 °C for 6 h to enlarge the damage tracks caused by incident alpha particle radiation. During the etching process a layer of material was removed from the CR-39® detector. Not every alpha particle that arises from a decay within the chamber of a solid state nuclear track dosimeter will strike the detector with full kinetic energy. The effect of the alpha particle losing energy due to interaction as it travels though air is commonly known as straggling. The depth that an alpha particle will travel into the CR-39® material is dependent on its kinetic energy. The thin layer of CR-39® material removed during the etching process will reduce the depth caused by alpha particle radiation interaction. Damage tracks due to alpha particle radiation below a certain energy level which corresponds to the thickness of the thin layer are removed. This energy level is the energy detection threshold of the CR-39® nuclear track detector. Quantifying this physical property is required as it can have a significant impact on the determination of the final film thickness of Mylar® C required.

The same Canberra Quad Alpha Spectrometer and ^{241}Am source configuration was used in the evaluation of the energy detection threshold of the CR-39® material. The experimental procedure was almost identical except that after each layer of Mylar® C was added, a batch of five CR-39® radon plaques where exposed to the attenuated alpha particles for 120 s. A control group of five CR-39® radon plaques was kept to evaluate the number of damage tracks on each plaque due to background. The exposed and control CR-39® radon plaques where then etched and analysed by a Semi-Automated Nuclear Track Etch Counting System (SANTECS) (Brown et al., 2006) to obtain the total number of etched damage tracks as counts on

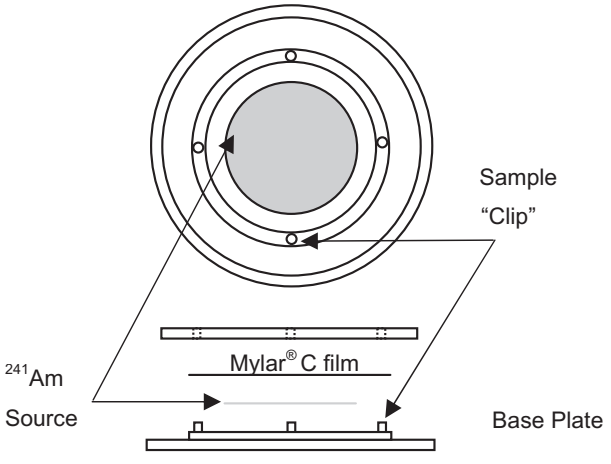

Fig. 1. Constructed sample holder for Mylar® C films using an ^{241}Am source (20 mm diameter) electroplated onto stainless steel.

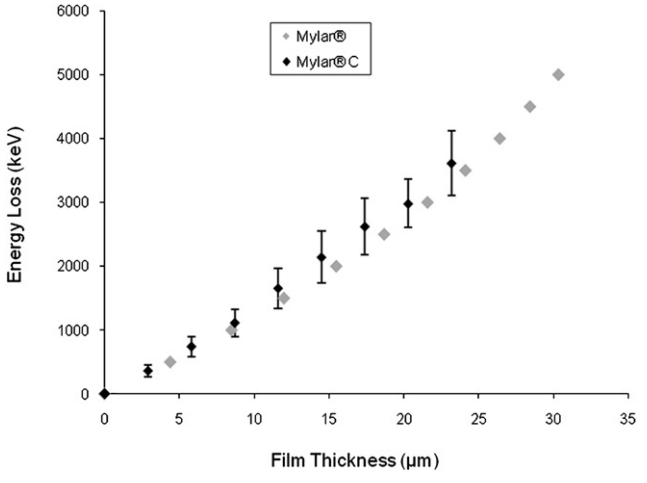

Fig. 2. A comparison of the level of variation in stopping power for experimental results for Mylar® C ($k = 1$) and simulated SRIM 2008 results of standard Mylar®.