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Comparison of LR-115 SSNTD based Integrated sampler with Yu-Guan bronchial dosimeter for measurement of inhalation dose due to radon progeny

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Abstract: Estimation of inhalation dose due to radon progeny is important as it is one of the major carcinogens for development of lung cancer. In recent years, Solid State Nuclear Track Detectors (SSNTDs) are widely used for evaluation of radon progeny concentration without measuring the parent radon gas concentration and subsequently deriving it using the assumed equilibrium factor. In the present study, the performance of LR-115 SSNTD based integrated sampler which is used for measurement of radon progeny concentration was studied against the bronchial dosimeter proposed by Yu and Guan. The comparison of inhalation dose measured using both the Integrated sampler and Yu-Guan dosimeter was carried out at three different ventilation rates such as $0.5\,h^{-1}$, $4.5\,h^{-1}$ and $9.5\,h^{-1}$ and two different relative humidity conditions such as 50% and 90%. It was observed that the doses measured using these two different dosimeters are very similar. An increase in ventilation rate or in relative humidity leads each to a decrease in annual effective dose as measured with both the detectors.

Keywords: Dosimetry concepts and apparatus; Solid state detectors

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2019 JINST 14 P01022

Contents

1 Introduction

It is a well known fact that inhalation of radon is a primary cause of lung cancer with progeny being the major dose givers. Some modeling studies showed that inhalation dose estimation from radon gas concentration is inadequate for the typical range of aerosol concentration that can be found in a dwelling, rather it should be evaluated from the actual measured progeny concentration [1, 2]. Again for radon progeny, Tracheo-Bronchial (TB) region is the most radiosensitive region among different regions of human respiratory tract [3, 4]. Many progeny samplers were developed recently for measurement of lung dose due to radon progeny [5–8]. Hopke [5] introduced the concept of using multiple wire screens for mimicking nasal (N) deposition and TB deposition. The radon progeny particles in the environment exist mostly in two size groups: unattached fraction (0.5–5 nm) by forming clusters with the gases and vapors present in the environment and the attached fraction (10–1000 nm) after their attachment with the aerosols. While passing through the wire-mesh, the unattached fraction of the progeny particles deposits on the wire-mesh due to enhanced diffusion phenomena while most of the attached fraction penetrates through it. Using the wire screen penetration theory [9, 10], Hopke [5] proposed to use a single 400 wire mesh for mimicking deposition in nasal region and four numbers of 400 wire mesh stacked together to mimic the deposition in TB region at a face velocity of 12 cm/s. Making use of Hopke's concept, Oberstedt and Vanmarke [6] developed the first bronchial dosimeter. This dosimeter consisted of 3 samplers: the first sampler has a filter paper to measure the total deposition (N+TB), the second sampler consisted of a filter paper and a single 400 wire mesh to give nasal deposition (N) and the third sampler consisted of a filter paper with 5 layers of 400 mesh to give total minus nasal and TB deposition (Tot-N-TB). But this dosimeter was not portable as it required three samplers and three alpha spectrometry systems. Yu and Guan [8] developed a portable bronchial dosimeter consisting of a single sampler with a 400 wire mesh and a filter paper by establishing a correlation between the collection efficiency of a single 400 mesh and the collection efficiency of four layers of 400 mesh. But the design of this dosimeter rely on the assumed unattached and attached progeny

2019 JINST 14 P01022

size distribution for typical indoor environment and mine environment. Again, for alpha counting of filter paper and wire mesh, Yu and Guan used gross alpha counting using ZnS based alpha counter which require the wire mesh and filter paper to be counted immediately. Yu and Guan proposed the use of PIPS detector for a portable bronchial dosimeter but it is expensive.

Recently, SSNTDs (LR-115 and CR-39) are widely used in the field of radon due to its light weight, cost effectiveness and ruggedness. The alpha tracks due to the short lived radon progeny are permanently registered in the SSNTDs and the detectors could be analyzed at a later convenient time. In the present study, we have investigated the use of LR-115 SSNTD based integrated sampler developed by Mishra et al., 2009 [11] as bronchial dosimeter for measurement of inhalation dose due to radon progeny. Inhalation dose due to radon progeny measured with the Integrated sampler was compared with that of the bronchial dosimeter proposed by Yu and Guan [8] at different environmental conditions such as ventilation rates and relative humidity conditions simulated in a test house.

2 Materials and methods

2.1 Yu-Guan dosimeter

A prototype bronchial dosimeter as proposed by Yu and Guan [8] was designed which consists of a progeny sampler with a 400 wire mesh (wire diameter $d_f = 25.4\,\mu m$, mesh thickness $d_w = 72.5\,\mu m$ and solid volume fraction $\alpha = 0.21$) and a glass fiber filter paper each of diameter 3.8 cm as shown in figure 1.

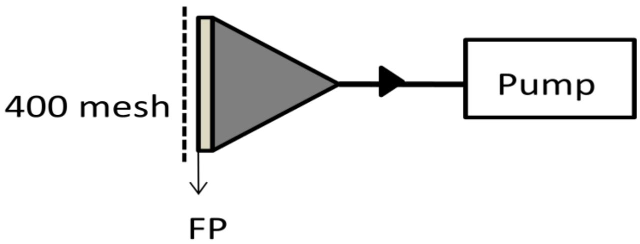

Figure 1. Schematic diagram of the Yu-Guan dosimeter (YG).

After the sampling, the Potential Alpha Energy Concentration (PAEC) on both WM and FP is measured using alpha counter from which collection efficiency of single 400 mesh (ε) is calculated using the following expressions [8],

$$\varepsilon = \mathrm{PAEC_{WM}}/\mathrm{PAEC_T} \tag{2.1}$$

$$\text{where,}\quad \mathrm{PAEC_T} = \mathrm{PAEC_{WM}} + \mathrm{PAEC_{FP}} \tag{2.2}$$

Yu and Guan derived the correlation between collection efficiency of single 400 mesh (ε) and the collection efficiency of four layers of 400 mesh (Γ) for typical indoor and mine environment described by the following expressions [8],

$$\begin{aligned} \Gamma &= (0.0673 \pm 0.0002)\varepsilon + (0.0316 \pm 0) \quad \text{for indoor} \\ \Gamma &= (0.0762 \pm 0.0018)\varepsilon + (0.0240 \pm 0.0002) \quad \text{for mines} \end{aligned} \tag{2.3}$$

2019 JINST 14 P01022

Then the PAEC in T-B region and the annual effective dose (E) could be calculated using the following expressions [8],

$$\mathrm{PAEC_{TB}} = \Gamma^{*}\mathrm{PAEC_{T}} \quad \text{and}$$
$$E(\mathrm{mSv\,y^{-1}}) = 10.5^{*}\mathrm{PAEC_{TB}}(\mathrm{mWL}) \tag{2.4}$$

2.2 Integrated sampler

Integrated Sampler is a progeny sampler developed by Mishra et al., 2009 for measurement of radon/thoron progeny concentration and its unattached and attached fraction [11]. The sampler consists of an array of a 200 wire mesh and a filter paper in which two Direct Radon Progeny Sensors (DRPS) each placed before the wire mesh and the filter paper as shown in figure 2. DRPS consists of a LR-115 Solid State Nuclear Track Detector (SSNTD) with an absorber (aluminized mylar) of thickness 37 µm mounted over it to selectively register the highest energy 7.69 MeV alpha particle tracks due to ^{214}Po in the detector film (LR-115). Detail description of DRPS system is available in literature [12]. When the air is sampled, the unattached fraction of the radon progeny is captured on the wire mesh and the attached fraction passes through and deposit on the filter paper which are respectively detected by the sensors kept opposite to the wire mesh and filter paper. After the sampling, these detectors are chemically etched for track enlargement and counted using spark counter or microscope to measure the track density, T (tracks cm^{-2}) which is then converted into Equilibrium Equivalent Radon Concentration (EERC) using the following expression,

$$\mathrm{EERC} = (T_{\mathrm{WM}} + T_{\mathrm{FP}})/t/s \tag{2.5}$$

where, T_{WM} and T_{FP} are the measured track density in wire mesh and filter paper respectively, t is the sampling time in h and s is the sensitivity factor which has the value as 2 tracks cm^{-2} h^{-1} per Bq m^{-3} [11]. From this EERC (Bq m^{-3}), annual effective dose, E is then computed using the dose conversion factor of 9 nSv h^{-1} per Bq m^{-3}proposed by UNSCEAR [13].

$$E(\mathrm{mSv\,y^{-1}}) = 9^{*}8760^{*}10^{-6*}\mathrm{EERC}(\mathrm{Bq\,m^{-3}}) \tag{2.6}$$

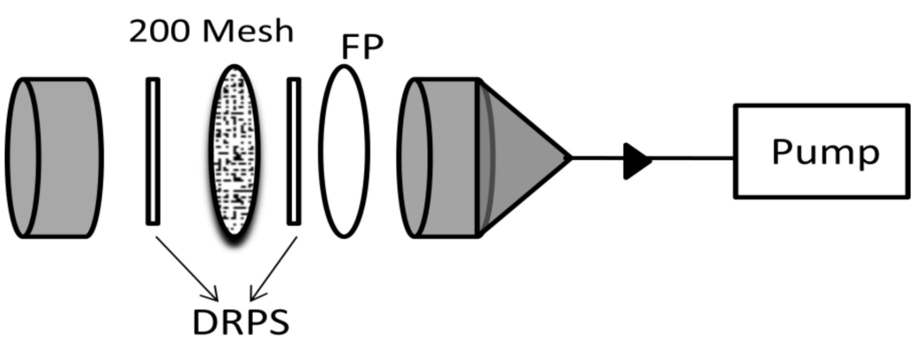

Figure 2. Schematic diagram of integrated sampler (IS) using wire mash and filter paper which face the direct radon progeny detectors (DRPS).

2019 JINST 14 P01022

2.3 Experimental details

An experiment was carried out in the specially designed HMGU thoron experimental test house, Germany (figure 3) of dimension $280 \times 154 \times 177\,\mathrm{cm}^3$ in which the inner walls are built with clay plaster of higher radium & thorium activity [14].

Figure 3. Thoron experimental test house, HMGU, Germany.

The test house has one door and two windows which were opened in succession in order to attain three different ventilation rates (λ_v) of $0.5\,\mathrm{h}^{-1}$, $4.5\,\mathrm{h}^{-1}$ and $9.5\,\mathrm{h}^{-1}$. Ventilation rates were measured by inserting CO_2 gas inside the test house and observing its decay pattern. Two relative humidity (RH) conditions of 50% and 90% were also maintained in the test house using humidifier. For each environmental condition, sampling was carried out for 6 h using both the YG dosimeter and IS. After the sampling, the wire mesh and filter paper of the YG dosimeter were counted using ZnS based alpha counter (efficiency of 30%) and the respective PAEC were determined. From that PAEC, the values of ε, Γ, $\mathrm{PAEC}_{\mathrm{T-B}}$ and hence E were determined using eqs. (2.1) to (2.4). The DRPS used in IS were subjected to chemical etching using the standard chemical etching procedure (90 minutes of etching with NaOH solution at 60 degree and without stirring). After the etching and drying of the films, they were counted using Polltec make spark counter for measurement of track density (T) and from the track density, EECR and E were computed using eqs. (2.5) and (2.6).

3 Results and discussion

The results of annual effective dose due to radon progeny measured using both the Yu-Guan bronchial dosimeter and integrated sampler in a test house at varying ventilation rates and relative humidity conditions are shown in table 1.

The linear correlation between the inhalation dose measured with Yu-Guan dosimeter and Integrated sampler for varying environmental conditions in the test house is shown in figure 4 which shows the slope very close to 1. This reveals that that the inhalation dose measured with both the Yu and Guan dosimeter and Integrated sampler are comparable. The relative error between the inhalation dose measured with the two devices was found to be within 20%.

2019 JINST 14 P01022

Table 1. Comparison of annual inhalation dose measured with Yu-Guan sampler, E_{YG} and with Integrated sampler, E_{IS} for different ventilation rates (λ_v) and relative humidity conditions (RH). The errors represent one sigma standard deviation.

Sample no.	λ_v (h^{-1})	RH (%)	Yu-Guan Dosimeter (YG)			Integrated Sampler (IS)	
			$PAEC_{WM}$ (mWL)	$PAEC_{FP}$ (mWL)	E_{YG} (mSv y^{-1})	WM+FP (Tr cm^{-2} h^{-1})×10^2	E_{IS} (mSv y^{-1})
S-1 (centre)	0.5	50	1.17 ± 0.08	9.12 ± 0.22	4.25 ± 0.33	1.23 ± 0.13	4.87 ± 0.52
S-2 (near wall)	0.5	50	0.52 ± 0.04	9.47 ± 0.30	3.68 ± 0.31	0.69 ± 0.06	2.73 ± 0.25
S-3 (centre)	4.5	50	0.60 ± 0.04	2.06 ± 0.12	1.82 ± 0.23	0.50 ± .08	1.97 ± 0.33
S-4 (centre)	9.5	50	0.49 ± 0.01	2.89 ± 0.13	1.46 ± 0.29	0.30 ± .05	1.20 ± 0.20
S-5 (centre)	0.5	90	0.69 ± 0.02	2.79 ± 0.12	1.65 ± 0.14	0.31 ± .05	1.24 ± 0.22

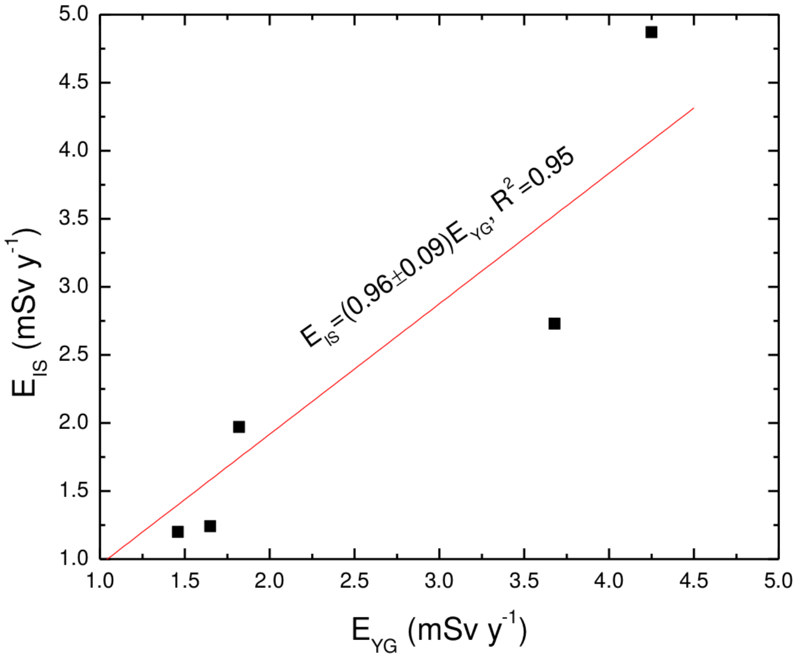

Figure 4. Correlation between inhalation dose, E (mSv y^{-1}) measured with Yu-Guan dosimeter and Integrated sampler.

The variation of inhalation dose with ventilation rate measured using both the Yu-Guan dosimeter and Integrated sampler at the centre of the test house at constant relative humidity of 50% is shown in figure 5 which shows that inhalation dose decreased with increase in ventilation rate. This is due to the reduction in radon progeny concentration with increase ventilation rate [15, 16] and hence inhalation dose decreased. Again, at a constant ventilation rate of 0.5 h^{-1}, with increase

2019 JINST 14 P01022

in RH from 50% to 90%, inhalation dose measured with Yu-Guan dosimeter was observed to be decreased from 4.25 ± 0.33 mSv y^{-1} to 1.65 ± 0.14 mSv y^{-1}. This is because of the fact that with increase in relative humidity, the size of the radon progeny increases leading to higher deposition due to settling. Thus the airborne progeny concentration decreases and hence the inhalation dose decreases. Similar decrease in inhalation dose by a factor of four was also reflected in case of Integrated sampler.

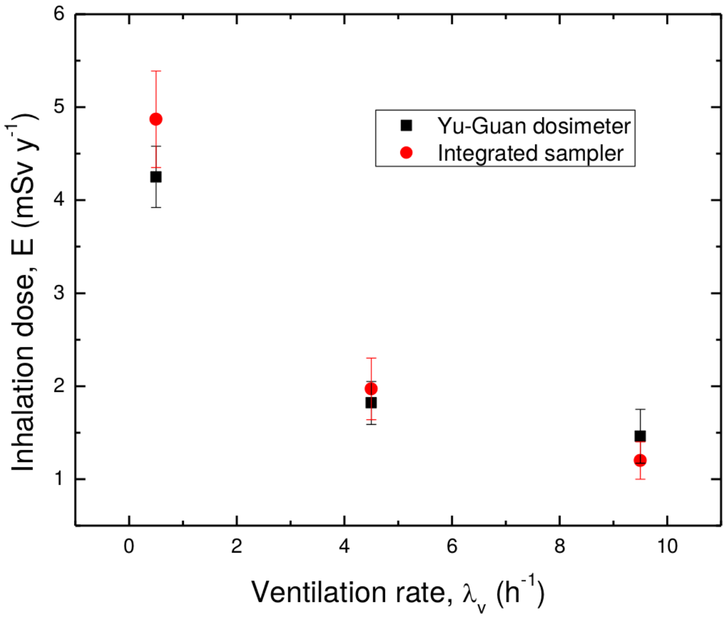

Figure 5. Variation of inhalation dose, E (mSv y^{-1}) with increase in ventilation rate measured with Yu-Guan dosimeter and Integrated sampler.

4 Conclusion

A comparison of the annual inhalation dose due to radon progeny measured with a LR-115 SSNTD based Integrated sampler was carried out with the Yu and Guan bronchial dosimeter in different ventilation rates and relative humidity conditions simulated in an experimental test house. The measured dose using these two dosimeters at different environmental conditions was found to be comparable. It was also observed that increase in ventilation rate and relative humidity leads to decrease in annual effective dose. Therefore, Integrated sampler could be used as a bronchial dosimeter for measurement of inhalation dose. Since it uses a LR-115 SSNTD film, the counting method is easy and also it is cost effective.

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2019 JINST 14 P01022

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2019 JINST 14 P01022